XXIII Congresso della Società Italiana di Analisi del Movimento in Clinica

Proceedings
SIAMOC 2023

Roma, 4-7 Ottobre 2023

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LA MISURA DEL MOVIMENTO UMANO NEI NUOVI SCENARI CLINICI, SPORTIVI E INDUSTRIALI

Approcci tradizionali, metodi innovativi basati sull'intelligenza artificiale e analisi dell'interazione uomo-robot

Il congresso annuale della Società Italiana di Analisi del Movimento in Clinica (SIAMOC), giunto quest'anno alla sua ventitreesima edizione, approda nuovamente a Roma.

Il congresso SIAMOC, come ogni anno, è l'occasione per tutti i professionisti che operano nell'ambito dell'analisi del movimento di incontrarsi, presentare i risultati delle proprie ricerche e rimanere aggiornati sulle più recenti innovazioni riguardanti le procedure e le tecnologie per l'analisi del movimento nella pratica clinica.

Il congresso SIAMOC 2023 di Roma si propone l'obiettivo di fornire ulteriore impulso ad una già eccellente attività di ricerca italiana nel settore dell'analisi del movimento e di conferirle ulteriore respiro ed impatto internazionale.

Oltre ai qualificanti temi tradizionali che riguardano la ricerca di base e applicata in ambito clinico e sportivo, il congresso SIAMOC 2023 intende approfondire ulteriori tematiche di particolare interesse scientifico e di impatto sulla società. Tra questi temi anche quello dell'inserimento lavorativo di persone affette da disabilità anche grazie alla diffusione esponenziale in ambito clinico-occupazionale delle tecnologie robotiche collaborative e quello della protesica innovativa a supporto delle persone con amputazione. Verrà infine affrontato il tema dei nuovi algoritmi di intelligenza artificiale per l'ottimizzazione della classificazione in tempo reale dei pattern motori nei vari campi di applicazione.

LETTURE MAGISTRALI

- **Francesco Lacquaniti**
  Università di Roma Tor Vergata e IRCCS Fondazione Santa Lucia, Roma,Italia

  Lo sviluppo del cammino dalla nascita alla maturità

- **William Geoffrey Wright**
  Università di Temple, Filadelfia, USA

  Interazione tra postura e percezione cosciente

- **John Rothwell**
  Università di Londra, Regno Unito

  Per esplorare la fisiopatologia del controllo motorio umano dobbiamo testare circuiti semplici o esplorare interazioni di reti complesse?

- **Yifat Prut**
  Università di Gerusalemme, Israele

  Reti neuronali per la coordinazione motoria

- **Arash Ajoudani**
  Istituto Italiano di Tecnologia, Genova, Italia

  Collaborazione uomo-robot per la riduzione del rischio biomeccanico nell'era industriale 4.0

- **Francesca Gimigliano**
  Università degli Studi della Campania "Luigi Vanvitelli", Caserta, Italia

  La riabilitazione del XXI secolo

- **Alberto Minetti**
  Università degli Studi di Milano, Milano, Italia

  Il ruolo dell'attrito articolare e tissutale nel bilancio energetico meccanico della locomozione umana

ELENCO DEI CONTRIBUTI PRESENTATI AL CONGRESSO

Fall risk assessment in older adults: insights from sit-to-stand transfers in the real world

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Introduction

Sit-to-stand (STS) transfers are essential functional movements commonly compromised in people susceptible to falls. In recent years, wearable sensors have allowed us to analyze the kinematic characteristics involved in STS transfers while participants perform functional tests such as the repeated chair stand [1]. However, given the complexity of daily tasks, whether these assessments reflect the ability to perform STS transfers in the real world is unclear. This study aims to characterize STS transfers in the real world and their potential ability to identify older adults at risk of falling.

Methods

The study analyzed data from 161 older adults (79.7±6.6 years, 50.9% female) from the 4th follow-up of the InCHIANTI study [2]. First, participants performed a five-times sit-to-stand test (5TSTS) in the laboratory. Later, participants were continuously monitored remotely for a week. During these tasks, participants wore an inertial sensor (Samsung Galaxy SII, 100 Hz, ±2g range) on the lower back. Prospective falls were ascertained through telephone interviews within 12 months of monitoring (139 non-fallers, 22 fallers).
A validated algorithm [3] was applied to identify STS transfers in both settings. For each STS, five features were computed: duration, maximum and minimum acceleration, smoothness (SPARC), and vertical displacement. In addition, only during real-world monitoring the number of STS per hour was computed. Features were averaged for each participant. A Welch t-test was used to compare kinematic characteristics between fallers and non-fallers; p-values were adjusted for false discovery rate.

Results

Laboratory measurements revealed no significant differences in the computed parameters between fallers and non-fallers. On the other hand, we observed notable differences when assessing the data obtained in real-world settings. Fallers exhibited longer transfer durations, lower maximum accelerations, and less smooth movements during STS transfers (Table 1).

Table 1. Averaged STS parameters in laboratory and real-world settings

	Laboratory (5TSTS)			Real-World		
	Non-Fallers	Fallers	p-value	Non-Fallers	Fallers	p-value
Duration $[s]$	1.35±0.59	1.31±0.45	0.8	2.48±0.33	2.66±0.32	**0.02**
Max. Acc. $[m/s^2]$	12.65±1.07	12.2±0.67	0.06	11.2±0.48	10.9±0.42	**0.02**
Min. Acc. $[m/s^2]$	6.17±1.67	6.63±1.35	0.4	8.61±0.29	8.7±0.27	0.11
Smoothness [-]	-2.16±0.18	-2.17±0.18	0.8	-2.38±0.03	-2.41±0.02	**0.01**
Displacement $[m]$	0.48±0.23	0.45±0.2	0.8	0.55±0.16	0.58±0.14	0.26
STS per hour $[/h]$	-	-	-	4.9±2.07	4.65±2.42	0.36

Discussion

The identified significant differences suggest that assessing sit-to-stand transfers in real-world settings holds promise for identifying individuals at risk of falls. By considering daily activities, with the related additional contextual factors and challenges, real-world analysis provides valuable insights into older adults' functional abilities and fall risk outside of the controlled laboratory environment, showing that real-world duration and performance (vertical push and smoothness) of STS can differentiate between fallers and non-fallers. In the end, by identifying distinct kinematic characteristics associated with prospective falls, we aim to develop more accurate fall risk assessment tools and targeted interventions for older adults, ultimately promoting healthy aging and reducing the burden of falls in this population.

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Exploring the Validity of Smart Socks for Non-Invasive Gait Analysis

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Introduction

In recent years, several technological solutions have been developed to analyse gait functions but, most of these can only be used in clinical settings, and this is a limiting factor because specific clinical trials not always reflect the true variability of a subject's gait. Based on this evidence, many researchers still support the potential value of remote monitoring through wearable devices and smart fabrics, which often also represent a less invasive solution than clinical instrumentation. In the context of remote and non-invasive gait analysis, smart sensing socks, able to collect kinematic and/or foot pressure signals, are interesting solutions. This study presents Sensoria Smart socks, a new e-textile based system for gait analysis and estimates its reliability in detecting the main temporal gait metrics through a benchmarking analysis.

Methods

Sensoria Smart Socks are wearable devices equipped with two types of sensors: Inertial Measurement Unit (IMU) worn at ankle height and three textile pressure sensors. The focus of this work is on gait metrics calculated starting from kinematic signals collected by the IMU embedded in the electronic core. The performance of Sensoria Smart Socks was validated through a benchmarking analysis with the IMU-based system for clinical gait analysis, the Mobility Lab system. Specifically, in this study, the test protocol consisted of walking over ground for 10 meters, turning around a pivot and walking back to the starting point. Five repetitions of the test were carried out on eight healthy subjects and during the test each subject wore both the sensing Sensoria Smart socks and three OPALs (two on the feet and one in lumbar position). The Gait Cycle Time (GCT) and Stance Phase Percentage (%CGT), measured for both feet independently, were the metrics selected for analysis. The agreement between measurements computed by the two system was investigated using Bland-Altman (BA) plots, a graphical method based on scatter plots with the differences between the systems' measurements on the y-axis and their averages on the x-axis. Quantitative assessment is given through the bias, as the mean of the differences, and the Limits of Agreement (LoA) assessed as the bias ±1.96 times standard deviation of the differences [1]. A further indication of the correlation among data was provided through Pearson's *r*.

Results

Table 1 reports the quantitative results deriving from the analysis.

Table 1. Results of BA analysis and Pearson correlation.

	Gait Cycle Time		Stance Phase	
	Left	**Right**	**Left**	**Right**
Bias	0.00194	0.00344	-10.5	-10.4
Lower Bound LoA	-0.0433	-0.0482	-14.8	-14.6
Upper Bound LoA	0.0315	0.0275	-6.03	-6.90
Pearson's *r*	0.977	0.969	0.615	0.427

Discussion

The preliminary results found in [2], with a similar experimental setting, are confirmed by this study conducted on a larger cohort of subjects and with further statistical approaches. General strong agreement is underlined in the measure of GCT by the novel smart device, with negligible bias and very narrow LoA including zero, and high correlation coefficient. In contrast, the smart socks underestimate the foot stance phase duration for both feet. The average bias is about 10% and the confidence intervals do not include zero. Moreover, low values of Pearson's *r* underline the low correlation between measures, showing that the disagreement is not only related to a systematic bias. Considering the heterogeneous results, the performance of the novel device in gait analysis could be affected by an error in the detection of intermediate gait events. A critical role is played by signal filtering, which may affect the detection of gait events on kinematic data. We are moving in this direction, to verify the effects of different filtering on the final assessment of gait parameters.

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Effects of fatigue on walking performance and dynamic balance in subjects with multiple sclerosis

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Introduction

Fatigability is a critical impairment in people with Multiple Sclerosis (PwMS) impacting on gait and participation. [1] An instrumented assessment of an innovative ecological fatiguing task can better profile the relationship between perceived fatigue and fatigability. Thus, this cross-sectional study aims at assessing the effect of experimentally induced motor fatigability on gait and balance.

Methods

Thirty-seven PwMS (mean±SD, age: 52.3±10.6years, EDSS 4±1.7points and 9 Healthy Subjects (HS, age:46.7±6.0years) were recruited. Kinematic data were collected using a 9-camera SMART-D motion capture system (BTS, Milano, Italy) using the total-body LAMB protocol [2]. PwMS and HS were asked to walk overground at a steady cadence. The test ended when subjects referred a perceived fatigue of 17 (very hard) on the Borg Scale, otherwise HS stopped the test after 30minutes. Data were collected on the 3 central strides recorded in the captured area and the following gait parameters were computed: normalized gait speed (%Body Height (BH)/s), normalized stride length (%BH), single stance time (SS, seconds), step symmetry (%stride), and stance time (seconds). While, for dynamic stability we considered: step width (%BH), trunk range of motion on frontal (TRUNK _ML, Deg) and on sagittal plane (TRUNK _AP, deg), Center of Mass displacement on frontal plane in SS (CoM_ML, mm), and the total head range of movement on frontal plane (HEAD _ML, mm). Finally, we calculated the percentage of energy recovery as the fraction of mechanical energy recovered during each step (Recovery, %). A Linear Mixed model with random intercepts was used to analyze the between-group differences over time in gait and dynamic balance parameters.

Results

PwMS walked 14.3±10.1minutes reaching a perceived fatigue (RPE=17points), while HS walked 30 minutes without exertion (RPE<11points). We found statistically significant between group differences at baseline and overtime in gait speed, stride length, single stance time and stance time indicating a gait deterioration in PwMS. We also found significant changes in HEAD_ML, and TRUNK_ML parameters without deteriorations in CoM control and recovery, as reported in table 1.

Table 1. changes per minute of gait and balance parameters in PwMS and HS

	PwMS	HS	P val
Gait speed (%BH/s per min)	-0.15	0.005	<0.001*
Stride length (%BH per min)	0.09	0.024	<0.001*
SS (sec per min)	-0.03%	-0.01	<0.001*
Step symmetry (%stride per min)	0.003	-0.0008	0.15
stance time (sec per min)	0.03	0.002	0.003*
step width (%BH per min)	0.009	0.008	0.93
HEAD_ML (mm per min)	0.59	0.20	<0.001*
CoM_ML (mm per min)	0.02	-0.02	0.39
TRUNK_AP (deg per min)	0.02	0.007	0.17
TRUNK_ML (deg per min)	0.03	0.007	0.01*
Recovery (% per min)	-0.00007	0.003	0.24

Discussion

The experimentally induced fatigability led to a sharp increase in perceived exertion in PwMS that was accompanied by only mild deterioration in gait and dynamic stability, suggesting a poor association between perceive fatigue and fatigability.

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The impact of increased perceived fatigue on postural control during a standing task in people with Parkinson's disease

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Introduction

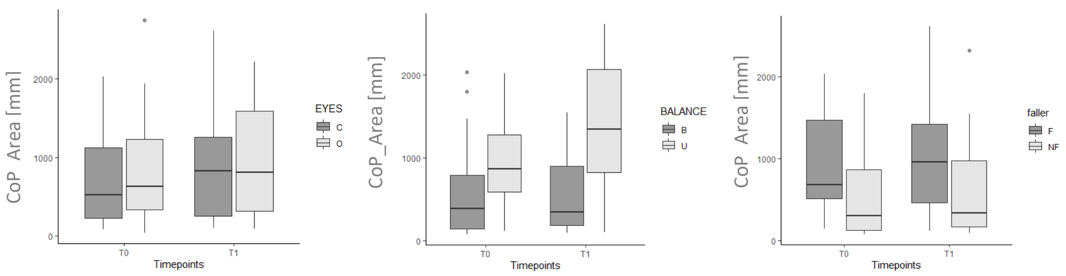
Fatigue is a disabling symptom affecting from 30% to 70% of people with Parkinson's disease (PD). [1] Even if several studies associate fatigue with the other non-motor symptoms, there is a lack of studies investigating the impact of increased perceived fatigue on postural control during standing task in people with PD.

Methods

Thirty people with PD (Age: 68±6 years, H&Y: 2-3, 14 females (47%)) were recruited for this ongoing cross-sectional study. All participants worn the optical markers (LAMB protocol) and walked continuously into a gait analysis laboratory equipped with a motion tracking system (SMART-TD and P6000, BTS S.p.A., Milan, Italy) until they reached a perceived exertion of 17 (lower limbs or breath) rated with the Borg scale (RPE), otherwise the test ended after 30minutes. Participants performed a standing task with eyes open (EO) and eyes closed (EC) on a force platform before (T0) and immediately after (T1) the end of the walking trial. We divided the whole sample into a fatigued group (FG), including subjects who reached more than 15 at RPE, and in a "not-fatigued" group (NFG). Moreover, we used the modified Dynamic Gait Index (mDGI) score, a clinical assessment of balance, to classify in a Balance group (BG) (mDGI>49), and in an unbalanced group (UG). [2] Data were processed to extract range of motion of the trunk on the sagittal (TrunkSagROM), frontal plane (TrunkFrontROM), mean velocity (CoPVel) and ellipse area (CoPArea) of center of pressure. To verify the impact of perceived fatigue on postural variables, comparison of medians between T0 and T1 were analyzed in the total sample using Wilcoxon sign rank test, while ANOVA was used to analyze differences between BG and UG groups, and between FG and NFG groups.

Results

Considering the whole group, we did not find statistically significantly differences in CoPArea (EO: W = 427, p= 0.92 Figure 1a, EC: W=373, p= 0.61), CoPVel (EO: W=443, p=0.73, EC: W=430, p=0.71) and Trunk movements (AP: EO, W = 406, p=0.83, EC, W =401, p=0.94, ML: EO,W = 359, p-value = 0.35, EC, W = 407, p= 0.99). We found a larger CoPArea in UG with respect to BG, that was increased at T1 with closed eyes (F=1.33, p =0.25, figure 1b). While FG did not differ from NFG group after the fatiguing task (F=p=0.86, figure 1c).



Discussion

The fatiguing task did not seem to affect balance and postural control. After an in-depth analysis, there seems to be a different behavior in subjects with poor balance at baseline with respect to patients with a good balance control, while a higher perceived fatigue did not seem to affect balance control. Future analysis could better profile the different behaviors induced by the fatiguing task.

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Fit for Medical Robotics (Fit4MedRob)

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Fit for Medical Robotics is an ambitious initiative coordinated by the Consiglio Nazionale delle Ricerche (CNR), which organized a scientific and technical task force made of committed researchers and innovators, from 24 additional Institutions (10 academic institutions, 11 clinical centers and 3 companies). Fit4MedRob aims to address and overcome the technological, cultural, economic, legal, and political barriers that currently limit the widespread adoption of cutting-edge robotic and digital therapies and treatments in the Italian health care system. Fit4MedRob will focus on both the implementation of already available technologies in clinical practice, and the investigation of emerging technologies or breaking-through ideas, in order to pave the way to the next generation of biomedical robotic systems.

Fit4MedRob aims to revolutionize current rehabilitation and assistive models for people of all ages with reduced or absent motor, sensory, or cognitive functions, by means of novel (bio)robotic and allied digital technologies and of continuum of care paradigms that can take advantage of the novel technologies in all the phases of the rehabilitation process. This paradigm will start from the prevention and will target all phases of the disease, from acute (bed-side) to chronic (home-rehabilitation) and will contribute to the design of new pre-habilitation protocols and diagnostic tools for fragile individuals or workers exposed to occupational diseases or repetitive stresses.

To address these objectives, the initiative is organized into three interconnected research Missions (Figure 1), each one conveniently overseen by one Spoke, following what the Call is asking:
• Mission 1: Clinical Translation & Innovation;
• Mission 2: Biorobotic Platforms & Allied Digital Technologies;
• Mission 3: Next Generation Components.

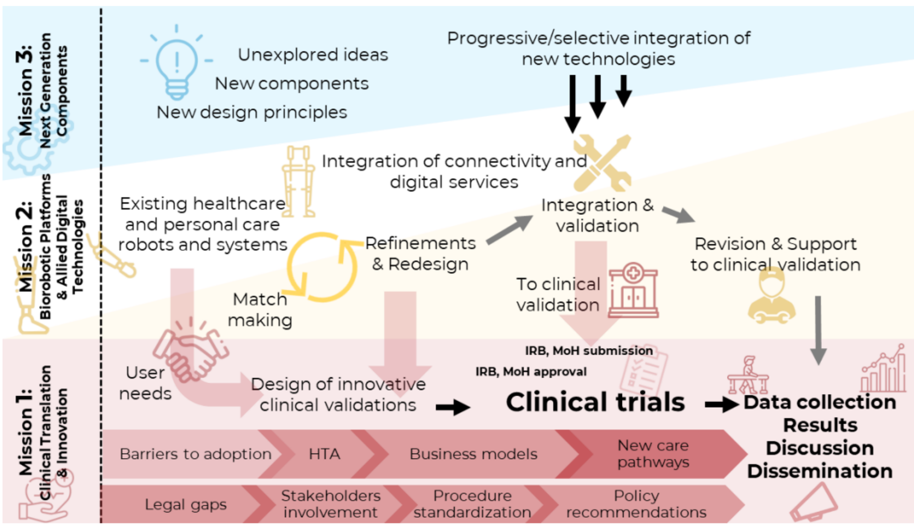

Figure 1. Graphical representation of the interactions and main activities within the three Missions of Fit4MedRob.

The first Mission, handled by Spoke 1, is the core of the initiative and is devoted to translational, technology assessment, and legal activities. The first Milestone aims to identify the unmet needs of the patients and healthcare practitioners, associated with specific selected pathologies, in order to translate these into functional and technical requirements which could be fulfilled by specific robotic treatments.
The progress of Mission 1 activities, related to surveys to collect patients' and health practitioners' needs and the designation of clinical trials, will be discussed.

Reliability of an instrumented Timed Up and Go test in people with musculoskeletal conditions

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Introduction

The "Timed Up and Go" (TUG) is a test widely used to measure functional mobility in elderly and in people with musculoskeletal conditions [1,2]. When using an inertial sensor measurement system, the individual components of the TUG test and the trunk kinematics can be measured separately, with the advantage of providing additional relevant information. The aim of this study was to assess the test-retest reliability of the TUG test performed with an inertial sensor system in people with musculoskeletal conditions.

Methods

45 consecutive patients admitted to an inpatient rehabilitation ward (ICS Maugeri, Institute of Veruno), aged 50 years or older, with a diagnosis of femur fracture, total knee or total hip arthroplasty, were included. The inertial sensor EXLs3-M (mTUG, mHealth Technologie, Italy) was worn at the lower back during the TUG test. The device measured acceleration and angular velocity in three directions at a rate of 200 samples/s. Patients performed the TUG test two times within 3 days of admission and, again, within 1-3 days apart. During the trials, patients were allowed to use their usual walking aid. Repeated measurements performed on different days were used to calculate the test-retest reliability. A correlation matrix was created to display the relationship between the 100 variables collected with the inertial sensor. To determine the test-retest reliability of the variables, intraclass correlation coefficients ($ICC_{3,1}$) were used. For clinical purposes, ICC values higher than 0.90 indicated good reliability [3].

Results

Based on the correlation matrix, 18 variables showed correlation coefficients < 0.90; as a consequence, they were excluded from the subsequent analysis of reliability due to redundancy. Four of the 82 remaining variables showed a good reliability: total duration, mean angular velocity of the sitting turn (MAV), antero-posterior angular velocity during walk (APAV), root mean square of the medio-lateral angular velocity during sit to walk (RMSML). The ICC values of nineteen variables (23%) were ≥0.70 and <0.90, suggesting a good-to-fair reliability. The remaining variables (72%) showed ICC values ≥0.50 and <0.70, indicating poor reliability.

Discussion

In conclusion, four components of the instrumented TUG test concerning total duration and other kinematic parameters showed a good test-retest reliability in persons with musculoskeletal conditions. In addition, the sub-durations and the turning durations showed a good-to-fair reliability. The results obtained from the instrumented TUG parameters, which are automatically acquired and analysed by the device, demonstrated that a small number of new reliable TUG variables can be identified. To provide a basis for a more precise, quantitative use of the TUG test in clinical practice, it will be necessary to demonstrate whether MAV, APAV and RMSML variables can offer some advantages respect to the total duration of the TUG test; a hypothesis may be their greater ability to discriminate subjects at risk of falling [4].

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Locomotor patterns during sidestepping in children with cerebral palsy

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Introduction

Early injuries to developing motor regions of the brain (such as cerebral palsy, CP) may significantly interfere with the development of locomotor function and the normal engagement of supraspinal structures [1,2]. Here, we investigated how cerebral dysfunction in children with CP affects the directional locomotor movements such as sidestepping. The importance of testing the ability of children with CP in this task lies in the assessment of flexible, adaptable adjustments of locomotion as a function of the environmental context.

Methods

Walking sideways is distinctive in that it necessitates a differential control of right and left limb muscles. We compared the bilateral coordination patterns during forward (FW) and sideways (SW) walking in 27 children with CP (17 diplegic, 10 hemiplegic, 2-10 yrs) and 18 age-matched typically developing (TD) children, by analyzing gait kinematics, joint moments, EMG activity of 12 pairs of bilateral muscles, and muscle modules evaluated by factorization of EMG signals.

Results

Task performance in several children with CP differed drastically from that of TD children. Only 2/3 of children with CP succeeded to step sideways, and they often demonstrated attempts to step forward. They tended to rotate their trunk FW, cross one leg over the other, and flex the knee and hip. Moreover, in contrast to TD children, children with CP often exhibited similar muscle activity patterns of the leading and trailing limbs and similar motor modules for FW and SW.

Discussion

Overall, the results reflect developmental deficits in the control of gait, bilateral coordination and adjustment of basic motor modules in children with CP. The remarkable feature of CP gait is the reduced flexibility in the differential control of the left and right leg pattern generators. In consideration of these results, we suggest that the sideways (along with the backward) style of locomotion potentially represents a novel rehabilitation protocol that challenges the child to cope with novel contextual requirements.

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Biomechanical efficacy of botulinum toxin treatment on gait in camptocormia associated with Pisa syndrome in Parkinson's disease

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Introduction

Parkinson's disease (PD) often presents abnormal posture such as forward axial flexion, called camptocormia, and lateral flexion, called Pisa syndrome (PS). These postures determine the veering gait characterized by a progressive deviation toward one side when patients walk forward and backward, with associated risk of falls. Botulinum toxin treatment is a therapeutic option for these abnormal postures because a pathogenesis of camptocormia or Pisa syndrome is axial dystonia [1, 2]. Patients with camptocormia/PS show a reduction in stride and step length, with an increase in stance duration and a subsequent reduction in swing on the bending side. The hip revealed an important reduction of extension during stance, the knee showed a flexed position in stance and a reduction of peak flexion in swing, the ankle revealed an important reduction of plantarflexion in pre-swing. The aim of the present study is to assess the effect of botulinum toxin treatment combined with a rehabilitation program on patients with PD.

Methods

54 patients with camptocormia/PS (28 females and 26 males with an average age of 73 years) participated in this study. 9 tests were performed for each patient with the optoelectronic system EL.I.TE. 3-D SMART (BTS, Milan, Italy), following the DAVIS protocol, with dynamic EMG of the trunk muscles. The patients were subjected to clinical evaluation with gait analysis on two moments: at inclusion and 1 month after botulinum toxin injection. Dynamic EMG showed a pattern of abnormal tonic hyperactivity, with potential of more than 100 µVolts/sec. for more than 500 msec. at rest and during movements, of the rectus inferior abdominis (RAI), internal oblique (OI) on the bending side and external oblique (OE) contralateral to the bending side. Using electromyographic guidance, we injected botulinum toxin (Dysport®, 180 U in 1,0 mL physiologic solution) into the rectus inferior (RAI) on the bending side, in 2 sites, for a total dose of 60 U, into the internal oblique (OI) on the bending site, in 2 sites, for a total of 60 U, and into the external oblique (OE) contralateral to the bending side, in 2 sites, for a total dose of 60 U. Patients underwent a rehabilitation program consisting of individual 90-minute daily sessions, 5 days a week for 4 weeks.

Results

There is a reduction in the inclination of the pelvis on the frontal plane, contralaterally to the "bending", from the stance of the homolateral foot to the "bending" up to the swing of the contralateral lower limb; always in the frontal plane the pelvis in the swing stabilizes and no longer "collapses" contralaterally; the knee show reduction of flexion bilaterally throughout the stance and increase in the maximum knee flexion ipsilateral to the "bending" in the swing; the ankle show increase of dorsiflexion ipsilateral to the "bending" in the swing. The kinetics records from the "bending" side an increase in the hip extension moment in stance and especially in pre-swing (Fig. 1), a reduction of the hip adduction moment, a reduction of the knee flexion moment at the initial stance, an increase in the ankle flexion moment at the terminal stance. The co-contraction of the proximal thigh and pelvis muscles on the bending side is reduced.

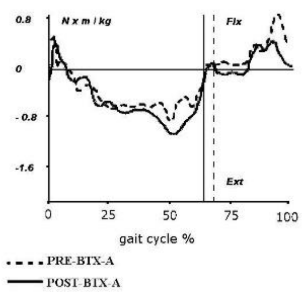

Fig. 1 Increased hip extension moment on the "bending" side

Discussion

The joint moments demonstrate a recovery of the push capacity of the lower limb on the "bending" side. By unlocking the constraints of the gluteal muscles, the activation of the other muscles of the proximal thigh improves. The transition of the gait pattern from anserine pre-botulinum toxin to sagittal post-toxin is completed, with the concrete possibility of reducing the falls of the veering gait [3].

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Test-retest reliability of gait parameters of instrumented 6-minute walk test in Parkinson's disease

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Introduction
The 6-Minute Walk Test (6MWT) has demonstrated a good test-retest reliability in assessing walking endurance in individuals with Parkinson's disease (PD) [1]. Nevertheless, objective gait features are lacking in the common clinical 6MWT. Inertial Measurement Units (IMUs) have been integrated in the 6MWT to obtain more quantitative information [2]. Despite the common use of multiple IMUs, the application of a single IMU has also been investigated due its easiness and quickness of implementation for elderly and post-stroke patients [3][4]. Therefore, the purpose of this work is to determine the test-retest reliability of gait parameters obtained by a single IMU during the 6MWT for subjects with PD.

Methods
Fifteen persons with PD (age 70.3 ± 6.3 years, 6 females, Hoehn&Yahr 1-3) were recruited. The assessment was performed with a test-retest interval of 48-72 h in the same test conditions. Following the ATP guidelines, participants walked at sustained speed between two cones placed at 30 m distance in a straight hallway, surrounding the cones to change directions. Participants executed 6MWT wearing a G-WALK sensor (BTS Bioengineering, Milan, IT) placed on trunk at S1 level with a semi-elastic belt. Forty-six features descriptive of temporal, intensity, regularity/variability, stability and symmetry aspects of gait were computed from trunk accelerations and angular velocities. Test-retest reliability was evaluated through the Intraclass Correlation Coefficient (ICC). Reliability was classified as poor if ICC≤0.49, fair if ICC is between 0.50 and 0.74, good if ICC is between 0.75 and 0.89, and excellent if ICC is between 0.90 and 1 [5].

Results
ICC values of a subgroup of 33 gait features are shown in Figure 1.

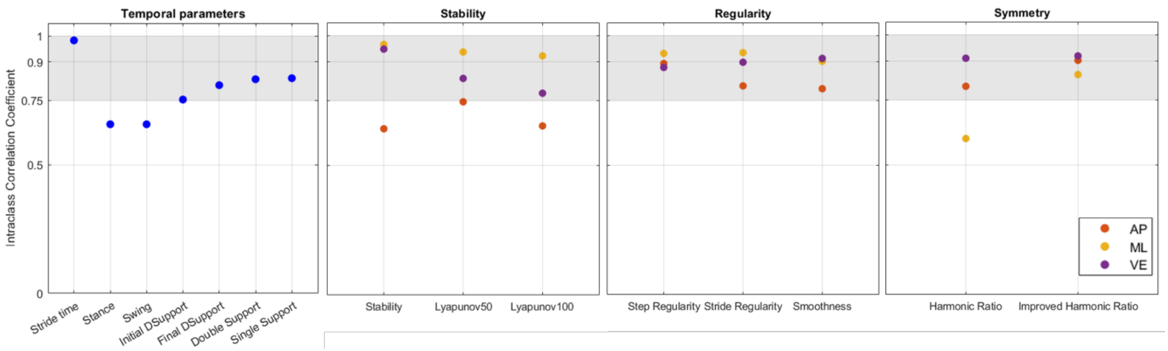

Figure 3: ICCs of temporal, stability, regularity and symmetry variables. Grey band indicates good to excellent reliability. AP: antero-posterior; ML: medio-lateral; VE: vertical.

Discussion
Out of 46 total variables computed, 40 showed a good/excellent reliability (ICC≥0.75) and 6 fair reliability (ICC≥0.60), indicating the absence of large variations of the parameters between test and retest sessions. Results suggested that 6MWT instrumented with a single IMU can provide trustworthy information about gait features in PD individuals, thus providing additional information about gait quality. More subjects will be included in further studies to deepen the reliability of the outcomes and analyze their concurrent and discriminant validity.

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Anterior cruciate ligament injury risk parameters during landing: are knee angles at ground contact correlated with ranges of motion after landing?

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Introduction

Instrumented movement analysis at the time of return to sport after Anterior Cruciate Ligament (ACL) rupture allows the investigation of potential impairments. Among the biomechanical parameters associated with ACL injury risk, high knee adduction and low knee flexion angles have been widely investigated [1]. Some studies analyzed these angles at landing (initial contact, IC), whereas others considered the knee joint range of motion (RoM) within a short time window immediately after landing (risk time window: RTW) [2]. However, it is unclear if these two parameters provide comparable information and can be used indiscriminately. Thus, the aim of this study is to analyze the relationship between knee angles (both ab/adduction and flex/extension) obtained at IC and their RoM during RTW in patients with ACL reconstruction and in healthy controls during a single leg hop test.

Methods

Fifteen healthy (HC: 25.0±4.5 years, 72.9±6.2 kg, 1.79±0.6 m) and five soccer players with ACL reconstruction (ACLR: 28.0±9.0 years, 83.7±7.6 kg, 1.83±0.4 m) participated in this study. ACLRs were evaluated within a postoperative time window of 8-12 months. All participants had a Tegner Scale score >6. After a 5 min warm-up, 3 single leg hop tests were performed for each limb, landing on a force plate (AMTI, USA, 1000 Hz). The 3D trajectories of 52 markers were measured by an optoelectronic system (Vicon, UK, 200 Hz) [3]. Kinematics parameters related to ACL injury risk were extracted: knee adduction/abduction and flexion /extension angles at IC (K_{add}IC, K_{add}RoM) and their RoM during RTW (K_{flex}IC, K_{flex}RoM). RTW corresponded to the first 100 ms after foot landing (vertical ground reaction force >20N) [4,5]. To investigate the relationship between knee angles at IC and RoMs, Pearson's correlation coefficient was calculated for both the safe/dominant and injured/non-dominant limbs for all participants and each group (HC and ACLR) after checking for the normality of data distribution.

Results

Table 1 Knee adduction and flexion angles at IC and RoMs and Pearson's correlation coefficients between them. Bold values indicate statistically significant results (p<.05).

		Knee angles [degrees]				*Pearson's Correlation*	
		K_{add}IC	K_{add}RoM	K_{flex}IC	K_{flex}RoM	K_{add}IC *Vs* K_{add}RoM	K_{flex}IC *Vs* K_{flex}RoM
ALL	D/SAFE	4.9±3.4	7.1±4.1	12.6±4.9	33.4±4.2	**0.75**	-0.03
	ND/INJ	5.1±3.4	7.1±4.1	13.9±5.1	34.8±3.5	**0.68**	0.06
ACLR	SAFE	4.7±3.4	8.1±5.1	12.9±5.0	33.9±5.3	0.52	-0.58
	INJ	4.7±2.3	4.6±2.9	17.2±6.1	34.2±5.2	**0.88**	0.27
HC	D	5.0±3.5	6.8±3.9	12.5±5.1	33.3±4.0	**0.80**	-0.17
	ND	5.3±3.8	7.9±4.2	12.8±4.4	35.0±2.9	**0.63**	0.34

Discussions

Knee joint angles at IC correlated with RoMs during the early phase of landing in the frontal plane (especially in the injured limb of ACLR), but not in the sagittal plane. This indicates that the higher the knee adduction at IC, the higher the RoM after landing, exposing the athlete to ALC injury risk. Conversely, the absence of a relationship between the knee flexion angle at IC and its RoM suggests that these two parameters do not necessarily provide the same information. Caution should be taken in their interpretation when detecting athletes at risk. It can be speculated that, in the tested population, knee flex/extensor muscles are able to better absorb the impact load with respect to the ab/adductor ones. Further research should include the analysis of muscle activity to address this hypothesis.

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Classifying Gait Type and Predicting Parkinson's Disease through Machine Learning Models

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Introduction

Machine Learning (ML) algorithms can be trained on large datasets of gait data to recognize specific patterns associated with diseases (*e.g.*, Parkinson [1]) or automatically assessing the quality/type of gait for supporting rehabilitation activities (*e.g.*, post-stroke rehabilitation [2]). Despite the promising results, a critical challenge of these approaches lies in the lack of standardization and consistency across features used for training ML models. For example, for predicting Parkinson's disease, some models are trained on step-related features only (*e.g.*, swing and stance), while others on more advanced features, such as GEI (Gait Energy Image) and SEI (Spatial Energy Image). The lack of standardized datasets and feature extraction methodologies hinders the reliability and reproducibility of ML models in different clinical or commercial settings. To mitigate such an issue, we perform the largest evaluation of ML models for classifying gait types and predicting Parkinson's disease.

Methods

The analysis of the datasets used in the literature to train ML for classifying gait type and predicting Parkinson's disease indicates that the most used gait analysis features belong to three domains: (i) 3D trajectories of body joints; (ii) step analysis; (iii) GEI and SEI data. It is also evident that none of these datasets contain a comprehensive set of features spanning all domains. Thus, we built a comprehensive knowledge base by merging instances from each dataset into a single dataset and calculating the missing features. For instance, some datasets had only 3D trajectories of human body joints. From this information, it was possible to calculate aggregate features related to the step (*e.g.*, swing and stance) through an *ad-hoc* feature engineering strategy [1]. Additionally, using the trajectory data, with a custom-built tool we animated a mannequin and reconstructed GEI and SEI data. Finally, some datasets only provided exercise execution videos. In this case, using the Plask tool, it was possible to derive 3D trajectories and obtain all the features through the same procedure used for other datasets. With such a procedure we were able to construct the largest dataset ever used in the literature. The dataset contains 557 features (304 features related to rotations, 228 to trajectories, 17 to pitch, and 6 to GEI/SEI) and 7,303 labelled instances: 20 labelled as Parkinson, 34 as healthy, and the remains instances labelled with 6 different gait types (*e.g.*, antalgic, lurch). Using such a dataset we trained different machine learning models for classifying gait type of gait and predicting Parkinson's disease.

Results

Table 1 reports the results achieved when classifying the gait type. The ML model is based on Support Vector Machine and on a combination of features belonging to all the considered domains: 131 from rotations, 63 from trajectories, 5 from pitch, and 6 from GEI/SEI. As for the prediction of Parkinson's disease, the best model was able to reach 1 for both precision and recall. Such a model is based on Decision Tree and, once again, on a combination of features belonging to all the domains: 304 from rotations, 228 from trajectories, 17 from pitch, and 6 from GEI/SEI.

Type	Evaluation metrics		
	Precision	Recall	F1-score
Antalgic	0.88	0.86	0.87
Lurch	0.98	0.97	0.97
Normal	0.90	0.97	0.93
Steppage	0.94	0.96	0.95
Stiff-Legged	0.98	0.97	0.97
Trendelenburg	0.90	0.85	0.87
		Global accuracy	0.93

Table 1. Gait type classification results.

Discussion

The achieved results suggested that a combination of numerical features with graphical features is worthwhile for improving the final accuracy of the models. Indeed, a model based on GEI and SEI alone was able to achieve an accuracy of 0.94. Further experimentations are required to corroborate our findings. Also, an experimentation with real users is required to assess the generalizability of the results.

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Using DeepLabCut to evaluate infants' upper limb general movements from RGB-Depth images: a strategy for selecting the training set

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Introduction

Recently, we developed a markerless protocol [1] for the analysis of infant's upper limb movements based on data from a single RGB-Depth camera. The protocol requires the use of DeepLabCut (DLC) for estimating the 2D trajectories of seven selected Points of Interest (PoI): belly button, left and right shoulders, elbows and wrists, and the reconstruction of their 3D trajectories [1]. DLC was trained by manually labeling PoIs on 10% of the video frames selected by a k-means clustering [2]. The implementation of a selection strategy for the training set is expected to improve the PoIs reconstruction by excluding critical frames (such as frames with occluded PoIs, repetitive informative content, occlusions due to the parents or objects entering the camera field of view). The aim of this study was to develop a method to generate a training set able to enhance the DLC performance in tracking videos of infants' general movements. To assess DLC performance, the lengths of the infant's upper arm (UA) and forearm (FA) were validated against their reference values obtained with manual measurements.

Methods

An infant sitting in a baby seat was positioned in front of an RGB-Depth camera and recorded for three minutes. The video sections containing the infant fully in the FoV were extracted and the k-means was applied to generate a training set with 10% of video frames (S1). Repetitive frames were then removed together with frames with less than 60% of the PoIs visible and frames where left and right shoulder and belly button were not fully visible (S2).

Since a single PoI may be seen by the camera with different angles (e.g., elbow joint center could be tracked on the medial or on the lateral epicondyle depending on the side of the arm facing the camera), the presence in the training set of all PoI views was checked (S3). DLC was then trained as in [1], and using S1, S2 and S3. Segment lengths in 3D (UA and FA lengths) were then estimated as in [3].

Results

Table 1. Duration, time needed to label PoIs and body segment lengths estimations and relevant errors at each step of the proposed method.

Method	Training set length *(frames)*	Labeling time *(hours)*	***FA length*** *(mm)*			***UA length*** *(mm)*		
			ref.	*mean ± sd*	*MAE*	*ref.*	*mean* ± sd	*MAE*
[1]	536	7.4	*95*	113 ± 10	18	119	103 ± 8	16
S1	480	6.6		93 ± 9	2		102 ± 9	16
S2	235	3.2		97 ± 10	2		108 ± 5	11
S3	235	3.2		97 ± 10	2		108 ± 5	11

Discussion

The results show an improved accuracy of the estimate of the length of the upper body segments with respect to [1], thus indicating that the proposed training set not including frames with PoI occlusions is more informative. PoI labeling times are reduced by approximately 50% after the removal of repetitive frames resulting in a higher applicability of the proposed markerless protocol [1]. S2 results coincide with those of S3 thus preliminary demonstrating that k-means may form a training set featuring all PoI positions assumed by the infant. Future studies will be devoted to validating the proposed method on a larger number of infants and to further reducing the PoI labeling time.

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TWIN-Acta-based RAGT for persons post-stroke: a pilot study on spatio-temporal gait parameters

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Introduction

Persons post-stroke often suffer from hemiparesis, which implies a between-limb imbalance impairing functional activities. For this reason, improving walking ability is a primary goal of stroke rehabilitation [1]. Robotic-assisted gait training (RAGT) is widely used in rehabilitation for persons with neurological disorders as it provides high-intensity repetitive task-specific practice, which is essential to induce motor learning [2]. A recent systematic review reported that exoskeletons are valuable tools to achieve an independent gait pattern in persons post-stroke [1]. However, these robotic devices were originally designed and developed for spinal cord injured subjects, who do not have any residual walking abilities, and are therefore based on a purely assistive approach. Rehabilitation approaches based on the active participation produce better outcomes because they promote functional reorganization of the nervous system with a more physiological recovery. For this reason, the TWIN-Acta control suite was specifically developed for persons post-stroke [3] that allows the control of the TWIN exoskeleton through the residual motor capabilities of the subject, enabling gait training with an assist-as-needed approach. The usability and acceptability of TWIN-Acta as a tool for post-stroke rehabilitation has already been demonstrated [3]. Therefore, the purpose of this study was to preliminarily assess motor recovery in persons post-stroke after a rehabilitation with TWIN-Acta.

Methods

Four persons post-stroke were enrolled and underwent rehabilitation treatment with the TWIN exoskeleton controlled by TWIN-Acta. Participants were asked to perform specific motor tasks (e.g., overground walking and sit-to-stand) while wearing the exoskeleton. Before (T0) and after (T1) rehabilitation, participants underwent clinical and instrumented assessments. The muscle activity of 12 muscles from EMG sensors (10 placed on the lower limb and 2 on the upper limbs per side) and movement data from 2 IMUs on the shanks were recorded during a 10-meter overground walk. Fourteen healthy subjects provided the normative reference. The heel strike and toe off events were identified according to Salarian [4]. The intermuscular coherence indexes, walking speed and gait asymmetry index were calculated. In details, gait asymmetry index (GAI) was defined as $[((NP - P)/(0.5 \times (NP + P))) \times 100]$, where NP (non-paretic) and P (paretic) are the percentage of single-limb support duration during gait cycle of legs (GAI higher values indicates greater asymmetry) [5].

Results

At T0 persons post-stroke showed lower speed and higher GAI (mean ± SD [m/s], 0.33 ± 0.16; [%] 44.85 ± 11.37, for speed and GAI respectively) compared to the normative reference (mean ± SD [m/s], 1.34 ± 0.26; [%] 0.07 ± 2.80, for speed and GAI respectively). After rehabilitation treatment (T1), persons post-stroke showed a 18% increase in speed and 20% decrease in GAI (mean ± SD [m/s] 0.37 ± 0.13; [%] 36.21 ± 14.85, for speed and GAI respectively).

Discussion

Persons post-stroke showed an increase of gait speed and a decrease of asymmetry after training, suggesting a recovery towards more physiological walking. These gait features are biomarkers of locomotor performances as they are predictors of falls and gait ineffectiveness [2]. From this point of view, the improvement of these gait-specific measures supports the use of TWIN-Acta-controlled exoskeletons as therapeutic tools for gait rehabilitation of persons post-stroke. Future studies with larger sample of participants should be performed to confirm the efficacy of TWIN-Acta as a rehabilitation device able to promote a more physiological recovery of gait.

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Gait deviation index to quantify the short-term effects of functional surgery on walking kinematics in patients with cerebral palsy. A prospective cohort study

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Introduction

The Gait Deviation Index (GDI) is used to summarize (on a 0-100 scale) the deviation of a patient's kinematics from the normal reference pattern [1]. It was developed and used to assess the long-term effects of functional surgery (FS), designed based on gait analysis (GA), in cohorts of children with cerebral palsy (CP). The short-term effects of FS are missing in the literature. Over time, these can be used as a starting point to follow the post-surgical recovery. We computed the short-term GDI variation in a cohort of children with CP who underwent FS followed by tailored physiotherapy.

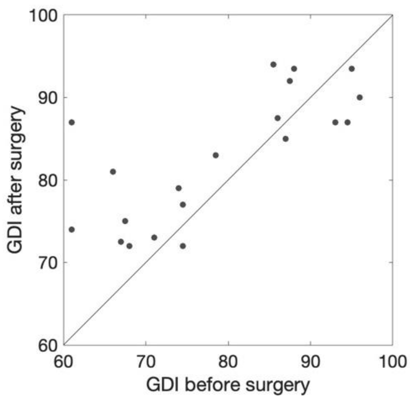
Methods

Prospective cohort study. Inclusion criteria: CP diagnosis, lower limb FS performed by the same surgeon (author PZ), ≥3 GA trials available both before and 1-2 months after FS, and an informed consent signed by the parents (Ethic Committee approval: CEROM 2201/2018). Gait kinematics with sEMG was acquired using a commercial system (Smart DX, BTS Bioengineering) and the Conventional Protocol. FS included a tailored combination of tendon lengthening, fascial release, osteotomy, and tenodesis. GDI was computed as in [1]. The GDI of the affected side was used for children with hemiplegia. Instead, for bilateral patients who underwent bilateral FS, the average (L/R) GDI was computed. Median GDI across all trials was used for further analysis. Paired GDI values were compared using the Wilcoxon test. Patient's global impression of change (pGIC, range 1-7), and knee and ankle ROMs (when treated) were also compared.

Results

Twenty-one patients were included (9/12 M/F), mean age 11.4 (3.3) years, with hemi/di/para/tetra-paresis 10/7/2/2, and GMFCS ranging between I and III. Eleven patients underwent distal FS, 6 proximal FS, and 4 multilevel FS. Six patients had undergone one or more previous functional surgeries. The short-term assessment was at 0.98 (0.42) months from surgery. GDI significantly increased from 77 (14) to 83 (8) ($p=0.03$), with a moderate effect size of 0.56 and with a significant correlation (Spearman's rho=0.67, $p<0.001$) with pre-surgical values (Figure 1). The greatest improvements in GDI were found for the most compromised patients. GDI decreased in patients with equinus deviation who recovered ankle dorsiflexion but had a slight increase in proximal kinematic deviations in the three planes. Walking speed decreased from 0.74 (0.23) m/s to 0.47 (0.22) m/s, as expected in the short term. The popliteal angle decreased from 60 (14) to 40 (12) degrees (n=12, $p=0.009$). Maximum passive ankle dorsiflexion measured at extended and flexed knee improved from -6 (12) degrees to +6 (5) degrees (n=20, $p<0.001$) and from 5 (7) to 13 (6) degrees (n=20, $p<0.001$) respectively. Median pGIC was 2 ("much improved") and ranged between 1 and 3.

Figure 1. GDI before/after FS



Discussion

For the first time in literature, we used the GDI to investigate the short-term effects of FS on gait kinematics in children with CP. Our results confirm, on average, the efficacy of FS in improving walking kinematics. Such functional improvement was confirmed by the subjective perception of patients and caregivers at the GIC scale and by the improvement of ROMs.

Our results also point out a limitation of GDI. By design, GDI considers joint kinematics in the three planes and assigns equal weights to all deviations. Consequently, its sensitivity is maximum in the case of alterations in the three planes (e.g. crouch gait) but reduced in the case of alterations mainly in the sagittal plane (e.g. equinus foot deviation).

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Driving simulator for assessing the driving abilities of individuals with spinal cord injury

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Introduction

Spinal cord injuries (SCI) affect mobility and independence, with driving being key for enhancing quality of life [1]. Recently, driving simulators have emerged as a valuable resource for safe assessment and training of driving skills [2,3]. However, current systems often lack realism, wheelchair accessibility, and progress monitoring. In response to these issues, we have developed a new version of the "Accessible Driving Simulator", called ADRIS 2.1, specifically tailored for individuals with SCI. The aim of this study was to evaluate the effectiveness and viability of ADRIS 2.1 as a tool for SCI-specific driving training.

Methods

ADRIS 2.1 incorporates a PC, a three-monitor setup, a steering wheel, an automatic transmission system and a joystick to enable wheelchair-bound users to have hand-controlled acceleration and braking. Developed using Unreal Engine, it features an AI-driven software to automatically manage and customize driving scenarios (environment variables and events). ADRIS 2.1 was tested on 11 SCI volunteers (51 ± 22 yo, 2 females), with lesion levels C6-L3. The test consisted of 4 phases: (i) free drive (FD), (ii) pre-training (Pre-TR), (iii) training (TR) and (iv) post-training (Post-TR). During the FD phase, participants drove freely for 5 minutes on an open map to familiarize with the simulator. In the Pre-TR and Post-TR phases, participants drove for 2 minutes, following a leading vehicle in a scenario without traffic and under good weather conditions. During the TR phase, participants drove in 4 different scenarios (TR1-TR4) with varying difficulties, including road type, weather, light conditions, and traffic volume. Each TR scenario featured a main static (e.g., a road obstacle) or dynamic event (e.g., pedestrian crossings). At the end of the test, participants compiled 3 questionnaires to rate their experience with ADRIS 2.1: (i) the Simulator Sickness Questionnaire (SSQ, 16 questions, score range: 0-3), (ii) the NASA Task Load Index (NASA TLX, 6 questions, score range: 0-20), and (iii) the Igroup Presence Questionnaire (IPQ, 14 questions divided in 4 categories, score range: 1-7). Alongside the analysis of questionnaire responses, we evaluated driving performance by extracting for each scenario the number of infractions/collisions (nIC) and computing the mean driving speed (MDS, km/h).

Results

According to the SSQ, SCI participants experienced minimal discomfort or symptoms of nausea, oculomotor disturbance, and disorientation during the test (median - Mdn - score of 0). The NASA TLX results revealed that participants experienced low frustration (Mdn 3) and physical demand (Mdn 6), moderate temporal demand (Mdn 10) and high mental demand (Mdn 12) and effort (Mdn 14). The IPQ results depicted a moderate participant involvement (mean 4.25 ± 1.12 std) and presence (mean 4.6 ± 1.58 std), a high virtual world presence (mean 4.73 ± 2.37 std) and low realism (mean 3.86 ± 1.09 std). As for the driving performance assessment, the outcomes are reported in Table 1.

Table 1. Driving performance results (mean ± std) in each scenario

	Pre-TR	**TR 1**	**TR 2**	**TR 3**	**TR 4**	**Post-TR**
nIC	0.47 ± 0.50	1.12 ± 0.36	1.7 ± 0.87	0.88 ± 0.19	0.9 ± 0.75	0.15 ± 0.14
MDS (km/h)	21.30 ± 7.62	12.93 ± 3.61	17.81 ± 3.58	13.50 ± 2.68	17.58 ± 4.56	23.71 ± 7.68

Discussion

SCI participants demonstrated high acceptance of the simulator and its virtual environment (SSQ), alongside a moderate workload perception (NASA TLX). The IPQ results indicated positive engagement and presence in the immersive reality. However, lower realism scores were noted, potentially due to the hospital setting not allowing for a faithful replication of a real driving scenario. Driving performance results revealed that with practice participants improved their driving skills (lower nIC at Post-TR) and gained confidence and familiarity with the simulator (higher MDS at Post-TR). These preliminary findings support the effectiveness of ADRIS 2.1 as a tool for SCI driving skills assessment and training.

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A novel force-constrained non-negative matrix factorization algorithm demonstrates that muscle synergies are useful in force control

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Introduction

Muscle synergies have been proposed as modules that simplify force generation by reducing the degrees of freedom that the CNS must regulate to generate the appropriate muscle patterns [1]. Existing synergy extraction algorithms such as NMF [2] only consider statistical regularities in the motor output and it remains unclear to which extent synergies encode task-relevant variations of muscle activity. To evaluate how well muscle synergies relate to motor tasks, we quantify, in addition to how well the muscle patterns are reconstructed by the extracted muscle synergies, how well the executed motor tasks can be described by them. We here propose a novel force-constrained non-negative matrix algorithm (FCNMF) and present its validation with simulated muscle data. Finally, we demonstrate its effectiveness in muscle data collected in healthy human subjects during an isometric reaching task [3].

Methods

We developed an iterative optimization algorithm (FCNMF) for extracting muscle synergies (**W**) from muscle activity patterns (**m**). We impose the assumption that (1) $\mathbf{m} = \mathbf{W}\mathbf{c} + \boldsymbol{\varepsilon}$, where **c** are the temporal synergy coefficients and $\boldsymbol{\varepsilon}$ is noise, and additionally (2) $\mathbf{f} = \mathbf{H}\,\mathbf{m} = \mathbf{H}\,\mathbf{W}\,\mathbf{c} + \mathbf{H}\,\boldsymbol{\varepsilon}$, where **f** is the forces and **H** is the linear EMG-force-mapping. We identify **W** and **c** by gradient descent minimization of the following cost function:

$$\mathbf{cost} = \frac{\mathbf{1}}{\mathbf{2}}\sum_{s=1}^{S}[\,\lambda\,\|\mathbf{m}(s) - \mathbf{W}\,\mathbf{c}(s)\|^2 + (1-\lambda)\|\mathbf{H}\,\mathbf{m}(s) - \mathbf{H}\,\mathbf{W}\,\mathbf{c}(s)\|^2]$$

with **S** being the number of synergies and weighting the contribution of muscle pattern reconstruction with respect to force reconstruction.

Trajectories of a cursor moving in a virtual environment according to the force estimated from muscle patterns (**f = Hm**) were either simulated or computed from data recorded from a human subject performing an isometric reaching task [3]. Trajectories were reconstructed using synergies ($\mathbf{f} = \mathbf{H}\mathbf{W}\mathbf{W}^{+}\mathbf{m}$, where $\mathbf{W}^{+}$ is the pseudoinverse of **W**) either extracted by the standard NMF [2] or by the FCNMF algorithm.

Results

We found that FCNMF outperforms NMF for different types and levels of noise. Moreover, synergies extracted by FCNMF from real data accurately reconstruct trajectories for all participants, even when the synergies extracted by NMF fail. The failure of reconstruction with muscle synergies extracted by the NMF algorithm is dependent on the characteristics of the noise added to the simulated data. In the case of zero-mean isotropic Gaussian noise, the NMF algorithm has high reconstruction quality levels with small deviations in the task performance even for high noise. However, adding small amounts of noise along the directions in muscle space generating force in the task space highly affects the NMF synergies. This is not the case for synergies extracted by the FCNMF algorithm. The FCNMF algorithm is not only outperforming the NMF algorithm for all noise types but enables also a good performance for even high noise levels in the task space.

Discussion

We demonstrated that the proposed FCNMF algorithm accurately reconstructs cursor trajectories in all participants, even when the NMF algorithm fails. We show the effectiveness of muscle synergies extracted considering the task space, possibly thanks to the robustness of FCNMF against non-isotropic noise present in muscle data, suggesting that they provide an effective strategy for motor coordination. Our results thus reveal a meaningful applicability of the FCNMF algorithm to real data. In conclusion, our results suggest that the CNS employs muscle synergies to cope with the high number of degrees of freedom in the musculoskeletal system and to simplify movement coordination.

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Association between average daily steps measured through a commercial smartwartch and clinical parameters in Parkinson's Disease

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Introduction

Commercial smartwatches could be useful for step counting and monitoring ambulatory activity in a home environment [1]. In Parkinson's disease (PD), motor impairment and reduced functional mobility are crucial aspects. However, only very few studies examined the relationship between average daily steps recorded by commercial smartwatches and clinical parameters in these patients [2].

Methods

Average daily steps (aDS) were collected at home through a Garmin Vivosmart 4 smartwatch for a median of 5 days (range 2-6) in 40 PD patients with no dementia [32% females; age 68.8 ± 8.2 years; disease duration 7.4 ± 5.2 years; levodopa equivalent daily dose (LEDD) 602 ± 302 mg; Hoehn and Yahr (H&Y) stage 2 (2-2, range 1-3)]. Data regarding motor and non-motor symptoms severity and fluctuations, disease phenotype, functional mobility, quality of life and fatigue were collected (Table 1). To assess the correlation between aDS and clinical-demographic variables, the Spearman test was used.

Results

In the overall population, Spearman test showed a moderate positive correlation between the aDSC and the SPPB (R=0.668; p<0.001), a moderate negative correlation with the MDS-UPDRS-III (R= -0.514; p=0.002), a weak negative correlation with the total MDS-UPDRS (R= -0. 430; p=0.014), LEDD (R= -0.366; p=0.033), disease duration (R= -0.418; p=0.014), age (R= -0.404; p=0.018) and H&Y stage (R=-0.409; p=0.016). In patients with tremor, test showed a moderate positive correlation between aDSC and SPPB (R=0.573; p=0.005) and a weak negative correlation with LEDD (R= -0.441; p=0.040) and disease duration (R= -0.445; p=0.038). In patients without tremor, test showed a strong positive correlation between aDS and SPPB (R=0.799; p=0.002), a strong negative correlation with MDS-UPDRS-III (R= -0.820; p=0.001) and a moderate negative correlation with H&Y stage (R= -0.627; p=0.029).

Table 1. Clinical parameters in enrolled PD patients

Variabili		Totale (N=40)	Tremor (N=28)	No Tremor (N=12)	T vs NT
MDS-UPDRS-I		6 (3-8)	6 (3-7; 1-11)	6 (4.5-10)	NS
MDS-UPDRS-II		5 (3-7)	5 (4-6.5)	5 (3-11)	NS
MDS-UPDRS-III		27 (22-31)	28 (22-32)	27 (23-30)	NS
MDS-UPDRS-IV		0 (0-0)	0 (0-0)	0 (0-1.5)	NS
MDS-UPDRS TOT		41 (29-46)	41 (27-46)	42 (33-48)	NS
PDQ-39		11.5 (6.8-18.6)	10.7 (7.2-18.3)	12.2 (6.9-19.2)	NS
WOQ-19		0 (0-2)	0 (0-3)	0 (0-0)	NS
SPPB		10 (7-11)	10 (7-11)	10 (8-11)	NS
FSS		3.7 (2.6-5.2)	4 (2.8-5.4)	3.2 (2.4-4)	NS
FMCS		87.5 (74.2-95.3)	87.5 (77.7-95.3)	78.1 (73.4-95.3)	NS
aDS		5722 ± 3197	5891 ± 3310	5411 ± 3097	NS

Discussion

Average daily steps measured at home by a commercial smartwatch were associated with motor symptoms severity and functional mobility in ambulating PD patients, particularly in those without tremor. This could potentially be due to a reduced step detention performance linked to tremor. Mobility-related parameters measured through commercial smartwatches could add valuable and easy-to-collect information on patients' status besides in-clinic evaluations.

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Quantifying muscular activity during Back Performance Scale tasks

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Introduction

Chronic low back pain (LBP) is a common condition whose severity needs to be assessed to determine appropriate treatment. Clinical scales quantify LBP severity based on the patient's perception of pain and functional disability [1]. Among these, the Back Performance Scale (BPS) [2] is an assessment tool for back functionality that is susceptible to observer bias as it does not allow assessing the accuracy of the muscular activation profile. Surface ElectroMyoGraphy (sEMG) provides support to the diagnostic process by identifying alterations in muscular patterns, and thus quantifying the severity of LBP. This work aims at assessing the muscular activation profiles of major body muscles during the administration of the BPS to healthy subjects.

Methods

The sEMG Delsys Trigno is adopted to record muscle activity while the five BPS tasks are performed: Lift (T1), Pick-up (T2), Sock (T3), Roll-up (T4), and Fingertip-to-Floor (T5) tests. Sixteen electrodes are placed bilaterally on Upper Trapezius (UT), Medial Deltoid (MD), Rectus Abdominis (ABS), low and high portion of Erector Spinae (LES and HES), Gluteus Maximus (GM) and Rectus Femoris (RF) (Figure 4 a,b). Seven right-handed volunteers are enrolled in the experiment (25.4±2.7 y. o.). Six repetitions of each task are recorded: sEMG signal is acquired at 1.11 kHz and filtered with a four-order Butterworth band-pass filter (20–500 Hz). The Root Mean Square of the signal is calculated for each task, normalized for each subject, and average activation profiles are compared with cosine similarity.

Results

All volunteers achieve the lowest score (0) of the BPS scale in all tasks, as evidence of their healthy condition. T1 presents high activation of all muscles, except ABS; T2 presents higher activation of the lower limbs (GM, VM, RF) and the HES and LES; T3 presents high activation of the UT, MD and ABS in the dominant side, and lower limb muscles in the non-dominant side; T4 presents an homogeneous activation profile; T5 presents high activation of the erector muscles (HES, LES) (Figure 1c–g, respectively). Cosine similarity quantifies the distance among different activation profiles (Figure 4h).

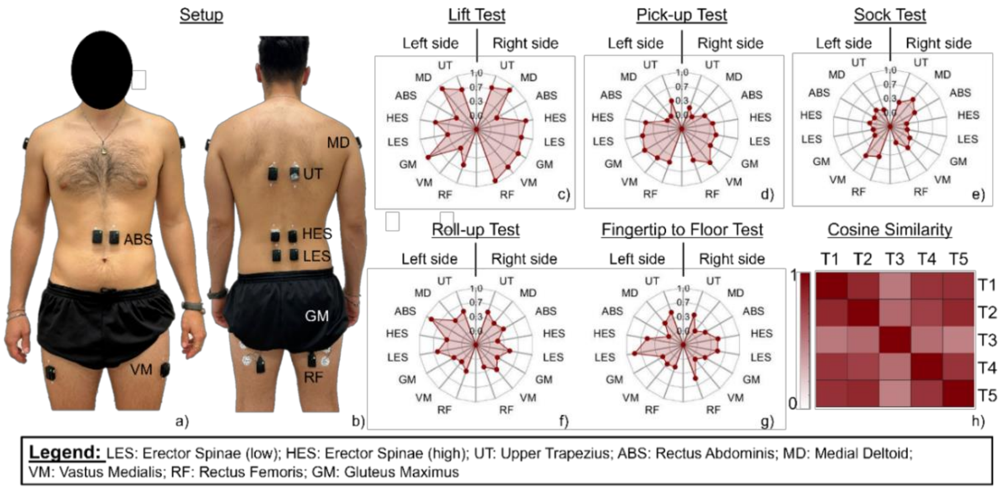

Figure 4: Setup and electrodes positioning (a,b), and average activation for lift (c), pick-up (d), sock (e), roll-up (f), and fingertip to floor (g) tests, and cosine similarities (h).

Discussion

The analyzed tasks resulted in different muscular activation profiles, suggesting that they bring complementary information about the muscular status. Future works will be devoted to compare collected data with respect to data from chronic LBP patients.

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An IMU-based ambulatory protocol for the quantitative characterization of locomotor performance in pediatric patients with rare neurological diseases

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Introduction

Rare diseases involving central and/or peripheral nervous system can manifest with gait disturbance and alterations. Quantitative gait pattern characterization can play a fundamental role for i) identifying elements that are specific of different syndromes, and for ii) defining reference objective developmental trajectories for populations of patients undergoing pharmacological and/or surgical treatments. Notwithstanding, studies that analyze quantitatively motor performance of these patients are lacking, probably limited by the need of laboratory assessment [1]. To this purpose, wearable inertial sensors (IMUs) can better suit the study of gait in ambulatory condition: human movement analysis methods calculated from IMU-acquired gait data allowed the quantitative characterization of locomotor performance (i.e., temporal parameters) and motor control characteristics (i.e., complexity and automaticity) in infants, toddlers, and young adults with typical and atypical development [1-4].
This work aims at investigating locomotor pattern alterations in children with neurological rare diseases using an IMU-based protocol.

Methods

Patients younger than 18 years and diagnosed with a rare neurological disease have been recruited at the IRCCS Institute of Neurological Sciences of Bologna, UOC Neuropsychiatry of the Paediatric Age, Bologna, Italy. Participants walked at self-selected speed (NW) and in tandem (TW) wearing three IMUs on the lower back and on the shanks [2-4]. Temporal parameters, short- and long- term variability, and nonlinear metrics of trunk kinematics (i.e., recurrence quantification analysis and multiscale entropy) were extracted from the collected data and compared to reference age-matched control groups (112 subjects, 6–25 years old) [3].

Results

So far, participants with the following rare diseases were included (number, n, years of age min-max, y):

- Chiari syndrome, CHIARI (n=10, 6-17y);
- Fetal alcohol spectrum disorders (n=1, 11y);
- myasthenia gravis, MYA (n=7, 9-16y);
- Myelin oligodendrocyte glycoprotein antibody disease (n=1, 11y);
- Mowat-Wilson syndrome (n=3, 4-9y);
- Neuro-oncology patients (n=1, 13y).

Given the preliminary number of participants, only CHIARI and MYA results are presented.
When compared to reference age-matched control groups, MYA patients showed increased double support and stance time both in NW and in TW, CHIARI only in NW. CHIARI showed decreased complexity in antero-posterior (AP) direction both in NW (age>10y) and in TW, and increased regularity in NW. MYA patients showed complexity similar to age matched controls, but an increased regularity in AP for age >12y.

Discussion

A stabilizing strategy was highlighted by increased stance and double support durations in CHIARI and MYA patients. When compared to typically developing peers, they also showed an increased regularity in AP at ages higher than 10-12 years, suggesting a limited flexibility of motor control performance. Clearly, these findings are preliminary and further inclusion of participants and analysis are required. Present work highlighted the potential role of locomotor performance assessment for investigating motor control development in children with rare nervous system diseases.

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Effect of single-event multilevel surgery on the gait of children with cerebral palsy: a retrospective observational study

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Introduction

The approach called single-event multilevel surgery (SEMLS) is increasingly being used for functional orthopedic surgery in children with cerebral palsy (CP) [1]. It consists of several interventions to correct skeletal deformities and/or soft parts in a single surgical session. Various studies affirm that SEMLS improves gait function, usually basing their conclusions on kinematic indexes and spatio-temporal parameters [1,2]. However, these parameters do not necessarily define functionality. An assessment of energy exchanges and efficiency aspects, highly compromised in CPs, is essential [3]. Still, dynamic data and even more oxygen consumption data are often not available. The kinematic parameters that most correlate with gait efficiency in CP are maximum knee and hip extension [3]. These parameters, that are relatively easy to assess, have never been used to verify the effect of SEMLS surgery.

Methods

Eighty-four SEMLS were analyzed. All the subjects in charge in the decade 2011-2021 at the Children Rehabilitation Unit of Azienda USL-IRCSS di Reggio Emilia who met the following requirements were included: age 4-20 years (mean 13±4); hemiplegic (9) or diplegic (75) CP diagnosis; GMFCS classes I (21), II (41) or III (22); 3D gait analysis both before and after surgery in a time span between 8 and 38 months. In this sample the more frequent surgical procedures were lengthening of knee flexors (115), hip adductors (68), gastrocnemius (35) and psoas (14). Gait efficiency was measured by maximum hip and knee extension in the gait cycle, propulsive capacity by normalized maximum power produced by the ankle during push-off phase (dynamic data was available for 64 subjects), global gait performance by normalized speed and normalized stride length.

Results

Results are reported in Table 1.

Table 1. Mean and standard deviation of the measured data and statistical significance of their pre- vs post-surgery variation. Reference values of a group of 24 typically developing children (TD, mean age 12 years, mean body weight 47kg) is presented.

	Efficiency		**Propulsion**	**Global performance**	
	Max knee extension [deg]	Max hip extension [deg]	Push-off power peak [W/kg]	Speed [%h/s]	Stride length [%h]
Pre-surgery	-18.0 ±14	-4,8 ±11	1.1 ±0.7	59.3 ±20	60,7 ±13
Post-surgery	-11.8 ±11	-2.9 ±11	1.4 ±0.8	58.3 ±21	61.3 ±14
Pre vs Post	+6.2* ±10	+1.9* ±8	+0.3* ±0.6	-1.0 ±13	+0.6 ±10
p-value	<0.001	0.001	<0.001	0.36	0.75
TD	-4	9	1.8	82	83

Discussion

An average 6.2° of knee extension and 1.9° of hip extension were added by SEMLS. Both parameters indicate a statistically significant efficiency improvement. However, for the hip, the clinical relevance of a mean change in extension of less than 2° is questionable. The greater increase in knee extension may be explained by more interventions with an impact on knee extension itself (i.e., hamstring and gastrocnemius lengthening) rather than hip extension (i.e., psoas lengthening). Furthermore, hamstrings lengthening, given their bi-articular nature, may lead to an increase in anterior pelvic tilt which indirectly adds hip flexion. Maximum push-off power increased by 23%, providing greater propulsion availability. However, this didn't translate into increased speed or stride length. More likely, the extra ankle power and efficiency were used to save energy. Therefore, speed may be a less relevant indicator of functionality as energy savings may take priority.

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Co-activation in time-frequency domain among EMG signals from several muscles during walking

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Introduction

The Central Nervous System recruits muscles as coordinated system, to produce functional movementand maintain stability. Thus, understanding the interplay and coordination among several muscles, is crucial to draw the biological laws underlying motor control, and therefore to develop effective rehabilitation strategies. Different EMG-based approaches have been proposed to this aim [1,2]. theseapproaches were based on the solely EMG amplitude, and neglected its spectral characteristics, whichmay underlie the existence of common drives shared among muscles [3]. The aim of the current studyis to preliminarily introduce a novel approach based on continuous wavelet transform analysis (CWT) to assess the co-activation among surface EMG (sEMG) signals of several muscles, captured during walking, both in time and frequency domains.

Methods

The proposed approach was tested on the sEMG signals acquired bilaterally (sampling frequency = 2 kHz) from Tibialis Anterior (TA), Gastrocnemius Lateralis (GL), and Vastus Lateralis (VL), during walking of a single young healthy subject at Movement Analysis Lab, Università Politecnica delle Marche, Ancona. After band-pass filtering, CWT analysis of sEMG signal was achieved by using the Daubechies of order 4 (as mother wavelet). Then, CWT scalograms were computed for each muscle. Co-activation in time-frequency domain among the activity of TA, GL, and VL was computed by CWT-based cross-energy localization of the three scalograms, extending the approach reported in [4].

Results

The results of the application of the proposed algorithm to sEMG signals measured in 31 consecutive strides of the subject show that, on average, two main co-activation intervals were detected within the gait cycles: in early stance (mean ± SD) from 3.3±5.2% to 6.7±5.8% of gait cycle, and during swing from 96.2±3.1% to 98.8±1.1% of gait cycle. The correspondent average frequency content ranges from31±7 Hz to 137±34 Hz. An example in a single representative stride of co-activation in time-frequency domain among the activity of TA, GL, and VL is depicted in Figure 1.

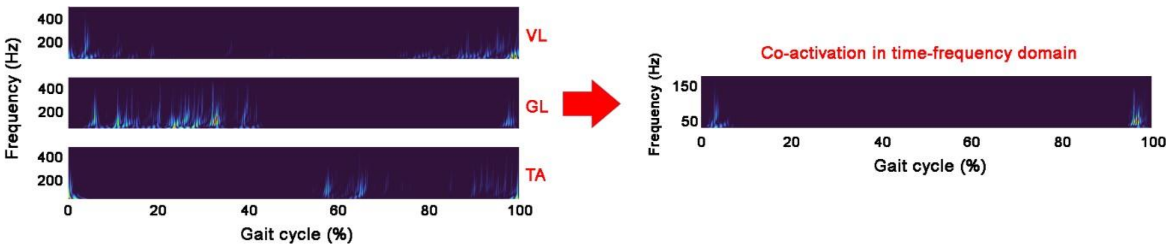

Figure 1. CWT-based co-activation of TA, GL, and VL in time-frequency

Discussion

The present study suggests that the CWT-based approach provides a reliable prediction of the co- activation between the activity of three different muscles during walking both in the time and frequencydomains. The current approach may reveal new insights into the control law underlying the muscle coordination, synchronization patterns, and muscle synergies during motor tasks. Moreover, this approach may represent an innovative aid in designing effective control strategies in developing prosthetics and assistive devices.

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Gait smoothness during straight and curvilinear gait in patients with multiple sclerosis: doesthe data source matter?

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Introduction

Gait smoothness is a clinically meaningful parameter in patients with Multiple Sclerosis (PwMS) [1]. Different metrics have been proposed in the past years to quantify movement smoothness [2] and applied to locomotion using acceleration and/or angular velocity data measured by an inertial measurement unit (IMU) located on the lower trunk [3,4]. Among them, the log dimensionless jerk (LDLJ) was suggested as a less variable and better discriminative metric when assessing smoothnessin neurological patients [4,5]. It is not clear, however, which data source (acceleration and/or angular velocity) should be considered when using the LDLJ for gait smoothness quantification and if the characteristics of the considered motor task (such as straight *Vs* curved walking) can influence the results and the discriminative capacity of this metric. The aim of this study is thus to verify if gait smoothness quantified using LDLJ from acceleration ($LDLJ_a$) and angular velocity ($LDLJ_w$) datachanges according to tasks (straight Vs curved walking) and populations (healthy control Vs PwMS).

Methods

Thirty-six healthy participants (12 F; 33±10.8 y) and 60 PwMS (20 M, age 50±10 y) were enrolled. PwMS were further divided into two groups based on their disease severity (Expanded Disability StatusScale (EDSS) score: MSC1=1<EDSS<4 (33 patients) and MSC2=4.5<EDSS<6 (27 patients), presenting mild and severe impairment, respectively). Participants performed three times a 10 m walking test (10mWT) and a figure of eight test (Fo8) while wearing three IMUs (APDM Opal, 128 Hz) on the lower trunk and both lateral malleoli, the latter used for stride segmentation. Acceleration and angular velocity data from the lumbar IMU were used to obtain $LDLJ_a$ and $LDLJ_w$ during each gait cyclefor each direction (anterior-posterior, medio-lateral, and cranio-caudal). Median and interquartile ranges were obtained for each participant. Two-way mixed model ANOVAs were performed to verify the *task* and *population* main effects, as well as the presence of a significant *task x population* interactions.

Results

Figure shows the boxplot of $LDLJ_a$ and $LDLJ_w$ components for which significant differences were found(*). Simple main *task* effects were found for cranio-caudal $LDLJ_a$ and anterior-posterior $LDLJ_w$. Significant *task x population* interactions were found for medio-lateral and cranio-caudal $LDLJ_w$.

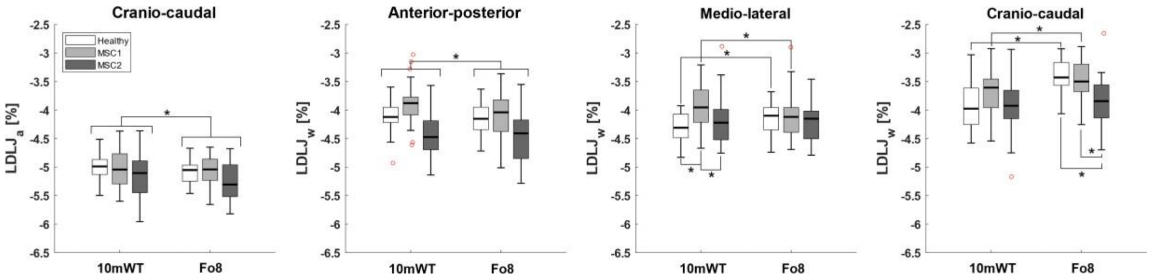

Figure. Boxplots of $LDLJ_a$ and $LDLJ_w$ smoothness metrics for healthy control, MSC1, and MSC2.

Discussion

Interestingly, no clear trend was displayed for both $LDLJ_a$ and $LDLJ_w$ in the three populations, with MSC1 characterized by the highest smoothness in the antero-posterior and medio-lateral directions. LDLJ obtained from angular velocity data discriminated between straight and curvilinear walking and among different populations, especially in medio-lateral and cranio-caudal directions. It is thus suggested to consider the angular velocity when assessing gait smoothness from inertial sensor data.

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Spine kinematic assessment during forwarw bending and sit-to-stand tests in low-back-pain patients

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Introduction

Low back pain (LBP) is a very common musculoskeletal disorder worldwide and represents one of the major cause of years lived with disability. LBP affecting performance at work and general well-being it has a huge social impact [1]. Visual estimation of the lumbosacral ROM limitation is frequently used by clinicians to assess patients with LBP, however this modality does not allow clear quantification of the deficit. This study proposes a previously validated system of 3 magneto-inertial measurement units (MIMU) [2] to quantitatively evaluate changes in lumbosacral ROM in a population with mild LBP.

Methods

11 patients (PG) who met the study inclusion criteria and 10 healthy volunteers as a control group (CG) were enrolled. Participants performed 5 consecutive Forward Bending (FB) and five consecutive Sit-to-stand (STS) tests. 3 MetaMotionR MIMU (MBIENTLAB INC, San Francisco, California, USA) were placed on T3, T12, and S1 vertebrae to record spine kinematics during the execution of the FB and STS tests. The Roland-Morris Disability Questionnaire (RMDQ) was used to rate physical disability caused by LBP.

Results

Characteristics of enrolled participants are reported in table 1. PG showed a mild degree of disability. Non-significant differences were found between the PG and CG during STS test. The FB test showed a significant reduction of total ROM in the PG recorded at T12 and S1 vertebrae. The sensor on T12 detected a ROM of 119,07±15,40° for CG and 102,10±6,96° for PG (p=0.03), the sensor on S1 detected a total ROM of 71,80±9,68° for CG and 59,71±7,48° for PG (p=0.01).

Table 1. Characteristics of enrolled participants.

	Patients group (PG)	Control Group (CG)
Participants (n)	11	10
Gender	7 M; 4 F	5 M; 5 F
Age (Year)	38 ± 10	29 ± 5
Body mass (kg)	75 ± 15,76	67,7 ± 11,60
Height (cm)	171,73 ± 11,13	171,8 ± 4,76
BMI	25,18 ± 3,19	22,83 ± 2,90
Roland-Morris Disability Questionnaire	3 ± 1,55	N.A.

Discussion

The MIMU allows to perform a quantitative and objective evaluation of lumbosacral ROM in patients with LBP. The FB task appears to be more appropriate than STS for assessing patients with mild disability as it showed significant lower ROM respect to the control group. The results of our study are consistent with literature [3].

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A 24-year-old girl with Friedreich's Ataxia and focal mechanical vibration: a case report

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Introduction

Focal mechanical vibrations can be used to improve proprioceptive stabilization in patients with Friedreich's Ataxia [1]. The aim of this study is to quantify the effect of focal mechanical vibrations on a patient with Friedreich's Ataxia during walking by investigating the spatiotemporal parameters of the gait cycle [2].

Methods

A 24-year-old girl with Friedreich's Ataxia participated to the present study. Data were collected before (T0) and 10 days after the therapy (T1). A focal mechanical vibrations therapy was administered throughout 6 sessions in consecutive days. The muscles involved in these sessions were: psoas, rectus femoris gluteus medius, and triceps suraeThis focal stimulation represents a selective intervention that does not have negative effects and allows for the use of high frequencies (100 Hz) and a width 0.2 mm [3]. Spatiotemporal parameters of gait were collected by means of our laboratory instrumentation: BTS GAITLAB SMART DX 4000 (Davis Protocol) and BAIOBIT BTS Bioengieering Group.

Results

In this study we are focusing on the improvements and effectiveness of the focal mechanical vibrations on the clinic status of the patient and her movement ability both on the proprioceptive side and the biomechanical aspect.

Table 1. Results of the spatiotemporal parameters of gait at T0 and T1.

	T0		**T1**	
	DX	**Sn**	**DX**	**Sn**
Stance phase (%)	70.7	63.36	66.52	67.68
Swing phase (%)	29.3	36.64	33.48	32.32
Single stance phase (%)	39.95	27.44	34.47	31.4
Double support phase (%)	15.78	21.09	18.33	15.05
Average gait speed (m/s)	0.5		0.6	
Cadence (steps/min)	75.6		82.5	
Step width (m)	0.12		0.14	

Discussion

Depending on what the results will be a therapy protocol for Friedreich's Ataxia could be defined with courses of focal vibrations therapy.

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Exploring the potential of low cost IMUs for telerehabilitation: the REHACT case study

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Introduction

A rapid increment of telemedicine gave to health services the possibility to perform in-home patient's rehabilitation [1], by using videocalls or videorecording. Current approaches usually quantify repetition number without quantitively characterize the rehabilitation exercises; rarely wearable sensors are used in this perspective, despite their potential to provide a multitude of physical parameters [2]. Therefore, the REHACT project (*Telerehabilitation care services based on respiratory exercise and motor reactivation*), aims to develop low cost telerehabilitation services for elderly people with or without pathologies (cardiac, respiratory, or long-covid19 disease) and rehabilitation protocols based not only on lower and upper limb rehabilitation exercises, but also on respiratory training, which is important for functional capacity in those subjects [3]. As a part of the project, the objective of this study is to explore the usability of low cost MIMUs (<100€) in motor and respiratory rehabilitation exercises for elders.

Methods

Five medically stable elderly females (height=1.63±0,04m, mass=58,8±5,9kg, age=70,8±4,9y) did a home-based rehabilitation protocol (8 repetitions for 2 sets) for upper limb (Up), lower limb (Lo) and respiratory muscles (Re) in different positions. Three low cost MIMUs (MPU-9250, InvenSense, United States; @26 frames/s) were positioned on wrist, ankle and above the last cost according to exercise type. Comfort and effort were assessed, and 3 feature types extracted: 1) Quantity: number of repetitions (threshold based); 2) Intensity: Euclidean norm of the acceleration (MI); 3) Quality: smoothness (log dimensionless jerk (LDLJ)) and movement stability (dynamic time warping (DTW)) [2].

Results

Participants referred a high comfort in using the system. It allowed to correctly count 954/960 repetitions, including the critical segmentation of respiration phases, and to identify intensity and quality features for the exercises as shown in Table 1.

Table 1.		**Intensity**	**Quality**		**Comfort**	**Effort**
	Exercise position	*MI [g]*	*LDLJ [a.u.]*	*DTW [m/s²]*	*VAS scale*	*RPE scale*
Up	lying	0.51±0.22	-7.30±0.12	1.87±0.41	8.8±1.0	0.4±1.3
	sitting with support	0.55±0.11	-7.66±0.13	1.58±0.55	8.8±1.0	1.2±1.0
	sitting without support	0.53±0.09	-7.64±0.10	1.37±0.42	8.8±1.0	1.0±1.0
	standing	0.17±0.05	-6.56±0.38	0.35±0.21	8.8±0.8	1.2±1.0
Lo	lying	0.74±0.29	-7.36±0.22	2.48±0.56	9.2±1.3	0.8±0.5
	sitting with support	0.91±0.32	-7.46±0.17	2.15±1.21	9.2±1.7	1.2±0.5
	sitting without support	1.02±0.30	-7.50±0.11	1.86±0.39	9.2±1.0	1.2±0.5
	standing	0.10±0.04	-5.72±0.95	0.78±0.31	9.2±1.9	1.4±0.5
Re	lying	0.15±0.15	-6.40±0.56	0.36±0.23	8.8±1.5	1.1±0.8
	sitting with support	0.19±0.06	-6.24±0.41	1.08±0.85	8.8±1.3	1.0±0.8
	sitting without support	0.11±0.08	-6.22±0.63	3.29±2.83	8.8±1.3	1.2±0.8
	standing	0.28±0.12	-6.59±0.37	3.44±2.21	9.0±1.0	1.2±0.8

Discussion

The low-cost MIMU system allowed a thorough characterization of intensity and quality of several rehabilitation exercises. For lower limb exercises. MI and LDLJ were reasonably scaled with respect to young people [2]. Stability (DTW) increased while decreasing movement constraints and showed greater variability for respiratory exercises. possibly due to the difficulty of prolongedly maintain the same breathing rate. This proof of concept supports progressing in the industrial development (TRL). Parallelly, increased reference data and acquisitions on pathological participants are required to test the system's ability to detect health status baseline and progression due to the rehabilitation program.

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Mechanical properties optimization and functional outcomes of an innovative passive dynamic custom Ankle-Foot Orthosis for foot drop patients

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Introduction

Ankle-Foot-Orthoses (AFOs) are orthopedic devices commonly prescribed to support the foot during the swing phase of walking in patients affected by foot drop (FD). Although cost-effective standard solutions are available, custom AFOs are often necessary to address the variations in foot and leg morphology and the degree of impairment in each individual. Aim of this study was the optimization of the mechanical properties of a novel passive dynamic custom AFO and the functional evaluation via gait analysis in a cohort of FD patients.

Methods

Ten unilateral FD patients were enrolled in the study (8M, 2F; age 65 ± 11 years). Clinical scores were used to assess patients' health-related quality of life and ankle strength. A custom set-up based on a uniaxial load cell was used to measure the residual ankle force in the affected limb. The geometry of each custom AFO was tailored on foot and leg morphology and was produced via laser-sintering of a fiberglass-reinforced polyamide powder (Windform GT, CRP Technology) [1]. Gait data from a cohort of healthy subjects were used to estimate the minimum AFO stiffness required to resist the ankle plantarflexion moment in the swing phase of gait. To assess the effect of the custom AFOs on gait parameters, the patients were instrumented with skin-markers according to a validated kinematic protocol [2] and were asked to walk at self-selected comfortable speed in three conditions: wearing the custom AFO, wearing a standard Codivilla spring, and shod with no-AFO. sEMG sensors were used to sample the activation of the major ankle plantarflexor and dorsiflexor muscles. A VAS was used to score the perceived comfort of each AFO condition. Wilcoxon and Friedman statistical tests were used to investigate the effects of the AFOs on kinematic, spatio-temporal parameters and comfort.

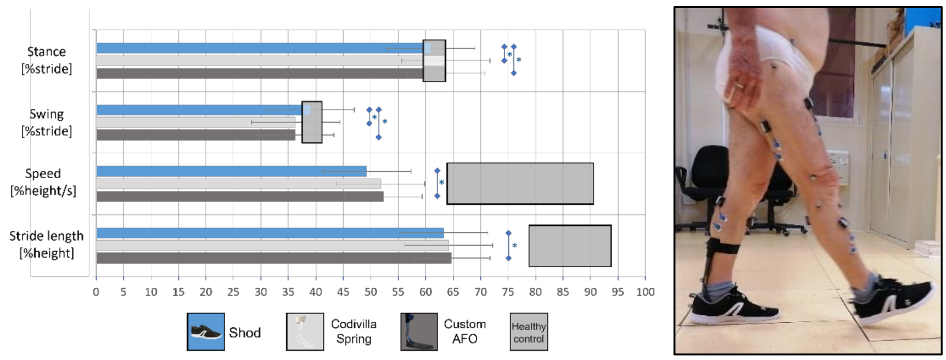

Figure. Left, spatio-temporal parameters during gait in the shod, Codivilla spring and custom AFO conditions. * indicates statistically significant differences between two conditions. Data from a healthy control population are superimposed. Right, an exemplary FD patient during the gait analysis while wearing the custom AFO.

Results

Patients walked at faster speed (%height/s) while wearing the custom AFO (AFO = 53.9±12.6; shod = 51.0±13.5; $p<0.05$) (Figure). Both AFOs allowed sufficient foot-to-ground clearance by increasing the ankle dorsiflexion angle in the swing phase. The custom AFO was scored overall more comfortable than the Codivilla spring ($p<0.05$).

Discussion

The present custom AFO resulted more comfortable than a standard orthosis, supported the foot in the swing phase of gait and allowed for significant faster walking speed and longer stride length with respect to the shod condition. This device appears to be a suitable and reliable alternative for FD patients who are not fully satisfied with standard off-the-shelf solutions.

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The Mini-BESTest scale and the TUG test turning duration have satisfactory criterion validity as balance measures: a longitudinal study with prospective falls reporting in neurological patients

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Introduction

Standing, walking and transferring, such as sit-to-stand and sit-to-walk, are often impaired in patients with neurological diseases. These impairments flag a balance problem, i.e. a reduced ability not to fall. Eventually, neurological patients suffer an increased falling risk. The Mini-Balance Evaluation System Test (Mini-BESTest), a rating scale, the Timed Up and Go (TUG) test and gait measures are often used as balance measures [1–3]. The current prospective, cohort, observational study aims to assess the criterion validity of Mini-BESTest, gait and TUG measures as balance measures.

Methods

One hundred seventy-five patients with neurological disease (stroke, peripheral neuropathy of the lower limbs, Parkinson's disease or vascular parkinsonism) were recruited among those attending the inpatient rehabilitation unit of Casa di Cura del Policlinico (Milan, Italy).
The Mini-BESTest, TUG (instrumented with inertial sensors) and the 10 m walking test were administered before and after rehabilitation.
Participants received a monthly paper calendar and were asked to annotate if a fall occurred. Moreover, research staff contacted all participants at the end of the first, second, third, sixth, and ninth months of rehabilitation discharge. The probability of being a faller within nine months was the balance criterion.
The dataset was analysed with multiple logistic regression and LASSO logistic regression. The Area Under the Curve (AUC) of the receiver operating characteristic curve was used to evaluate the regression models' accuracy for faller identification.

Results

Sixty-four participants have fallen once or more in nine-month after rehabilitation discharge. Logistic regression identified the Mini-BESTest (AUC = 0.67; likelihood ratio test: $p<0.010$), the duration of the TUG turning phase (AUC = 0.71; $p<0.010$), and other TUG measures as faller predictors. However, LASSO logistic regression only selected gender, disease chronicity, urinary incontinence, the Mini-BESTest and turn duration as the faller predictors.

Discussion

The Mini-BESTest and the duration of the turning phase of the TUG test are valid balance measures helpful in assessing the falling risk in neurological patients.

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The effect of robotic rehabilitation on gait in stroke patients

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Introduction

Stroke is considered one of the most important causes of disabilities and death in the World and represents the third cause of long-term disability. Patients experience deficits in the lower limb function, which compromises, with varying degrees of severity, the sensorimotor strategies used by the brain during gait and balance control. In recent years, next to conventional rehabilitation's techniques, new technologies, such as robotic devices, have been developed to enhance gait training in the early phase after stroke. The study intends to highlight the role of robotic rehabilitation in the gait training of post stroke patients.

Methods

A retrospective study including 168 acute stroke patients, with diagnosis of cerebral hemorrhage and ischemia, undergoing intensive rehabilitation and classified into 2 groups. Group A (experimental group) underwent conventional rehabilitation integrated with robotic therapy (G-EO Reha Technology AG Olten, Switzerland, Ekso Bionics CA USA, Copernicus Rehalife Crotone Italy, OAK Khymeia Italy, OMEGO, PEGASO FES-CYCLING Barbieri Srl Italy) and group B (control group) received conventional rehabilitation. At the beginning of the treatment (T0) and at the end of the treatment (T1), the subjects underwent a clinical examination, clinical scales (VAS, Barthel Index) and gait analysis with inertial sensor (BTS Bioengineering, Garbagnate Milanese MI).

Results

As shown in Table 1, both groups improved in functional results analyzed from T0 to T1. At T1 we recorded a statistical difference ($p<0.05$) in gait analysis between group A and group B in gait parameters (Cadence, Support Phase, Single Support Phase, Symmetry Index, Propulsion, Tilt, Obliquity and Rotation); details of functional improvement are showed in table 1 with a subgroups analysis based on the etiology.

Table 1.

			Cadence		Velocity		Cycle Duration		Cycle Length		Support Phase		gle Support Ph		dex Symmetr		Propulsion		Tilt		Obliquity		Rotation	
			T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1	T0	T1
Gruppo B		AVE	64,52	87,99	0,54	0,74	2,27	1,51	1,04	1,12	71,79	62,29	30,70	36,15	72,50	81,10	3,40	4,30	69,40	78,90	47,70	62,20	68,00	76,00
		STDV	16,95	17,09	0,17	0,19	0,66	0,36	0,19	0,19	3,82	4,09	3,90	5,00	10,20	9,80	0,50	0,60	10,90	9,90	17,80	19,60	16,40	15,30
Gruppo A		AVE	65,76	94,01	0,53	0,79	2,34	1,45	1,03	1,15	71,98	60,52	31,50	41,00	71,80	89,70	3,50	6,60	70,10	94,70	46,70	66,90	67,20	82,40
		STDV	14,85	12,64	0,18	0,18	0,97	0,34	0,18	0,20	5,81	5,36	6,40	7,10	10,00	8,00	1,40	1,20	16,10	3,40	16,80	12,10	17,00	13,60
			p < 0,05								p < 0,05		p < 0,01		p < 0,01		p < 0,01		p < 0,01				p < 0,05	
hemorrhage	B	AVE	60,28	85,09	0,49	0,70	2,30	1,50	1,01	1,07	70,52	62,41	31,5	36,9	70,5	83,3	3,4	4,2	68,3	75,6	44,5	59,4	66,5	78,0
		STDV	13,40	16,63	0,13	0,16	0,51	0,32	0,16	0,17	4,50	4,44	4,5	5,4	10,6	9,8	0,7	0,7	11,6	9,8	18,8	22,4	16,4	12,8
		AVE	63,52	92,26	0,49	0,74	2,56	1,51	1,03	1,14	72,66	60,39	31,2	40,8	71,1	93,4	3,4	6,0	68,1	93,5	44,2	66,6	66,1	84,8
	A	STDV	14,44	10,08	0,20	0,17	1,27	0,33	0,16	0,17	6,37	6,12	6,7	7,3	9,7	9,7	1,5	1,0	13,0	2,9	11,2	12,7	15,0	13,1
											p < 0,05		p < 0,05		p < 0,01		p < 0,01		p < 0,01				p < 0,05	
ischemia	B	AVE	67,41	89,96	0,57	0,77	2,25	1,51	1,06	1,15	72,60	62,20	30,1	36,0	70,2	81,1	3,5	4,4	70,2	81,1	50,0	64,1	69,0	74,4
		STDV	18,57	17,27	0,19	0,21	0,75	0,39	0,20	0,20	3,05	3,88	3,4	5,0	10,4	9,4	0,4	0,5	10,4	9,4	16,9	17,5	16,5	16,7
		AVE	67,28	95,20	0,57	0,82	2,20	1,41	1,04	1,15	71,51	60,61	31,8	41,1	72,4	87,4	3,6	7,0	71,4	95,5	48,4	67,0	67,9	80,7
	A	STDV	15,04	14,10	0,17	0,17	0,67	0,35	0,20	0,21	5,42	4,84	6,3	7,1	10,2	8,6	1,4	1,1	17,8	3,5	19,6	11,8	18,3	13,7
											p < 0,01		p < 0,01		p < 0,01		p < 0,01		p < 0,01					

Discussion

Considering our results, robotic rehabilitation provides additional benefits, in comparison with standard rehabilitation alone. In particular, we obtained an improvement in lower limb kinematic and gait performance, influencing patient independence during the activity of daily life. Therefore, robotic rehabilitation represents an adaptable, multi-faceted rehabilitation tool that can be considered in post-stroke rehabilitation, improving the compliance of the patients to the treatment, and increasing the level of functioning and quality of life of stroke survivors.

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SensoFlex: a novel exergame device for motor-cognitive telerehabilitation in older adults

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Introduction

Technology-based home rehabilitation is gaining relevance in the treatment of elderly. One form of telerehabilitation is motor-cognitive training using exergames. Exergames can have comparable effects to traditional training approaches [1,2], yet being more accessible and cost-effective [3]. This study aims to: (a) describe a novel exergame device (SensoFlex, Dividat, CH) developed within an ongoing European project (CoCare, aal-2020-7-145-CP), (b) present preliminary results about the ability of the performance measures extracted from 3 exergames to discriminate between older (OA) and younger adults (YA), (c) provide data on the acceptance and enjoyment of SensoFlex.

Methods

Ten YA (age: 35±10 years, 40% females) and 45 OA (age: 72±8 years, 47% females) were tested while using SensoFlex. SensoFlex is a foldable mat (1m x 1m) equipped with 47 x 47 piezoresistive force sensors (resolution: 0.5 kg, accuracy: <1%) which measure the force exerted by the user moving on the mat and use it to move "avatars" displayed on a TV screen to play motor-cognitive exergames independently at home. A web-based software (Dividat Manager) computes instrumental measures of performance and allows clinicians to remotely plan/modify personalized trainings and monitor users' performance. Participants performed 3 exergames (80 s each): (1) "Targets": 4 targets appear on the screen. Several balls from all directions move towards one target. The task is to react with a step in the direction of the target as soon as the ball exactly reaches its center; (2) "Evolve": hoops and balls move across the screen. Participants have to shift their body weight (while standing with a hip-width stance) to catch hoops and avoid balls (distractors); (3) "Rocket": participants walk in place on the mat to fly a rocket. A green arrow or a red bar appears on the screen if cadence is, respectively, too low or too high. The following measures, automatically computed by Dividat Manager, were compared between YA and OA via t-test: "Targets": number of hit targets; "Evolve": precision (number of caught hoops as a percentage of caught hoops and distractors); "Rocket": cadence (step/s). Questions about perceived ease of use, usefulness, and intention to use were administered to OA as measures of acceptance. Enjoyment during exergames was assessed with the Exergame Enjoyment Questionnaire (EEQ).

Results

Compared to YA, OA hit significantly less targets during "Targets", executed "Evolve" with lower precision and "Rocket" with lower cadence (Table 1). Ninety-one % of OA considered SensoFlex easy to use and useful, while 84% expressed their intention to use the device. EEQ score was ≥ 70/100 in 66% of the OA.

Table 1. Instrumented measures (mean ± SD) at the three SensoFlex exergames. *p<0.05 (YA vs OA)

Exergame	Measure	YA	OA
Targets	Hit Targets [n]	42 ± 20	19 ± 11 *
Evolve	Precision [%]	80 ± 15	66 ± 17 *
Rocket	Cadence [step/s]	2.4 ± 1.4	1.3 ± 0.7 *

Discussion

The present results suggest that (i) all performance measures of the 3 SensoFlex exergames are able to discriminate between YA and OA, (ii) SensoFlex is highly accepted by OA, and (iii) the tested exergames are considered enjoyable by two thirds of OA. Future studies will analyze the feasibility and efficacy of a SensoFlex-based motor-cognitive home training in older adults within the scope of a pragmatic randomized controlled trial.

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Real-time joint kinematics optimization through a constrained ISB-consistent upper limb model

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Introduction

The reliable description of upper limb joint kinematics is fundamental for several biomechanical applications. The use of wearable sensors (IMUs) together with state-of-the-art sensor fusion algorithms represents a convenient solution to unobtrusively monitor the subject performance in real-world environments. However, for acquisitions lasting several minutes, errors in joint angle estimates increase with time due to orientation drift thus affecting joint kinematics reliability. The aim of this work is two-fold: i) to propose a multi-segmental model of the upper limb compliant with the guidelines of the International Society of Biomechanics (ISB) and ii) to propose a real-time optimization framework for the IMU-based joint kinematics estimation by setting *ad-hoc* model constraints based on both the physiological joint limits and the performed movement.

Methods

A three-segment chain was designed following the Denavit-Hartenberg robotic convention to model the upper limb including the trunk, the upper arm (UA), and the forearm (FA). The shoulder and elbow joints were modeled as three (θ_1, θ_2, θ_3) and two (θ_4 and θ_6) degrees of freedom, respectively, following the ISB axis sequence. The carrying angle θ_5 was modeled as a fixed and subject specific parameter. One healthy subject was equipped with two IMUs on the UA and FA and asked to draw a continuous path with a pencil over a printed page on a horizontal surface while seated. Four reflective markers were placed on each IMU to provide the orientation reference. IMU and marker data were recorded for 10 minutes at 100 Hz. Experiments were repeated eight times with eight pairs of IMUs (Xsens – MTw) to test the method robustness to different IMU noise. For each instant, the joint angles were obtained in an optimization framework by minimizing the difference between the orientation predicted using the upper limb model and the corresponding magnetometer-free orientation computed using [1]. In addition, optimal (θ_1, θ_2, θ_3, θ_4, and θ_6) solution had to satisfy two sets of constraints including both the extreme values for each θ based on the physiological joint limits and the a priori task-specific knowledge (i.e., during the entire recording the elbow and wrist joint center positions spanned limited volumes). Errors were computed as root mean square differences between the reference joint angles and those obtained through the optimization framework with and without applying the constraints, respectively.

Results

Average errors (deg) for θ_1, θ_2, θ_3, θ_4, and θ_6 obtained with (without) the constraints over the eight repetitions amounted to 10.9 (13.0), 6.4 (7.5), 3.9 (3.9), 14.4 (16.4), 5.4 (5.7), respectively. The average execution time to perform about 62000 iterations amounted to 9.42 ms.

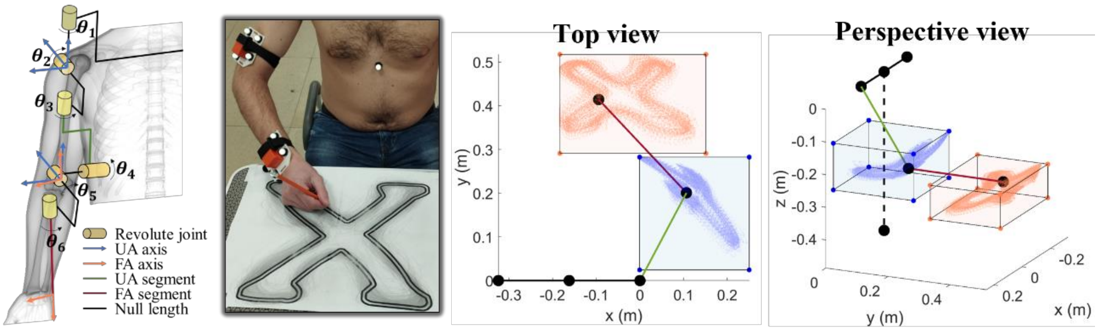

Figure 5: from left to right, the upper limb model, the experimental setup, the obtained wrist and elbow trajectories with the corresponding imposed volume limits shown as blue and red rectangular boxes, respectively.

Discussion

By exploiting the knowledge of the performed movement, the constraints application allowed to reduce both shoulder and elbow angular errors by around 12% and 11%, respectively, thus limiting the impact of the IMU orientation errors on the estimated joint angles. The execution time lower than the sampling period is suitable for a real-time joint kinematics computation. This abstract is part of the project NODES which has received funding from the MUR – M4C2 1.5 of PNRR with grant agreement no. ECS00000036. Part of DoMoMEA project funded by Sardegna Ricerche with POR FESR 2014/2020.

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Kinematic and muscle synergies analysis in patients with Parkinson's disease

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Introduction

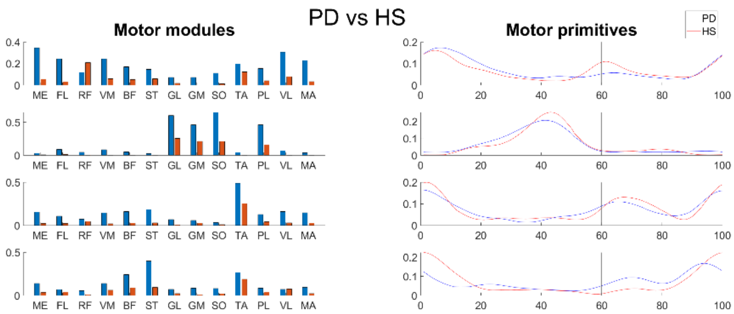
Parkinson's disease (PD) can cause gait disorders. Muscle synergy analysis is increasingly used as a computational tool to examine the physiological basis of motor control [1,2]. This study is a preliminary investigation on the effect of L-Dopa-based drug therapy on the joint angles of lower limbs and on the composition of muscle synergies of PD patients, also with respect to a control group of healthy subjects (HS).

Methods

Sixteen PD patients and five HS were asked to walk for a length of 40 m wearing EMG and IMU systems. PD patients were monitored in both OFF and ON state of drug therapy. The EMG signals of 13 muscles of the right leg and the inertial data of the lower body were acquired. The joint angles of the hip, knee and ankle were extracted. By means of the NNMF (Non-Negative Matrix Factorization) the muscle synergies of the PD patients for both the OFF and ON state and of the HS were calculated. The number of synergies was identified through the VAF (Variance Accounted For). Subsequently, the motor modules and motor primitives were analyzed for 4 synergies in such a way that they could be compared with those of HS.

Results

Lower joint angles emerged in PD patients compared to HS, especially for the hip. Angles improved after drug intake. The number of synergies ranged from 4 to 6 in PD patients and was equal to 4 for HS. In the ON state there was a slight increase in the VAF value for PD patients when considering the 4 synergies model. The composition of the synergies did not show differences in PD patients regardless of the therapy status. However, the synergies of PD patients showed a higher value of motor modules than HS, but a similar trend of motor primitives as can be seen in figure 1. These results are limited by the small number of HS.



ME: gluteus medius
FL: tensor fasciae latae
RF: rectus femoris
VM: vastus medialis
BF: biceps femoris
ST: semitendinosus
GL: gastrocnemius lateralis
GM: gastrocnemius medialis
SO: soleus
TA: tibialis anterior
PL: peroneus
VL: vastus lateralis
MA: gluteus maximus

Figure 1: Comparison of the four synergies between PD patients and HS.

Discussion

Hip angles of PD patients showed lower values compared to HS. Angles improved after taking the L-Dopa, indicating a usefulness for the improvement of gait kinematics. The number of synergies in PD patients is equal to or greater than that of HS. The trend of the motor primitives is similar to HS one but presents a reduced amplitude of the activation peaks in the first and fourth synergies. Furthermore, there is an abnormal modulation in muscle weights that is not reduced after drug intake, showing a limited effect of L-Dopa on muscle synergies. Future foresee the expansion of the PD and HS sample.

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Ability of a set of trunk acceleration-derived gait indexes to characterize gait imbalance in subjects with migraine

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Introduction

Subjects suffering from migraine may experience static and dynamic balance impairment, as well as a reduction in the limits of stability, which leads to a reduction in anticipatory postural adjustments and an increased risk of falling [1–3]. The aims of this study were: (i) to assess the ability of 16 gait stability indexes to identify gait instability in subjects with episodic migraine without aura (swMO) regardless of age and gait speed and (ii) to investigate their correlations with clinical and kinematic variables.

Methods

A single lumbar-mounted inertial measurement unit was used to measure the gait of 31 swMO and 32 age, gender, and gait speed matched healthy subjects (HS). Based on trunk acceleration patterns in the anteroposterior (AP), medio-lateral (ML), and vertical (V) directions, the harmonic ratios, percent recurrence (RQArec), percent determinism (RQAdet), coefficient of variation (CV), normalized jerk scores, and maximal Lyapunov's exponents for short time series (LLE) were calculated. Independent sample t-tests, the area under the receiver operating characteristic curves, and cutoff analysis with post-test probabilities were computed. To assess the correlations between clinical scales and gait parameters, partial correlation coefficients were calculated while controlling for gait speed.

Results

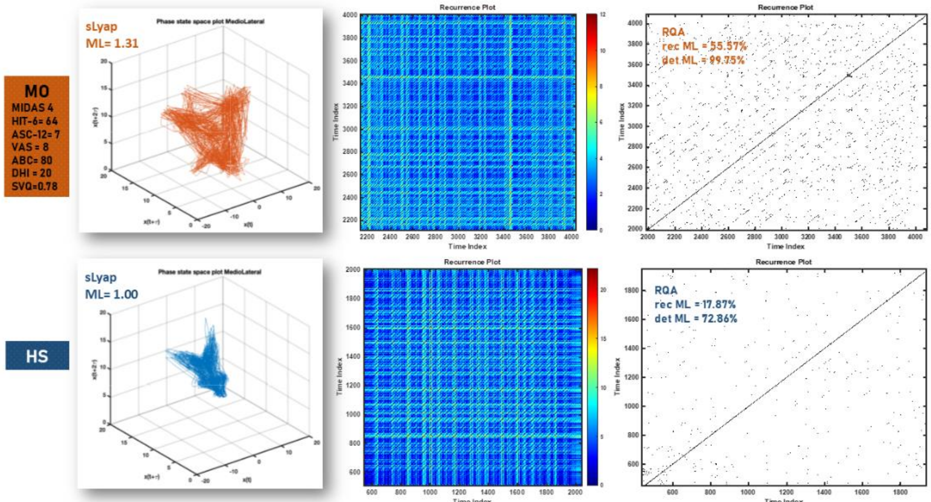

Fig. 1. LLE and RQA of a representative swMO and a HS.

CV values ≤ 20.78, RQArecAP ≥ 50,25, RQArecML≥ 48,46, RQArecV ≥ 37,47, RQAdetAP ≥ 96,44, RQAdetML ≥ 96,05, RQAdetV ≥ 97,72, LLEAP ≥ 1,10, LLEML ≥ 1,18, and LLEV ≥ 1,09 characterized the gait of swMO with 66% to 93% probabilities.

Regardless of gait speed, CV (r = -0.67, p <0.00), RQArecAP (r = 0.40, p = 0.02), RQArecML (r = 0.49, p = 0.00), RQArecV (r = 0.44, p = 0.01), RQAdetAP (r = 0.35, p = 0.04), LLEAP (r= 0.43, p = 0.01), and LLEV (r= 0.41, p = 0.02) values correlated with MIgraine Disability Assessment Score (MIDAS); RQArecML (r = 0.41, p = 0.02) and RQAdetV (r = 0.41, p = 0.02) correlated with the monthly number of symptomatic medications; pelvic tilt (r = -0.51, p = 0.00) and pelvic rotation (r = - 0.42, p = 0.02) correlated with pain intensity.

Discussion

CV, RQArec, RQAdet, and LLE can capture the subtle gait imbalance experienced by swM, reflecting a loss of local dynamic stability and a reduced ability to respond adequately to small perturbations during gait. As a result of their perceived imbalance, swMO reduced their gait variability and increase their gait regularity, as evidenced by lower CV and higher RQA when compared to HS.

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Longitudinal falls risk prediction in subjects with Parkinson's disease using trunk acceleration-derived gait indexes.

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Introduction

Recently, gait parameters derived from lumbar-mounted inertial measurement unit (IMU) showed to characterize the gait abnormalities of subjects with Parkinson's disease (swPD) [1]. Particularly, the harmonic ratio (HR) showed to characterize the gait of swPD [2], to correlate with the self-reported retrospective history of falls [2] and to be responsive to rehabilitation [3]. The aim of this study was to assess the ability of clinical and trunk acceleration-derived gait parameters to predict future falls in a cohort of swPD.

Methods

The gait of 39 swPD was recorded through a lumbar-mounted inertial measurement unit along a 30 meters pathway. Spatio-temporal gait parameters and pelvic kinematics, as well as harmonic ratios (HR) and percent determinism in recurrence quantification analysis were calculated. The falls rate during a period of 9.26 ± 5.26 months was recorded through monthly telephonic follow-up. Feature selection through independent sample t-test or Mann-Whitney test and correlation analysis, and data normalization was performed before implementing a stepwise logistic regression analysis using the occurrence of recurrent falls as dependent variable.

Results

After feature selection, the Activities Balance Confidence Scale, the score of the section II of the Unified Parkinson's Disease rating scale, gait speed, and the HR in the antero-posterior (AP) direction as covariates, and the Hoehn & Yahr disease rating scale as factor were input in the logistic regression model. The model composed by gait speed and HR_{AP} values at baseline predicted falls with 80% probability (Table 1).

Table 1. Logistic regression analysis results.

Model					
AIC	**BIC**	**ΔX²**	**p**	**Nagelkerke R²**	**Cox & Snell R²**
21.749	25.405	7.172	0.007	0.691	0.511

AUC	Sensitivity	Specificity	Precision	F-measure	LR+	LR-	PTP+	PTP-
0.940	0.800	0.867	0.800	0.800	6.015	0.230	80%	13%

Predictors	Standardized β	Odds Ratio	Wald Statistic	p	AUC	ocp	LR+	LR-	PTP+	PTP-
HRap	-2.346	0.113	4.364	0.037	0.79 (0.56-0.90)	≤ 1.61	3.00	0.42	66	21
Gait speed	-2406	0.120	4.367	0.037	0.80 (0.58-0.91)	≤ 0.78	5.25	0.47	78	24

Discussion

Falls risk of swPD can be predicted in ambulatory settings by assessing gait with a single lumbar-mounted IMU. Particularly, HR values ≤ 1.61 and gait speed ≤ 0.78 m/s predict the occurrence of recurrent falls with an 80% probability.

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Immediate effects of trunk rotator stretching exercise on gait parameters in subjects with Parkinson's disease: a randomized clinical trial

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Introduction

Reduced trunk rotation and pelvic mobility, which are associated with a higher risk of falling and one of the best predictors of gait improvement following rehabilitation [1], are characteristics of subjects with Parkinson's disease (swPD) [2]. The Progressive Modular Rebalancing System (PMR) proved to be an effective multimodal exercise therapy strategy with a trunk mobility focus that can enhance the effects of cognitive strategies in swPD gait training [3]. The purpose of this study was to compare the immediate effects of PMR trunk rotator stretching exercise to active upper trunk rotation exercise (Control) on gait parameters in swPD.

Methods

An expert neurologist screened 40 swPD for inclusion before randomly assigning them to the PMR or control exercise groups using sealed envelopes. Gait trials were collected using a magneto-inertial measurement unit placed at the lower back before (T0) and immediately after (T1) a single exercise session. Spatio-temporal parameters, pelvic kinematics, and harmonic ratios (HR) in three spatial directions were calculated. Four physical therapists who were not aware of the gait assessment carried out the PMR or control exercise. The entire procedure took between 10 and 15 minutes. To assess differences between groups, the independent sample t-test or Mann-Whitney test was used. Within-group differences were assessed using the paired sample t-test or the Wilcoxon test.

Results

At T1, there were significant differences in pelvic obliquity and HR in the antero-posterior (AP) direction between the PMR and control groups (Fig. 1). The PMR group improved in pelvic obliquity, pelvic rotation, HR in the AP and medio-lateral directions, gait speed and cadence, and double support time. Pelvic obliquity and cadence improved in the control group (Fig. 1).

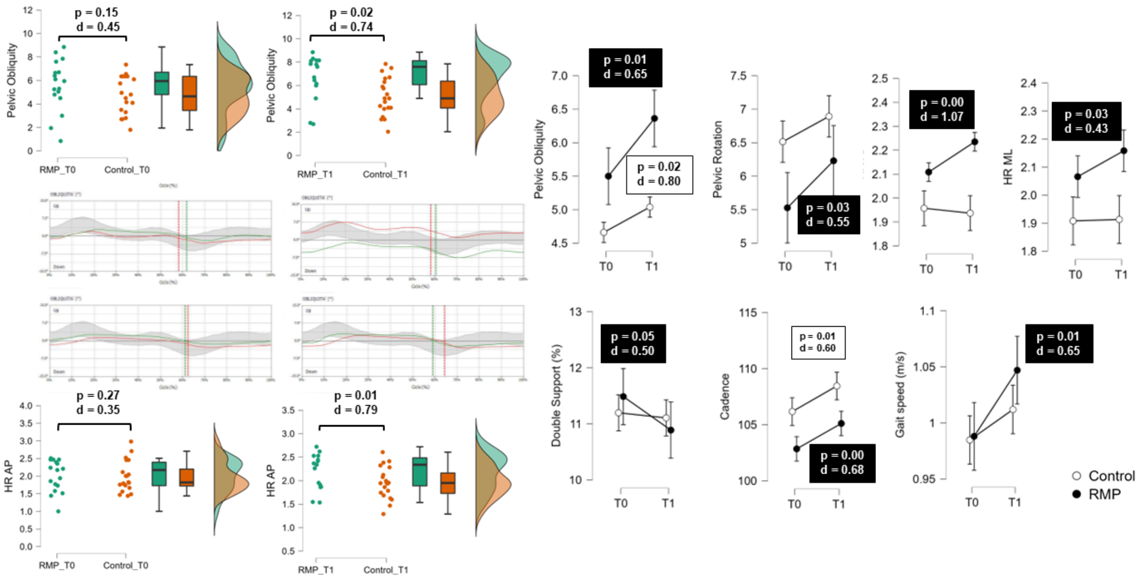

Figure 1. Between and within group comparisons at T0 and T1.

Discussion

PMR trunk rotation stretching was more effective than upper trunk rotation exercise in improving pelvic mobility and harmonic ratio during gait in swPD in a single exercise session. Implementing a PMR trunk rotation stretching exercise into a gait rehabilitation program may enhance the effects of gait training by improving pelvic mobility and trunk behavior during gait.

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Lower limb muscle co-activation during one (single) and two (team)-person liftings at different risk levels

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Introduction

Muscle co-activation is one of the strategies used by the central nervous system (CNS) to simplify the control of effector movements, coordinate the body, and stabilize joints [1]. It can, however, be counterproductive because it increases compression and shear forces on the joint, which can cause damage. Lifting activity, which is one of the leading causes of work-related musculoskeletal disorders, has been shown to increase the co-activation of the trunk muscles at the L5/S1 level, resulting in moments that do not contribute to the required net trunk moment as the risk level increases. While it is clear what happens at the trunk, lower limb muscle co-activation during lifting has received little attention. As a result, in the current study, we had the aim to investigate the simultaneous activation of different lower limb muscles during liftings at different risk levels and lifting types (performed by both one and two people, single vs. team lifting respectively) to better understand how the CNS controls the lower limb stiffness under the hypothesis that the risk level increases the co-activation and the lifting type reduces it.

Methods

Thirteen healthy volunteers (6 females and 7 males, mean age = 36.85±7.57 years, height = 1.67±0.07 m, weight = 62.88±10.08 kg, body mass index [BMI] = 22.47±2.17 kg/m2) executed single and team lifting tasks in the sagittal plane at progressively increasing risk levels designed using the revised NIOSH lifting equation, (Lifting Index, LI, from 1 to 3) [2]. The surface electromyography was recorded over the following right lower limb's muscles: gluteus medius, rectus femoris, vastus lateralis and medialis, tensor fascia latae, semitendinosus, biceps femoris, tibialis anterior, gastrocnemius medialis and lateralis, soleus, and peroneus longus. Then, after sEMG processing, we computed the global, flexor, extensor, and rostro-caudal lower limb muscle co-activation curves, using time-varing multi-muscle co-activation function (TMCfs), [3]. We calculated the area of each curve as synthetic parameter. The two-way repeated measures ANOVA was performed. A p value lower than 0.05 was considered statistically significant.

Results

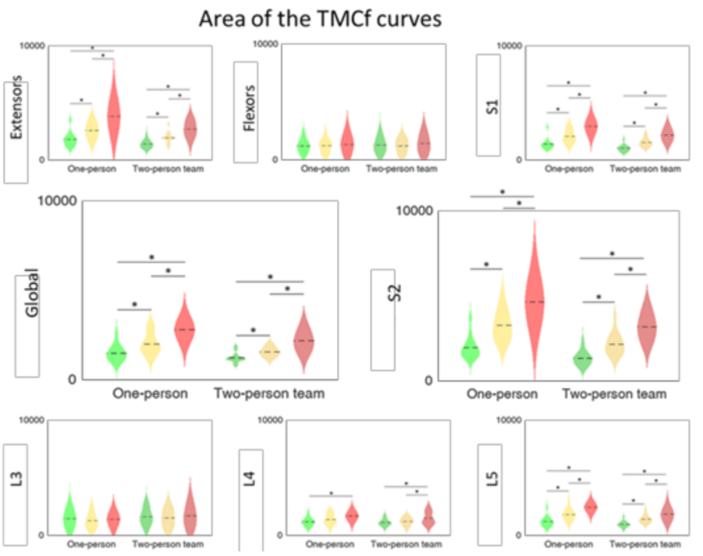

Fig. 1: *The area of the global, flexor, extensor and rostro-caudal lower limb muscle co-activation curves for each risk level and lifting type.*

The statistical analysis showed a significant main effect of the risk level and lifting type on the TMCf area in the global, extensor, and rostro-caudal (from L3 to S2) muscles co-activation, (Fig.1). The post hoc analysis revealed a significant increase in TMCf area with risk level and a decrease in team liftings when compared to single liftings. (Fig.1).

Discussion

In the present study we have shown how the lower limb muscle co-activation changes during liftings at different risk levels (low, LI=1, medium, LI=2, and high, LI=3) and types (single vs. team lifting), (Fig. 1), from global, flexor to extensor muscles and from rostral to caudal muscle recruitment. Overall, our findings suggest that CNS simplifies the motor control of lifting by increasing/decreasing the whole-limb stiffness within a clear global, extensor and rostro-caudal co-activation pattern, with the risk level/lifting type.

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Exploring Test-Retest Reliability of Spatio-Temporal Gait Metrics in Foot Drop Patients

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Introduction

Foot drop is a deficit that involves the muscles innervated by the peroneal nerve, which are generally responsible for controlling the dorsiflexion of the ankle and which, if damaged or paralyzed, do not allow the dorsiflexion movement of the ankle to be performed correctly, resulting in difficulty walking and risk of falling. The Codivilla spring is a thermoplastic ankle foot orthosis (AFO) designed to support foot dorsiflexion in patients with foot drop deficit. It is easily understandable that the study of gait in such patients is of great interest. The aim of this study is to explore the intra-session test-retest reliability of a gait analysis system based on three wearable inertial sensors, in calculating the main spatio-temporal gait parameters on a cohort of foot drop patients. The analysis can suggest the most reliable parameters which can be used in a clinical setting to identify and characterise the specific pathological scenario.

Methods

The acquisitions were conducted on 10 patients (8 males) with unilateral foot drop. Each patient repeated the test in two conditions, barefoot and wearing a passive AFO, repeating the trial three times for each walking condition under repeatability requirements. The experimental trial consisted of overground walking on a 7-meters path, turning around a pivot and walking back to the starting point. The system used in the experimental trials consists of the Mobility Lab software and three inertial sensors, two of which placed on the dorsal surface of the feet and one on the lower back (lumbar L5). The spatio-temporal parameters considered in this analysis are gait cycle time (GCT), stance phase (expressed as percentage of GCT) and foot clearance (FC). The Intraclass Correlation Coefficient (ICC) was used to assess the test-retest reliability, based on single measurement, absolute-agreement, 2-way mixed-effects model. Absolute reliability was obtained using the Minimum Detectable Change (MDC), i.e the smallest difference needed between separate measures on a subject to be considered a real change. It is calculated from the Standard Error of Measurement (SEM) and ICC as follow: $SEM = SD_{alltestingscores} \bullet \sqrt{1 - ICC}$ and $MDC = SEM \bullet 1.96 \bullet \sqrt{2}$. Statistical tests were performed on R v. 4.0.3.

Results

Table 1 shows the results of analysis. MDC values are expressed in the unit of the gait parameter and in percentage of the mean value to facilitate interpretation and comparisons (in parentheses).

Table 2. In the upper part ICC estimates and confidence intervals in parentheses. In the lower part MDC values also expressed in percentage of the mean value of the parameter in parentheses.

	ICC (95% CI)			
	Without AFO		With AFO	
	Affected foot	Contralateral foot	Affected foot	Contralateral foot
GCT	0.931 (0.803-0.981)	0.936 (0.821-0.982)	0.968 (0.911-0.991)	0.967 (0.909-0.991)
Stance	0.960 (0.891-0.989)	0.950 (0.865-0.986)	0.927 (0.805-0.979)	0.872 (0.681-0.963)
FC	0.984 (0.953-0.996)	0.839 (0.619-0.952)	0.991 (0.975-0.998)	0.967 (0.905-0.991)
	MDC (MDC%)			
GCT	0.161 (11.8)	0.156 (11.4)	0.0827 (6.26)	0.0847 (6.41)
Stance	1.38 (2.18)	1.84 (2.80)	1.80 (2.86)	2.61 (3.95)
FC	0.872 (31.9)	0.681 (38.7)	0.559 (20.0)	0.399 (23.5)

Discussion

Very high reliability was found for all the parameters in all the analysed conditions. The only ICC values lower than 0.9 were found in the measures of healthy foot clearance when not wearing the AFO and in stance phase when wearing the support. These results underlined that the gait measures of foot drop patients obtained with inertial sensors are very reliable. The MDC was also explored in this study. It can be interpreted as a sort of threshold to quantify the effects of rehabilitation or specific treatments. Changes in gait parameters lower than the MDC could be interpreted as measurement errors. The MDC was very low for stance phase, moderate for gait cycle time, while foot clearance MDC presented very high values. This suggests that stance phase (and consequently also swing phase) is a reliable parameter to assess the subject's pathological condition and to quantify the changes and improvements over time. Conversely, the interpretation of foot clearance parameter should consider the variability of the parameter measured by the system, to verify whether it can be considered a relevant improvement for the subject, or just an effect of its intrinsic variability.

Aknowledgment. *This research was partially funded by APTIS—Advanced Personalized Three-dimensional printed SensorIzed orthosiS project, financed by the Italian Ministry of Economic Development.*

Optimized EEG-based Action Observation Therapy for stroke rehabilitation.

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Introduction

Subjects with limited mobility can restore their motor functions through adaptive and dynamic responsesto external stimuli or environmental experiences. Action Observation Therapy (AOT) is a validated stroke rehabilitation treatment that stimulates and facilitates the reorganization of the neural network byactivating the Mirror Neuron System (MNS) [1] [2] [3]. However, the methods and video contents of theactions observed in the AOT protocols are still different and uneven.

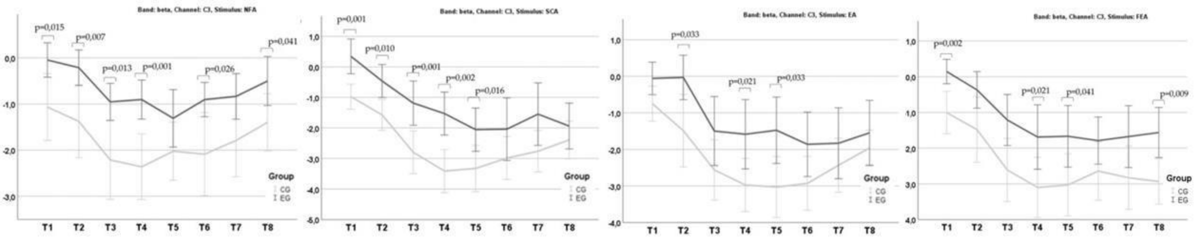
Methods

In this study, the analysis of electroencephalographic (EEG) signals was used to assess the categoriesof actions that elicit the most intense cortical activation in the observer's brain. During a synchronized EEG recording (Geodesic 400; 128-channels; 1000 Hz), 19 subjects with right hemiparesis observed videos of daily life activities of the following 5 categories: Feeding Actions (eating, FA), Self-Care Actions (taking care of oneself, SCA), External Actions (using objects external to the person, EA), Non-Finalized Actions (moving the upper limbs without a purpose, NFA) and Control Videos (landscapes, CV). EEG biomarkers of 15 right-handed healthy subjects and 15 chronic stroke patients (with right hemiparesis) were statistically analyzed and compared: the between-group Mann-Whitney Test (significance level set at $p<0.05$) was applied in order to compare the "Time Course" indexes calculatedfrom the ERSP for each subject, band, and region of interest.

Results

The dynamics of the cortical rhythms related to the viewing of videos of daily life actions or CV were studied as an index of the activation of the MNS, the FA and SCA video categories were more effectivein stimulating the neuronal recruitment. By qualitative analysis, all FA categories elicit a central visuomotor reactivity during AO with respect to non-finalized actions. The Mann-Whitney Test registered between-group differences in the β band, especially in the hemisphere opposite to the moving hand in videos, considering the frontal perspective with which they were shown: i.e. the left hemisphere (channel C3). Both FA and NFA elicit a β suppression in the left motor area in healthy andstroke participants. However, significantly weaker suppression was found throughout the whole video in stroke patients. Moreover, the lowest activation of motor area induced by NFA compared to FA for both the investigated groups and a common trend across all the categories of a visible rebound in the final part of the video in healthy subjects occur.

Figure 1. Pairwise comparison between healthy subjects and stroke patients of time-frequency 8 indices trends from C3 channel during AO of FEA, SCA, EA, and NFA categories in β band**.**



Discussion

Analyzing the cortical response opens a new possibility for an objective assessment of recovery in stroke patients. The results of this study pave the way to an EEG-based optimization and personalization of an AOT program that uses video stimuli to maximize the cortical responses and efficiently activate residual brain resources.

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Kinematics during the BBT: a pilot study on subjects with Parkinson's disease and post-stroke

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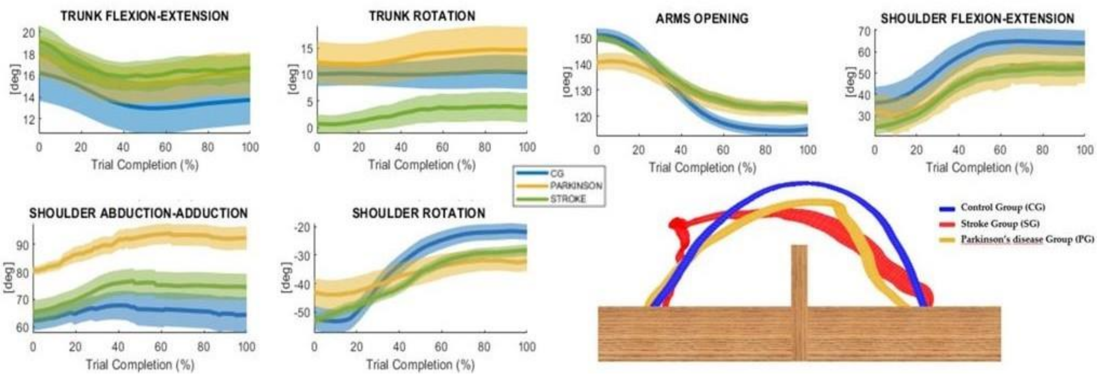
Introduction
The Box and Block Test (BBT) is one of the most commonly used tests to assess the manual dexterityability in neurological patients [1]. Kinematic analysis during the BBT using Inertial Measurement Units(IMUs) could provide an accurate and objective evaluation of upper limb and trunk movements, identifying potential compensation strategies [2,3]. This study aims to develop IMU-based kinematic analysis during BBT to characterize upper body strategies in Parkinson's disease and post-stroke subjects, comparing them with data obtained from able-bodied individuals.

Methods
This was an observational single-session-assessment pilot study assessing upper body kinematics during the execution of a BBT motor task, comparing 5 able-bodies person (Control Group - CG), 5 subjects with Parkinson's disease (Parkinson Group - PG) and 5 post-stroke subjects (Stroke Group - SG). Demographic and clinical data were recorded for each participant. Seven IMUs (MOVIT, Captiks srl, Italy) were positioned on the following anatomical points: front head; C5; T10; L5; mid arm; mid forearm; and hand (III° metacarpus). Data were collected at a rate of 60 Hz. Each participant performedtwo tests with both upper limbs: standard BBT and targeted BBT. An in-house software (developed in MATLAB R2020a) analyzed the main joint angles**.** The 3D hand trajectory was estimated by using calibrated quaternions and anthropometric data. The Kruskal-Wallis test was applied between the PG and the CG, and between the SG and the CG with a significance level set to $p < 0.05$.

Results
The SG and PG were assessed with the Fugl-Meyer Upper Limb (mean±SD=49.0±12.02) and UPDRS (mean±SD=46.0±25.1). The clinical BBT test registered the following numbers of cubes: CG=63.7±4.3 (dominant), 65.2±6.3 (non-dominant); SG=31.5±24.3 (affected), 57.3±17.3 (unaffected); PD=51.4±20.8 (affected), 53 ± 20.5 (unaffected). Figure 1 depicts the joint angles which were significantly different, and the average hand trajectories (mean trajectory with the associated standard error) for each group of patients.

Figure 1. Preliminary results referred to joint angles and hand trajectory.



Discussion
The current study found significant differences between the CG and the SG and between the CG and the PG, showing compensatory strategies in neurological subjects. The proposed BBT protocol allows the assessment of manual dexterity tasks and could be used in the future to evaluate the efficacy of rehabilitation treatments with a muscle activity analysis by surface electromyography (sEMG). By achieving these goals, IMU-based BBT could serve as a potential system for standardized upper extremity assessment.

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Inter-limb muscle synergy similarity as marker of post-stroke impairment in Box & Block Test

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Introduction

Muscle synergy approach has been validated as powerful tool to provide insights into the impaired upper limb movement of stroke survivors [1],[2]. To date, no study has explored muscle synergies and their features in one of the most used clinical tests to assess motor function performance, such as the Box and Block Test (BBT). This study aims at exploring the relation between the BBT clinical outcome and an index of inter-limb muscle synergy similarity in a sample of stroke survivors.

Methods

Ten stroke participants (5 females, age 50.0 ± 18.7 years, 5 right-sided lesion hemisphere, 5.9 ± 3.8 months from the stroke event) were instructed to perform the BBT adapted to an experimental setting (repeatable trials separated by reaching and return phases), 20 times at self-paced velocity with both upper limbs (CE PROG.752/2019). Electromyographic (EMG) signals and kinematic data were simultaneously collected. EMG data were recorded (2000 Hz sampled) from the extensor digitorum, flexor digitorum superficialis, lateral head of the triceps, long head of the biceps brachii, anterior deltoid, lateral deltoid, pectoralis major and upper trapezius muscles. Kinematic data were recorded (100 Hz sampled) by means of inertial measurement units positioned over hand, forearm and arm of both upper limbs, trunk, and pelvis. For each participant and limb, the BBT outcome measure as clinical test, i.e., number of blocks transferred from one compartment to the other in 60s, was also collected. EMG data were band-pass filtered (50-500 Hz), rectified and low-pass filtered (10 Hz) to extract envelope. The EMG envelopes were segmented in repetitions of the task (trials) by means of single-subject biomechanical model results, resampled (100 points per trial) to have the same temporal duration and averaged across trials. The non-negative matrix factorization was applied to extract muscle synergies for each participant and side. Parameters and criteria for the computation of the optimal number of synergies were set as in [1],[2]. For each participant the index of similarity across muscle synergy's weights between affected and unaffected sides (inter-limb) was computed by means of the cosine similarity. The relation between the muscle synergy similarity, the BBT clinical outcome and the duration of the executed task was investigated by means of the Spearman's rank-order correlation.

Results

Figure 1 shows the relation between the inter-limb muscle synergy similarity (independent variable) and the duration of the task performed by the affected limb (weak correlation $\rho=-0.33$ p-value=0.35) and the inter-limb BBT clinical score difference (moderate correlation $\rho=-0.51$, p-value=0.13).

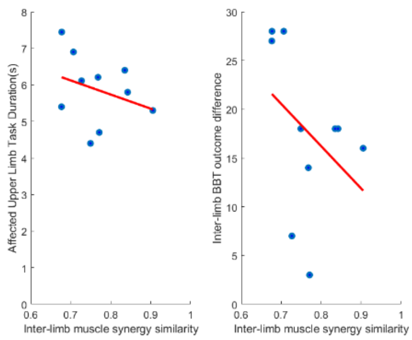

Figure 1 – Duration of the BBT task performed by the affected upper limb (*left panel)* and difference between limbs of the BBT clinical outcome, i.e., number of blocks moved in 60s (*right panel)*, both expressed as function of the muscle synergy similarity between upper limbs.

Discussion

Results revealed that the more severe the stroke patients are, i.e., significant differences between the number of blocks moved by the unaffected and affected upper limb and more time-consuming task execution, the lower the muscle synergy similarity index is, meaning that synergy pattern differs in stroke survivors between affected and unaffected limbs.

Acknowledgements

Research partially supported by the Italian Ministry of Health (GR-2018-12365874, RF-2018-12365210, RF-2019-12369396) and by Sapienza University of Rome (RM120172B8899B8C).

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Proposal of a tool to assess human gait coordination using parallel - coordinates plot

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Introduction

Several methods have been proposed for assessing intersegmental coordination during gait. To date, however, only up to three segments have been considered for coordination [1, 2]. In this study, we proposed a parallel-coordinates plot (PCP), a multivariate data analysis tool, to assess coordination between five body segments.

Methods

A stereophotogrammetric motion analysis system was used to record the motion of 19 healthy volunteers' trunk, pelvis, thigh, shank, and foot. The parallel coordinates domain was then created by aligning axes parallel to the embedded 2D Cartesian coordinate system in the plane. The domain of parallel coordinates was represented by the x y-plane in $\mathbb{R}^2$. Points in the plane were represented by lines connecting the corresponding coordinates at the respective axes. Kendall's tau correlation coefficients (Inselberg 1985) were calculated to represent the correlation between each pair of body segments (Fig. 1c). The tool was also tested on a subject with gait impairment as a proof of concept to assess its ability to capture differences in gait coordination between HS and subjects with gait impairment.

Results

The correlations between each pair of body segments have been represented for each subphase of a gait cycle. (Fig. 1 a, c). Diagonal connecting lines represent out-of-phase coordination, horizontal lines represent in-phase coordination. Body segments can be moved along the coordination graph to dynamically assess coordination between preferred body segments. The PCP-based coordination tool also showed to capture differences in intersegmental coordination between HS and subjects with cerebellar ataxia and Parkinson's disease (Fig. 1 b).

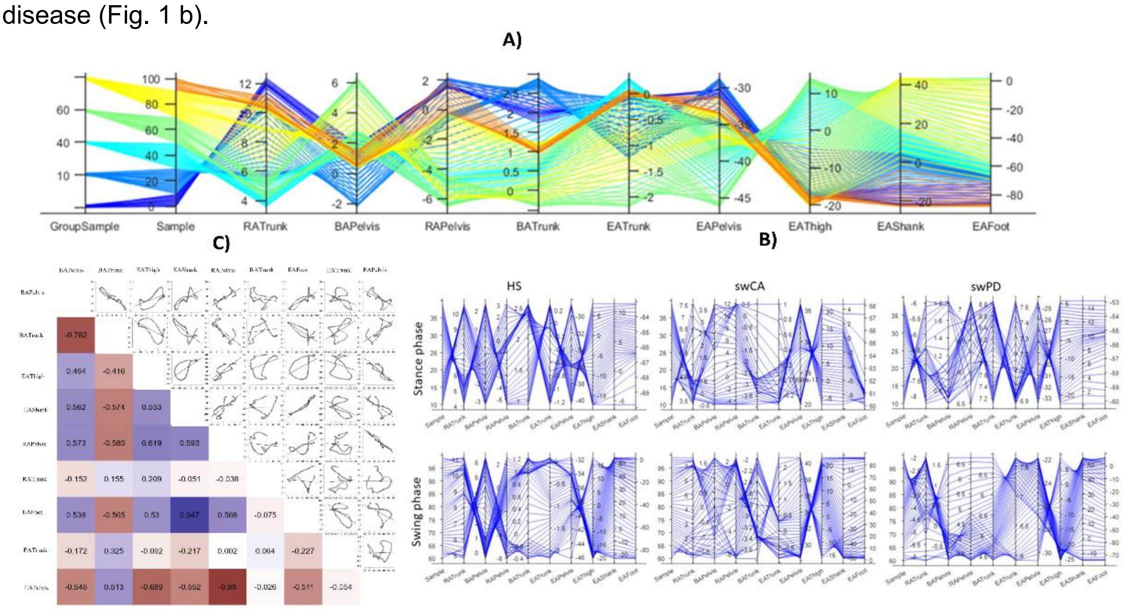

Figure1. A) PCP of five segments during entire gait cycle, B) PCP of five segments during gait sub-phases in HS, swCA, and swPD, C) Kendall's tau correlation plot and results.

Discussion

By assessing coordination through PCP, we provided an effective tool to assess multi-segmental coordination that could be implemented into gait analysis software to speed up and optimize the effectiveness of gait reports interpretation.

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Abnormalities of trunk acceleration-derived gait indexes in subjects with GLUT-1 deficiency.

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Introduction

Gait disturbances and movement disorders are frequent in patients with GLUT-1 deficiency, mostly represented by pyramidal, cerebellar, and extrapyramidal dysfunction. This study aimed to assess the ability of a set of trunk acceleration-derived gait indexes to identify gait unbalance in subjects with GLUT-1 deficiency, and to detect potential correlations with clinical and biochemical parameters.

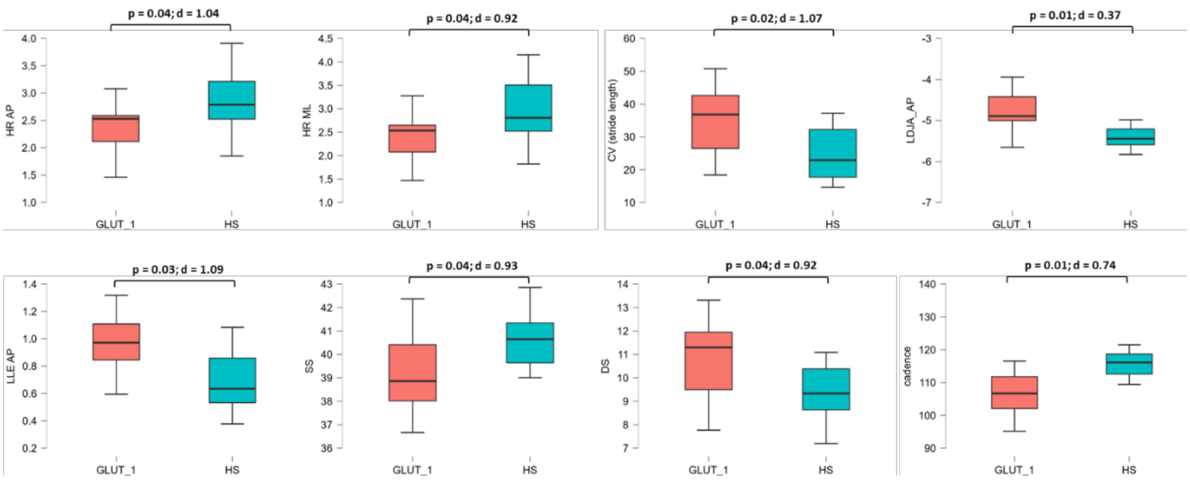
Methods

We recorded a 30 meters gait of 10 subjects with GLUT-1 deficiency and of 10 age-, sex- and gait speed-matched healthy subjects (HS). Gait analysis was performed via an inertial measurement unit (IMU) placed at the lower back. Based on trunk acceleration patterns in the antero-posterior (AP), medio-lateral (ML), and vertical (V) directions, we calculated: spatio-temporal gait parameters, pelvic kinematics, harmonic ratios (HR), recurrence quantification analysis (RQA), stride length coefficient ofvariation (CV), the longest short term Lyapunov's exponent (sLLE), and the log dimensionless jerk score (LDLJ).

Results

When compared to the HS group, the GLUT-1 subjects showed lower values of HR AP, HR ML, singlesupport (SS) phase, and cadence. Moreover, they showed higher values of CV, LDLJ AP, LLE AP, anddouble support (DS) phase duration (Figure 1). In the GLUT-1 group, HR AP negatively correlated witha positive history of recurrent falls (r = -0.88, p = 0.03), while CV negatively correlated with ketonemia (r = -0.64, p = 0.04).

Figure 1. Differences between subjects with GLUT-1 deficiency and HS in the different trunk acceleration-derived gait indexes.



Discussion

Subjects with GLUT-1 deficiency exhibited multiple alterations in the trunk acceleration-derived gait indexes. Interestingly some of these alterations correlated with clinical/biochemical features, such as history of falls and ketonemia.

Assessing biomechanical risks in human-robot collaboration: analysis of muscle activity with different intervention conditions

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Introduction

The introduction of collaborative robots (cobots) in workplaces led to a revision of traditional methods to assess biomechanical risks in working activities. In light of this, quantitative indexes relying on kinetics, kinematics and electromyography (EMG) were proposed to focus on the task and operator's characteristics [1] also during Human-Robot Collaboration (HRC), where wearable sensors were shown to yield significant benefits [2]. When multiple sensors are placed on different muscle groups, surface EMG can be used to study workers' motor activities by means of the Coactivation Index (CI), able to monitor the amount of muscular simultaneous activity across different muscle groups. This index was proven to reliably reflect biomechanical risk [3], and in this study, it was used to identify how different HRC conditions modify the muscle involvement of the human operator during object manipulation tasks.

Methods

Twelve subjects were requested to simulate the assembly of a physical panel (Figure 1, left), by performing sequentially the following operations: grab the panel, open a lever, unscrew a knob twice, turn a button, close the lever and then put the panel back. The task was performed 5 times for each of the following three randomized intervention conditions: in the *Free* condition, the operator works without cobot assistance; in the *Robot Free* condition the cobot sustains the panel, while the human operator can move it freely in the 3-D space; in the *Robot Plane* one, the panel is again sustained by the cobot, but it can be moved only on a horizontal plane in front of the operator. EMG activity was recorded by using bipolar electrodes (BTS Bioengineering) on the following muscles (left and right sides) not directly involved in the manipulation: Trapezius, Erector Spinae, Gluteus, Biceps Femoris and Gastrocnemius. The CI, extracted from the envelopes, was averaged across the five repetitions first and then averaged across subjects. ANOVA test was performed on the Coefficient of Variation (CoV) of the CI extracted from each individual during the manipulation phase (between 25% and 75% of the activity duration).

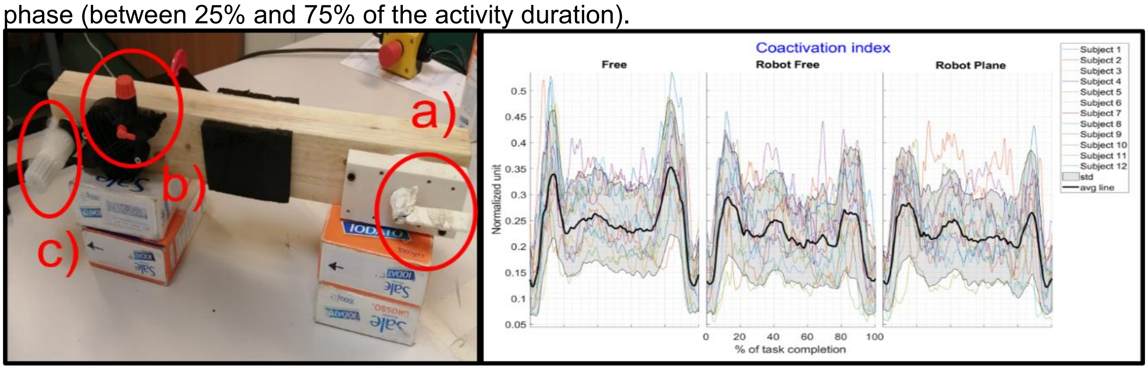

Figure 6 On the left, object to be manipulated: a) lever, b) knob), c) button. On the right, Coactivation index in the three intervention conditions.

Results

CI showed a similar temporal trend across the three intervention conditions, as illustrated in Figure 1 (right). Higher CI resulted in the *Free* condition during the initial and final phases of the activity. CI Coefficient of Variation during the manipulation phase was significantly higher ($p<0.05$) in both collaborative intervention conditions compared to the *Free* one.

Discussion

Higher CI values during panel loading/unloading phases in the *Free* condition outline that cobot assistance may help reduce coactivation. During manipulation, increased CI variability in the collaborative interventions might indicate a more effective muscle involvement reducing continuous muscle coactivation. In conclusion, HRC during working activities can help reduce operator muscular activity, both by sustaining the weight of the objects to be manipulated, and by offering compliant modalities of HRC; the latter ones were shown to assist in optimizing muscle control strategy, reducing unneeded coactivation, and possibly decreasing biomechanical risk.

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New kinematic parameters for sagittal plane analysis of the spine and whole-body during walking by 3D-Stereophotogrammetry using DB-Total protocol

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Introduction

3D motion analysis is the gold standard method for the quantitative assessment of the walking [1]. Previous stereophotogrammetric protocols have been used to assess the kinematics of pelvis, hip, knee, ankle, trunk (considered as a single segment) and rarely head and upper limbs during walking. Recent studies [2,3] have also analyzed the multi-segmental trunk and whole-body kinematics. Our study aimed to evaluate the sagittal spine and the whole-body during walking in healthy subjects by 3D motion analysis using a specific marker set.

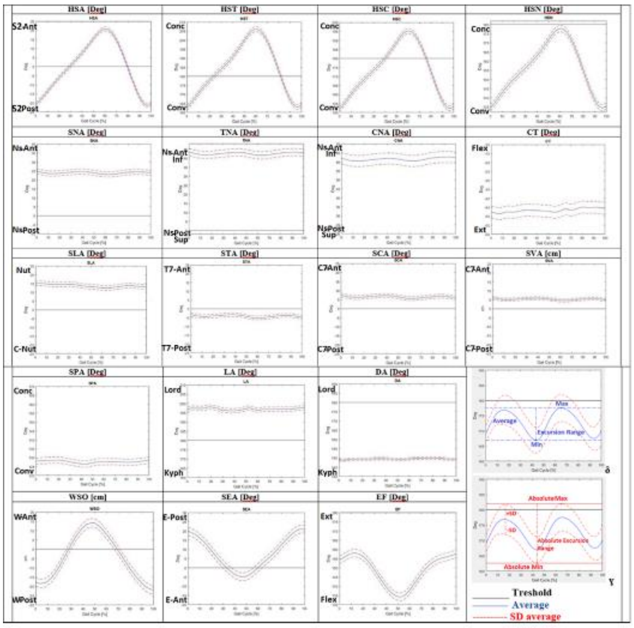

Figure 1. Average of kinematic curves during gait cycle for new eighteen sagittal DB-Total parameters.

Methods

Fourteen healthy subjects were assessed by 3D-Stereophotogrammetry using the DB-Total protocol [2]. Excursion Range, Absolute Excursion Range, Average, intra-subject Coefficient of Variation (CV) and inter-subject Standard Deviation Average (SD Average) of new kinematic parameters related to sagittal spine and whole-body posture were calculated.

Results

The analysis of the DB-Total parameters showed a high intra-subject (CV < 50%) and a high inter-subject (SD Average < 1) repeatability for the most of them. Kinematic curves and new additional values for all 18 DB-Total parameters [C7–Nasion Angle (CNA), T7–Nasion Angle (TNA), S2–Nasion Angle (SNA), Heel–S2 Angle (HSA), S2–C7 Angle (SCA), S2–T7 Angle (STA), S2–L5 Angle (SLA), Spinal–Pelvic Angle (SPA), Cervical Tilt (CT), Dorsal Angle (DA), Lumbar Angle (LA), Sagittal Vertical Axis (SVA), Heel–S2–Nasion (HSN), Heel–S2–C7 (HSC), Heel–S2–T7 (HST), Shoulder–Elbow Angle (SEA), Elbow Flexion (EF) and Wrist–SIAS Offset (WSO)] were represented in Figure 1 and 2.

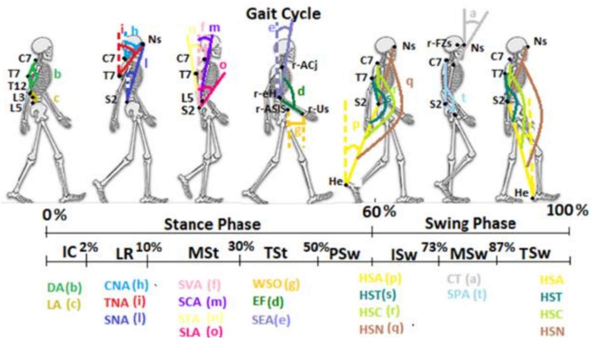

Figure 2. Graphic representation of new sagittal DB-Total parameters during different phases of gait cycle.

Discussion

Our results revealed typical spinal and whole-body kinematic patterns in healthy population that may explain the biomechanical whole-body strategies for maintaining balance during walking. The use of DB-Total parameters and the normal dataset might help to understand and diagnose whole-body kinematic deviations in an adult pathological population.

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Single leg drop jump landing test classifier in young male team sport athletes: a preliminary study of a low-cost screening tool solution

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Introduction

The risk of occurring in an injury is a critical aspect intrinsic to most sports [1]. Most injuries are related to lower limbs, limiting the performance capacity as well as other life-related and competitive aspects. Tools able to assess the risk of injury and programs to limit it are an essential aid to players. Specific to ankle sprains, the single leg drop jump landing (SLDJ) test implementing force plates has been used to assess their risk [1,2]. However, this test needs access to that instrumentation. To reduce the entailed costs and export this test in-field, a proof-of-concept protocol was developed, based on smartphones and a machine learning classifier, to perform an out-of-lab binary screening for the risk of ankle sprains.

Methods

A group of male soccer and basketball players (31M; mean±standard deviation: age: 17±2 y; mass: 70±11 kg; height: 180±8 cm) was tested considering the standard SLDJ procedure proposed by Fransz [2]. Participants were asked to perform two SLDJs, one for leg: the participant stands on a 20-cm-high box, placed 5 cm behind a force plate (FP) (Bertec, Columbus, Ohio, USA; fs = 1,000 samples/s; size=40×40 cm) maintaining the left hand on the hip and holding with the right hand a smartphone (SP) near to the hip (Samsung Galaxy S9+, Samsung Group, Seoul, South Korea; fs = 500 samples/s; full scale range: accelerometer = ± 8g; gyroscope = ± 500 deg/s). After 3s of static phase, they jump down and forward so that both limbs leave the box simultaneously and land on the FP with one leg, trying to maintain the equilibrium for 15s. The test is acquired using both FP and SP. To have a correct execution, the participant has to maintain the equilibrium for all the task duration, without moving the SP in the hand. SP sensors data are extracted using the Phyphox app [3]. After data acquisition, two selected indices (RMS ML, HOR GRF late) are calculated from both FP and SP signals (MATLAB v.R2022a, The MathWorks Inc., Natick, Massachusetts), Fig. 1a. The FP indices are used to assess the injury risk giving a score of 0 (not risky) or 1 (risky) following Fransz. The SP indices are used as input variables to implement a binary KNN classifier optimized through resubstitution validation scheme having the assessed scores as output variable. The classifier is implemented through the Classification Learner app. The optimized KNN classifier is trained using 50 trials and tested with the remaining 12.

Results

All the 62 tests acquired were considered valid, giving 62 FP signals and 62 SP signals. The classifier showed an accuracy of 100% in training, and of 83.3% in the test phase (Fig. 1b).

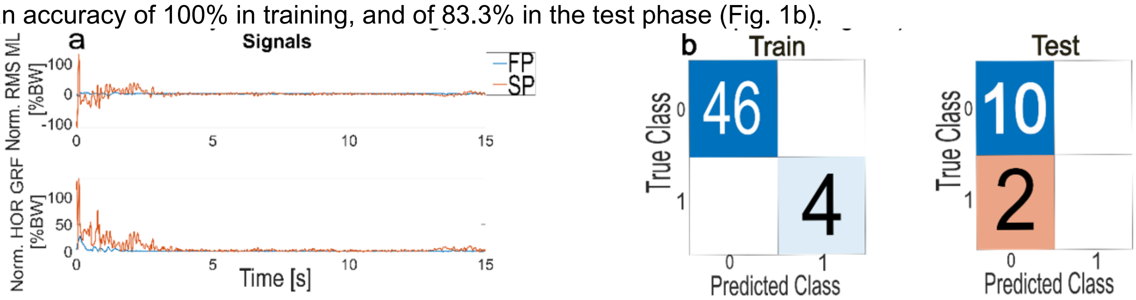

Figure 1. a. Signals used for indices elaboration normalized with respect to body weight (BW). b. confusion matrix of training and test of the KNN model.

Discussion

Despite the limited number of trials, this result invites us to further explore this smartphone-based approach by increasing the dataset, to have a more balanced dataset in which the number of participants at risk or not is almost the same, allowing a finer classification. Thus reinforced, this tool could become a solution to screen for ankle sprain risk avoiding the use of expensive instrumentation.

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Anticipatory responses characterize the Alzheimer's Disease continuum in a reaching task

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Introduction

Difficulties with motor skills can have a considerable impact on the ability to perform activities of daily life and consequently can worsen quality of life. Individuals affected by Alzheimer Disease (AD) could have impairments in motion prediction and in the smooth execution of sensorimotor tasks, even at an early stage. However, sensorimotor impairments in AD have not been investigated and their correlation with cognitive deficits is still unknown. We hypothesized that sensorimotor impairments caused by Alzheimer's Disease continuum could represent an early and sensitive indicator of the disease.

Methods

20 AD, 20 Mild Cognitive Impaired (MCI), and 20 age-matched healthy control (HC) individuals performed reaching tasks in virtual reality (VR). All participants were recruited after they performed cognitive tests (Mini Mental State Examination – MMSE) and gave written consent. Kinematic data were recorded with the 3 HTC Vive embedded tracking system sensors used in the VR scenario, located in headset, tracker and controller.

Participants performed a reaching task towards 8 targets in the frontal plane. They had to wait for the go signal (i.e. appearance of the target) to start their movement. Several kinematic features have been examined, such as success rate, reaction time, peak speed, and anticipatory response. Anticipatory responses have been identified as the occurrence of the speed profiles getting at 20% of its maximum before the go signal. Anticipatory responses have also been correlated with the other kinematic features and the cognitive evaluation (MMSE).

Results

HC participants achieved a higher success rate than AD and MCI. In addition, AD participants showed slower movements and significantly longer reaction times. Both MCI and AD participants (especially AD) displayed a higher rate of anticipatory responses than their age-matched controls. Moreover, anticipatory responses affected the kinematic variables examined: anticipatory responses rates correlated with lower success rates, longer reaction times and lower peak speeds. In addition, a lower MMSE value significantly correlated with the anticipatory behavior.

Discussion

The presence of anticipatory responses could represent a sensitive indicator of the Alzheimer's Disease, since it is able to differentiate among the 3 tested groups. Further analyses are needed to evaluate the direction of such anticipatory responses to better understand this behavior, which in turn could correlate with other traits of AD.

In general, these findings suggest that a more comprehensive characterization of Alzheimer's Disease continuum, which includes both cognitive and sensorimotor features, might improve our understanding of the disease.

A novel upper limb rehabilitation protocol for chronic post-stroke bimanual reaching tasks based on virtual reality and myoelectric control

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Introduction

Upper limb hemiparesis is one of the main disabilities caused by cerebral stroke. Recent technological advancements may help improving motor recovery by increasing exercise dose and intensity. Rehabilitation systems integrated in virtual reality (VR) platforms provide complex and engaging training scenarios, simulating daily life activities in controlled environments and allowing for quantitative motor recovery assessment through integrated motion capture sensors. Moreover, myoelectric interfaces allow to decode patients' intention through paretic limb residual myoelectric activity and to promote voluntary movements. The aim of this study was to evaluate the effectiveness of a novel post-stroke upper limb neuromotor rehabilitation protocol based on VR and myoelectric control.

Methods

Twenty chronic post-stroke patients (8 females), aged from 27 to 72 years (55 ± 15, mean ± sd) were enrolled and randomized into an experimental and an age-matched control group performing conventional motor upper limb rehabilitation. Recovery of motor functions were assessed through clinical and instrumental indicators evaluated at the baseline (T0), after a one month (T1), and after a two-months treatment (T2). The physical treatment was composed of 3 sessions per week, half-hour per session. Usability and acceptability data were collected through questionnaires.

The intervention is based on the application of a commercial VR system (HTC Vive), including two motion capture sensors (HTC Vive Tracker) and two 8-channels myoelectric sensors (Myo Armband) for recording respectively upper limb movements and forearms muscles electromyographic activity. The system enables bimanual reaching exercises in a VR environment, providing visual feedback on the movement of a virtual limb that reproduces and improves the movement of the paretic limb, according to assistance parameters controlled by the therapist expert in neurorehabilitation. Assistance to the motion of the virtual paretic limb is provided by a weighted combination of the paretic and non-paretic limb pose and gesture, extending conventional mirror therapy.

Results

A linear mixed model analysis shown a significant increment of the Fugl-Meyer Upper Extremities Assessment score for both groups along sessions ($p < 10^{-10}$) in the within-subject analysis and a higher improvement for the experimental group ($p = 0.005$) in the between-subjects comparison. The system received overall good usability and acceptability ratings according to the specific questionnaires.

Discussion

A virtual reality-based self-assisted approach could be an effective complementary rehabilitation strategy for the recovery of the upper limb motor functions in chronic post-stroke survivors in both clinical and home-based telemedicine scenarios.

Risk of injury and kinematic assessment of the shoulder biomechanics during strokes in padel players: a cross-sectional study

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Introduction

Padel players commonly suffer from shoulder pain and the particularly high incidence is probably linked with the small court and surrounding walls, which increase the frequency of strokes. In addition, due to the repetitive technical gesture to which the joint is subjected, an adequate technique is essential in terms of performance and injury risk prevention. [1] The aim of this study was to evaluate shoulder kinematic during the athletic gesture to analyze the risk factors linked to padel strokes.

Methods

In this cross-sectional study professional and amateur padel players were involved. Participants underwent a shoulder analysis during padel strokes utilizing a surface electromyography system (sEMG) (BTS bioengineering– Italy) on pectoralis major, deltoid, trapezius, latissimus dorsi, following SENIAM guidelines.

Results

We included 20 padel players:10 professional players (Group A) and 10 amateurs (Group B). No significant differences in VAS score at rest between Group A (0.85 ± 0.89) and B (0.51 ± 0.97). Percentage of shoulder stabilizer muscle activation is shown in Table 1.

Table 1. Muscle activation ratio of the shoulder stabilizer during padel strokes

Male players	*Bandeja*	*Forehand*	*Backhand*	*Smash*	*Vibora*	*Volley*	*Backhand volley*
Trapezius	11% ± 3%	13% ± 6%	20% ± 12%	15% ± 5%	15% ± 4%	12% ± 6%	16% ± 12%
Deltoid	23% ± 11%	19% ± 13%	32% ± 12%	23% ± 14%	25% ± 11%	23% ± 10%	29% ± 9%
Latissimus dorsi	29% ± 16%	22% ± 10%	19% ± 8%	24% ± 12	31% ± 18%	24% ± 7%	21% ± 9%
Pectoralis maior	36% ± 11%	46% ± 16%	29% ± 17%	38% ± 12%	37% ± 8%	41% ± 11%	34% ± 12%
Female players	*Bandeja*	*Forehand*	*Backhand*	*Smash*	*Vibora*	*Volley*	*Backhand volley*
Trapezius	21% ± 9%	12% ± 7%	18% ± 11%	23% ± 10%	19% ± 9%	18% ± 10%	16% ± 8%
Deltoid	38% ± 13%	22% ± 13%	36% ± 16%	32% ± 9%	33% ± 10%	29% ± 18%	26% ± 6%
Latissimus dorsi	14% ± 8%	27% ± 23%	23% ± 22%	20% ± 6%	19% ± 9%	23% ± 13%	18% ± 11%
Pectoralis maior	27% ± 14%	39% ± 20%	23% ± 8%	25% ± 14%	30% ± 19%	36% ± 19%	40% ± 8%

Discussion

Analyzing the muscle activation ratio during the padel stroke, data revealed that during backhand there is an unbalanced muscle activation in favor of the deltoid, not counteracted by latissimus dorsi and pectoralis major. This could potentially result in a suboptimal centering the head of the humerus inside the glenoid, representing a risk factor for shoulder pain and subacromial impingement, especially when the players force the stroke to recover a difficult ball. Moreover, during backhand volley the elevator/depressor ratio of the humerus in men predispose to a greater risk of impingement. On the contrary, in women, the greatest risk occurs in the forehand volley. Finally, during smash, that is considered as one of the strokes most at risk, a correct execution of the athletic gesture can lower the risk of impingement. In conclusion, overhead strokes might represent an important risk factor for shoulder injuries in padel players. More in detail, the smash and the vibora are considered the stroke requiring most attention and high technical skills to avoid the risk of impingement. In this context, the sEMG assessment of shoulder movements might play a role in the prevention of musculoskeletal injuries in these subjects. Especially for players with a low experience, it is mandatory to avoid overscheduling and to perform an adequate athletic training to practice the strokes starting from the knowledge of the main principles of padel and shoulder biomechanics.

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Neural networks and surface EMG to identify the transitions between the four main gait phases

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Introduction

The assessment of gait phases is required to identify the timing of muscle activity during human walking. Encumbrance and time-consuming experimental set-up are often associated to these measurements [1]. The present study is designed to propose a specific approach based on machine learning to identifythe timing of the transition events between the four main gait phases, i.e., Heel Strike (HS), Contralateral Toe Off (CTO), Heel Rise (HR), and Toe Off (TO), using essentially surface electromyographic (sEMG)signals acquired during ground walking.

Methods

Basographic signal is collected by three footswitches and processed to identify the four main gait phases, Initial Stance, Mid Stance, Terminal Stance, and Swing, used as ground truth for the neural network. sEMG signals collected bilaterally during walking of 31 healthy subjects from Tibialis Anterior, Gastrocnemius Lateralis, Rectus Femoris, Vastus Lateralis, and Hamstring muscles (sampling frequency = 2 kHz) are processed and organized to feed a neural network (Multilayer Perceptron, MLP). After filtering (band-pass 20-450 Hz), the root mean square signal (RMSS) of the sEMG signal is extracted. Then, the RMSS is further processed to compute the Weighted Signal Difference (WSD), asthe point-by-point difference between the RMSS of sEMG of a muscle and the RMSS of sEMG of the same muscle of the contralateral leg [2]. The neural network is trained with WSD separately for each subject on 80% of subject's strides. Then, identification of gait-phase transition is attempted in the remaining unlearned 20% of subject's strides. The procedure is then repeated five times, each time changing the testing set to cover the entire dataset, following the 5-fold cross validation strategy. Modelperformances are evaluated by standard metrics as F1-score and mean absolute error (MAE).

Results

Figure 1 depicts an example in a representative subject of the predictions of the 4-phase foot-floor contact signal achieved by proposed architecture compared with the ground truth provided by the footswitches. Average (± standard deviation, SD) F1-score values of event prediction are: 88.3±11.2%for HS, 79.3±10.6% for CTO, 86.6±9.2% for HR, and 82.2±11.5% for TO. Corresponding mean MAE values are: 17.2±11.3 ms for HS, 38.2±14.6 for CTO, 27.0±14.7 for HR, and 26.0±17.8 for TO.

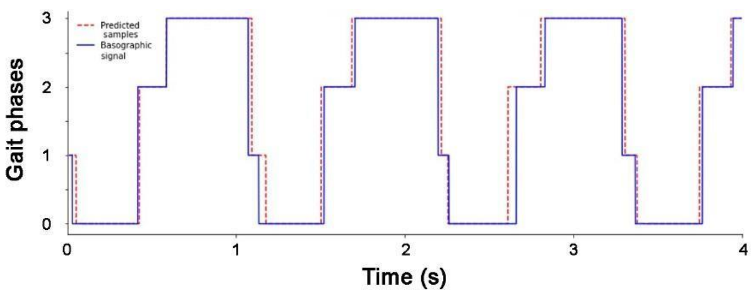

Figure 1. Predicted foot-floor contact samples (red dashed line) vs. basographicsignal adopted as ground truth (blue line) in four seconds of the signal.

Discussion

This study presented an attempt to identify the timing of the transition events between the main four gait phases, based on the implementation of MLP model to interpret only sEMG data. Despite some issues related to the identification of CTO, the proposed approach was able to provide encouraging performances in prediction of HS, HR and TO (F1-score > 82% and MAE < 30 ms). In particular, the predictions of HS and TO events were comparable with those achieved by similar architecture in the simpler task of binary classification [3].

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Prospective observational study on movement disorders and muscle changes in the patientwith liver cirrhosis: analysis of electroneurographic data in a subgroup of patients, with andwithout cognitive impairment

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Introduction

Liver cirrhosis and its complications have a significant impact on the patient's quality of life. The aim of this prospective observational study was to assess the presence of muscle changes and movement disorders, focusing on the correlations between clinical parameters, and the data receivedfrom the electroneurographic examination, to which a subset of patients underwent.

Methods

The study has involved 26 patients with liver cirrhosis, respecting accurate exclusion criteria. Patientswere investigated for the detection of minimal hepatic encephalopathy, and underwent an instrumental evaluation, including analysis of parameters detected at the Six Minutes Walking Test and muscle changes (sarcopenia and/or myosteatosis) detected on radiological imaging, and the presence of sensory and/or motor neuropathy, detected by electroneurography, carried out on ten of the twenty-six patients involved in the study. The patients were also contacted for follow-up at three and six months.

Results

The data analysis considered age, sex, etiology of cirrhosis, severity of hepatopathy (Child-Pugh Score and MELD Score), previous hepatic encephalopathy, falls. Gait analysis focused on trunk accelerations (Harmonic Ratio indices, and temporal recurrence and determinism of RecurrenceQuantification Analysis) and spatiotemporal parameters, compared with the same parameters measured in a group of healthy subjects comparable in sex and age. HR indices were lower in cirrhotic than in healthy subjects, characterizing subjects with prior hepatic encephalopathy.

Decreased RQA indices were found to correlate with presence of sarcopenia. The electroneurography results, although limited by the small sample size, confirmed the data from the gait analysis: lower values in the HR indices at baseline were found to correlate with the presence ofsensory and motor neuropathy. Greater deteriorations in the RQA index were found to correlate withthe presence of motor neuropathy. (Table 1).

Table 1. Correlation between gait indices and presence of polyneuropathy

Variable		Motor polyneuropathy	Sensory polyneuropathy
HRap	Kendall's Tau B	-0.629	-0.707
	p-value	0.039	0.020
HRml	Kendall's Tau B	-0.070	-0.629
	p-value	0.020	0.039
DeltaRQAdetv	Kendall's Tau B	0.393	0.550
	p-value	0.197	0.035

Electroneurographic parameters, also were found to correlate with clinical variables, such as numberof falls and MELD score.

Discussion

HR indices appear to represent a marker of cirrhosis-induced neurological damage independent of fatigability, sarcopenia, or myosteatosis. Deterioration in RQA indices represents a marker of fatigability related to the presence of alterations in motor production capacity.

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The velocity-dependent features of rigidity in Parkinson's disease: a robot-assisted neurophysiological study

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Introduction

Since the 70s, early studies have demonstrated increased long-latency reflexes (LLRs) as the neuropsychological hallmark of rigidity in Parkinson's disease (PD) [1,2]. More recent investigations identified specific biomechanical components of muscle tone, including the neural component (NC), viscose component (VC) and elastic component (EC) contributing to the objective rigidity in PD [3,4]. However, the role of individual muscle components to the overall 'objective rigidity' in PD is still unknown. Also, none has previously combined the biomechanical with the neurophysiologic recordings of muscle tone. Finally, the putative velocity-dependent feature of parkinsonian rigidity has never been assessed. The aim of this study is to measure simultaneous changes in specific biomechanical components of muscle tone and neurophysiologic measures, at various angular velocities.

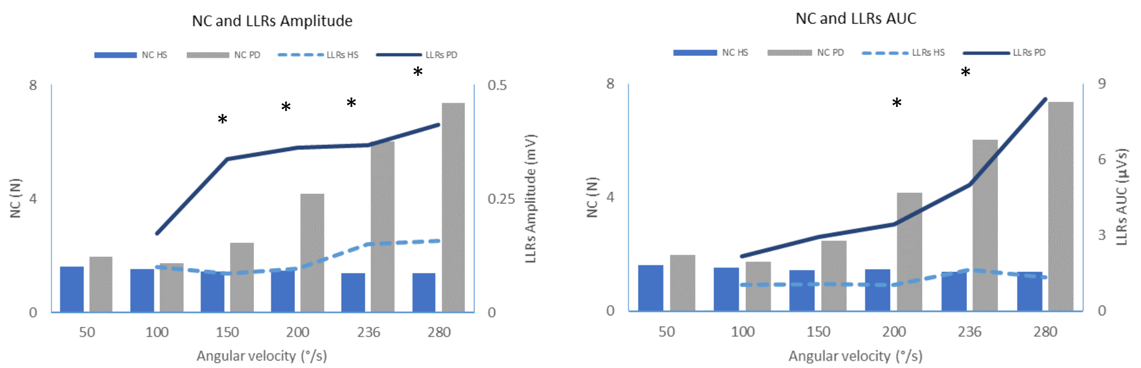
Methods

In this study, we recruited 20 PD patients and 25 age- and sex-matched healthy subjects (HS). Participants underwent an experimental paradigm based on the assessment of spinal and sovraspinal reflexes (i.e., SLRs, LLRs and SR) as well as relevant components of muscle tone (i.e., NC, VC and EC) recorded from the right flexor carpi radialis (FCR) and right extensor carpi radialis (ECR) muscles, through a robot-assisted wrist mobilization at different velocities (i.e., 50, 100, 150, 200, 236 and finally 280°/sec). All PD patients were evaluated ON therapy.

Results

In patients, objective rigidity progressively increased along with the rise of angular velocities during robot-assisted wrist extensions. The neurophysiological examination disclosed increased LLRs, but not SLRs nor SR, in PD compared with controls. The amplitude and the AUC of LLRs, as neurophysiologic features, and the NC, as biomechanical components, progressively increased according to angular velocities only in patients with PD (Fig. 1). Specific biomechanical and neurophysiological abnormalities correlated with the clinical score of rigidity.

Figure 1



Discussion

Objective rigidity in PD correlates with velocity-dependent abnormal neuronal activity, as shown by the previously unreported increase of both NC and LLRs by raising the muscle stretches angular velocities.

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Relationship between propulsion, symmetry, stability, and height in three different static figuresof artistic swimming

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Introduction

Biomechanical analysis enables a quantitative assessment of the performance in artistic swimming techniques. Previous research has examined the motion and the forces involved in different sculling techniques using underwater cameras, load cells, and wired sensor pressure [1], showing that usual sculling motions of artistic swimming continuously provide vertically upward force [2]. Due to the progress in wearable technology, it is now possible to ecologically evaluate the propulsion and the stability of the synchronized swimmer during their regular training sessions. The objective of this currentstudy was to explore the correlation in three static figures (flamingo = *FLA*; crane = *CRA* and vertical =*VER*) between: i) the force exerted by the hands during sculling motion, ii) the symmetry of this force between the two hands, iii) the stability of the vertical leg (out of the water) and the pelvis and iiii) the body's position relative to the water surface.

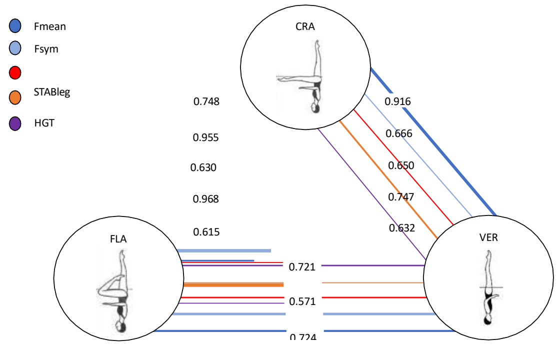
Methods

Sixteen female synchronized swimmers (19.1 ± 3.0 ys, 163.7 ± 4.3 cm, 56.3 ± 6.0 kg) were analyzed. *FLA, CRA* and *VER* figures were randomly executed 3 times during a single trial (each figure held for 5s, followed by 10 s paused). Using the differential approach [3], the resultant force exerted by the handswas estimated by means of 2 wireless pressure sensors each hand (SEAL, Platysens, Hong Kong). Mean value (*Fmean*) and force symmetry index (*Fsym*) were estimated for the 5/trials central sculling. The stability of the pelvis (*STABpel*) and of the vertical leg (*STABleg*) were estimated using the stabilityindex [4] of the acceleration (all 3 components) measured with 2 waterproofed inertial sensors(Wavetrack, Cometa, Milan, Italy) attached to the pelvis between the two posterior iliac spines and to the shank 2 cm above the ankle. The body position relative to the water was evaluated using the height(*HGT*) of the water surface with respect to 3 thigh zones (proximal, central and distal part) in the videorecorded frames (GoPro Hero 7 Camera, San Mateo, USA). Correlation analysis for each variable wereconducted between the different figures.

Results

Large to extremely large significant ($p < 0.05$) correlations between the figures were found for *Fmean*, *Fsym*, *STABleg*, *STABpel* and *HGT* (Fig. 1).

Figure 1. Significant correlation between GRU, CRA and VER.



Discussion

The results supported the technical coherence in terms of propulsion, stability, symmetry and height among the artistic swimming figures of flamingo, crane, and vertical. Larger correlation were found for the force symmetry index and the pelvis stability between the two asymmetrical figures: flamingo and crane.

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Postural control in pediatric neuromuscular and neurological diseases

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Introduction

Several pediatric neurological and neuromuscular diseases are characterized by motor deficits. Among these pathologies, Duchenne Muscular Dystrophy (DMD), Charcot-Marie-Tooth disease (CMT), Hereditary Spastic Paraparesis (HSP) and Cerebral Palsy (CP) are of particular interest because they are characterized by impairments predominantly located in the muscle tissue (DMD), in peripheral nerve fibers (CMT) or in the CNS (HSP and CP). Despite the different etiologies, all these disorders share a motor impairment of the lower limbs meaning that any damage to one or the other component within the 'motor chain' is reflected by a 'final common pathway' [1]. However, a situation in which an almost intact nervous system must cope with impaired muscles is apparently different from a condition in which muscles are intact but driven by impaired nervous structures. Considering that the control of posture provides the basis for standing and walking and it has a crucial role in the execution of motor tasks [2,3], a postural characterization of the specific motor deficits in each disease could be of great help to identify hallmarks of the different pathologies.

Methods

We tested 8 children with HSP, 5 with Cerebral Palsy CP, 5 with CMT and 4 with DMD, as well as 12 healthy participants (H). They were instructed to stand quietly for 30 s with eyes open, repeating the task for three trials. Kinematic data were recorded with an optoelectronic system and a full body marker set [4], allowing to directly determine the Centre of Mass (CoM). Two force plates measured the Center of Pressure (CoP) of each foot, the whole-body CoP and the body weight distribution between feet. To standardize the absolute position of the CoPs, the coordinates recorded in the laboratory reference system were re-referred to the vertical projection on the ground of the midpoint between the centres of the ankles. For each variable and group after checking normality and removing outliers, comparisons were drawn by ANOVA, followed by Tukey-Kramer post-hoc. The level of significance was set to 0.05.

Results

This analysis showed that CP patients shifted their CoP more forward than H and were more asymmetric in distributing their weight between the feet, while DMD assumed a larger base of support (Table 1).

Table 1. Postural parameters reaching significant difference with ANOVA test. Data are shown as mean (standard deviation). AP: anteroposterior, positive when forwards; ML: mediolateral, positive towards the right foot). * Tukey-Kramer significant difference.

	DMD	**CMT**	**HSP**	**CP**	**H**
CoP AP position [mm]	49.31 (8.46)	39.20 (9.7)	40.52 (18.38)	52.72 (11.16) *	30.97 (5.81) *
Δ weight *between feet* [%]	10.02 (2.94)	2.81 (2.02)	5.69 (5.40)	10.72 (9.68) *	2.37 (1.85) *
ML position *right foot* [mm]	115.0 (14.51) *	101.42 (12.56)	97.28 (14.12)	94.29 (16.62)	86.56 (8.57) *
ML position *left foot* [mm]	-112.95 (11.47) *	-100.88 (14.84)	-99.77 (14.49)	-92.68 (19.13)	-88.52 (9.49) *

Discussion

The forward CoP shift, characterizing CP patients, indicates a less efficient postural control, since it requires greater activity of calf muscles to counteract the gravitational torque. In DMD, instead, the functional increase of their base of support might reflect the need to counteract their lower ability to stabilize posture. Present results do not allow to differentiate CMT and HSP from H behavior.

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Virtual Art Therapy for patients with stroke: a kinematic analysis of virtual sculpturing

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Introduction

The works of the artist Michelangelo inspired the development of a protocol of art therapy for the neurorehabilitation of patients with stroke using virtual reality [1]. Moving a virtual brush, they coloured the canvas obtaining the illusion to recreate a masterpiece of painters. The scientific explanations behind this effect could be found in the recent studies of neuroaesthetics. In fact, the processes involved in the observation of an artwork have three different levels of aesthetic experience: a perceptual, a cognitive and an emotional stage [2]. The aim of this study was to investigate the same effect using 3D virtual sculptures.

Methods

30 young adults (mean age: 25±4 years, 15 females), participated to this study. Each subject wore an Oculus Rift Headset and hold in each hand a joystick to perform the requested task. The virtual environment, designed using the game engine Unity (version 2021.3.16f1), was composed of a wooden pedestal with above a solid light grey block, formed by voxels (3D pixels) that cover a 3D reproduction of famous statues (David of Michelangelo, Venus from Milo, Laoocon group) or a rough version of these statue or a set of cubes covering the same volume of the statues. Similarly, to the previous studies [3], the voxels touched by the hands disappeared, giving to the subject the feel of sculpting. As the previous studies [1, 3], after each trial, the subject was asked to assess (from 0 up to 10) how much the stimulus was beautiful, how much the subject liked the stimulus, and how much tiring (fatigue) was the task according to a numeric rating scale. Furthermore, the subject was also required to quantify in percentage how much the right and left hands were used. The system was able to record the 3D trajectories of right and left index fingertip with a sampling frequency of 50 Hz (Figure 1).

Results

Kinematic analysis is going on at the moment. Despite objective and subjective beauty are higher for the statues (Anova: $p<0.01$), the perceived fatigue is not different among three stimuli ($p=0.306$), as well as the perceived symmetry of movements ($p=0.068$). The perceived fatigue resulted significantly correlated with the subjective and objective only for cubes ($R=-0.25$, $p<0.001$).

Discussion

More complex stimuli, such as classical sculptures, did not increase the fatigue of the task, but increased the perceived beauty. The perceived fatigue depended by the beauty of for cones, the less appreciated stimuli. This study confirmed the perceived fatigue is related to the beauty of the stimuli [1], despite our results could be affected by a floor/ceiling effect. Further analyses are carrying on about the hand kinematics.

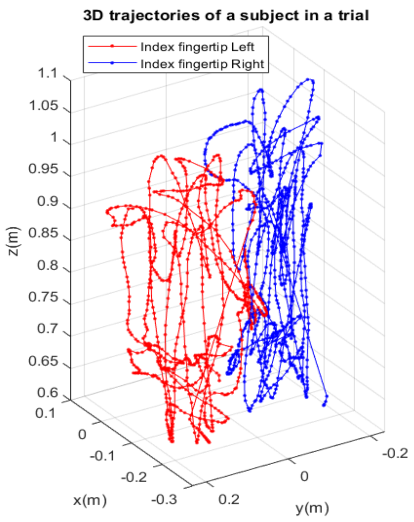

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Figure 1 *3D trajectories for the left (red) and right (blue) index*

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Toward an active omnilateral walking support robotic system

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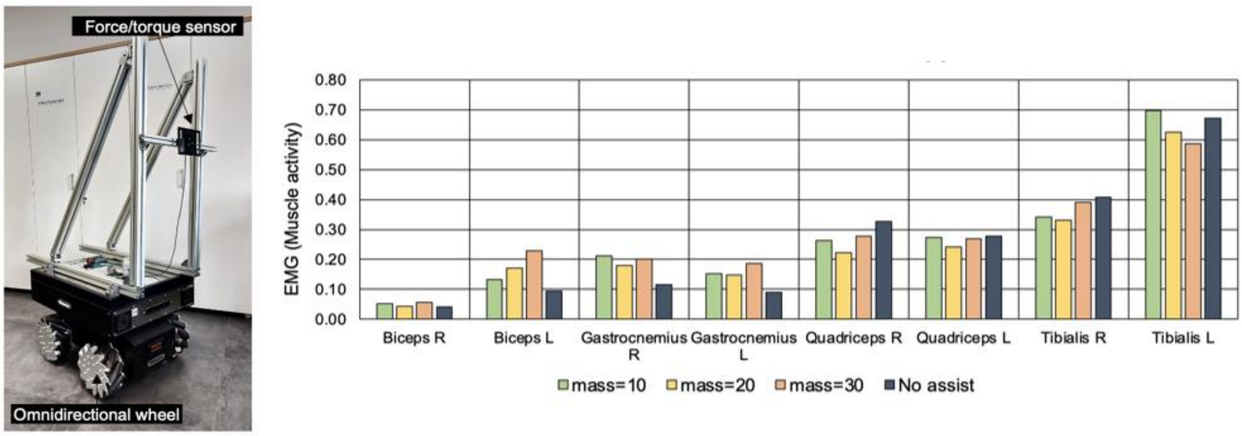
INTRODUCTION
Walking assistive devices for elderly people and patients who have limited mobility have been developed to rehabilitate and restore walking functionality and improve gait stability [1]. However, most of them are handle-type devices with limitations for users that cannot use their hands or harness-type devices, usually too bulky. In this work, we aim to develop an active omnilateral walking support robotic system (Fig. 1) that moves by user intention and assists during walking.

METHODS
The platform is intended to follow and physically assist in daily walking activities. Ideally, the user should not perceive resisting forces or other motion constraints while stably walking with the platform. To this end, an admittance controller is developed to implement a dynamic relationship between the user-inserted forces and the robot movements to follow or assist the user as needed. This control method takes as input the forces applied by the person, measured by a force torque sensor (Fig. 1 on the left) directly coupled to the back of the user through a comfortable brace, to determine as output the direction and velocity of movement of the platform.

RESULTS
For the performance assessment, we asked one subject to follow a path that included longitudinal, lateral, and turning sequences. We measured electromyogram (EMG) on eight muscles for assessing the transparency of the platform. The results (Fig. 1 on the right) show that by tuning the mass parameter of the admittance controller, we can operate the platform with high transparency. When the virtual mass value was set to 20 kg, the percentage difference of EMG values with and without the support of the platform was about 17%.
Figure 1. (left) Omnilateral assistive robot system, (right) activity of muscles (R: right, L: left) as root mean square of EMG with varying admittance controller parameters and without the platform.



DISCUSSION
In this work, we presented a prototype of the omnilateral walking support robotic system and we designed an admittance controller based on the interaction force measured on the pelvis of the user. In further work, we will focus on optimizing the parameters of the controller to improve movement transparency. In addition, we will improve the stability of walking, for example, balancing and preventing falls.

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Review of Mixed Reality applications in medical and athletics fields

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Introduction

Mixed Reality (MR) is an innovative technology to overlap virtual objects in the real word and to interact with them bare handed. MR differentiates itself from Virtual Reality thanks to the headsets design consisting of transparent glasses through which the user can see the virtual object contextualized in the real world. HoloLens2 (HL2) from Microsoft is the most used headset for MR because of its versatility, innovations, and open-source plugin for Unity or Unreal. Several studies have demonstrated the efficiency and the advantage of using MR in the medical field, predominantly in rehabilitation and surgical planning [1]. HL2 was also validated for these applications evaluating the accuracy of hand tracking [2,3], of eye tracking [4] and of the IMU incorporated in the headset [5]. The aim of this review is to present all the activities and apps for MR developed for different applications in the medical field: neurorehabilitation, sport, and balance diagnostics.

Methods

MR apps are developed and built on Unity (version 2020.3.30f1), real-time development platform for 3D apps. MRTK asset (version 2.7) is installed in the Unity project in order to implement apps for HL2. MR apps can be built and uploaded as standalone on the device or developed to run in Holographic Remoting. With the last setting, the app runs on the computer while the HL2 is connected via USB-C and managed by the computer. The installation of other plugins for Unity project allows to integrate devices, such as 3D scanner, haptic or inertial sensors, and to manage their data in the project. According to this, several data can be collected to develop a more complex MR experience.

Results

In [6], a MR app was developed for upper limbs rehabilitation specific for ataxic patients. The app presented is built to work in Holographic Remoting settings and, though still a prototype, some patients have given positive feedback. Franzò et al. [7] shows a MR app integrated with the Azure Kinect, the Microsoft external depth camera device. This device with the Unity assets provides estimation of the 3D positions of 25 joints of a subject standing in its view volume. The app allows the user to visualize in real-time joints of a second subject in MR together with other information that can be calculated and shown on the headset. In [8], HL2 was used to perform the Dynamic Gait Index test. The app provides accurate quantification of gait, movement along the walking axis, mobility, and deviation from the standard range.

Discussion

MR has proven its reliability in a wide range of applications. HL2 reveals limitations due to the small memory RAM and the narrow field of vision. The hand tracking algorithm and the MRTK for the virtual button interactions might be improved. However, HL2 is comfortable, light and does not cause nausea or eye fatigue. Considering that the Holographic Remoting settings can lighten the computational load on the device, HL2 is still adequate and accurate enough to these categories of application and to provide the user with a successful MR experience, considering also that biomechanical evaluation and post-processing analysis are considered of secondary importance to the outcome of the experience.

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Combo Mixed-Reality system empowering occupational therapy and daily-life actions of visually impaired

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Introduction

Mixed-Reality (MR) is an innovative technology that allows to show and interact with holographic 3D objects contextualized in the real-world. MR has been applied in neurorehabilitation for various diseases such as chronic stroke [1], Alzheimer [2] and ataxia [3]. According to WHO report 2019 [4], in Europe approximately 90 million people have vision impairment or blindness. The extent to which vision impairment impact people's lives depends on the environment they live in and supports they receive. To develop innovative systems and supports for everyday life of vision impaired, several research works [5] have been proposed. Augmented Reality apps were also proposed for navigation [6] and recognition of objects [7]. Considering that age-related eye conditions are the most common cause of sight loss in Europe, a proof of concept is presented on the possibility of use MR in a daily-life support system for elderly people living alone or in RSA. This system provides navigation in the environment and occupational therapy in the interaction with objects present in the room.

Methods

The system is composed of the MR headset of Microsoft, the HoloLens2 (HL2). The app running on the device was implemented and build on Unity platform (2020.3.30f1) for real-time 3D environment. Recognition and detecting of objects were implemented with a 3D scanner for the 3D reconstruction and Vuforia assets for tracking in the app. For the navigation, GPS and Unity anchors were used integrated with the IMU, the camera and the spatial mapping of the HL2.

Results

In the figure screenshots of the HL2 view during the running app are reported.

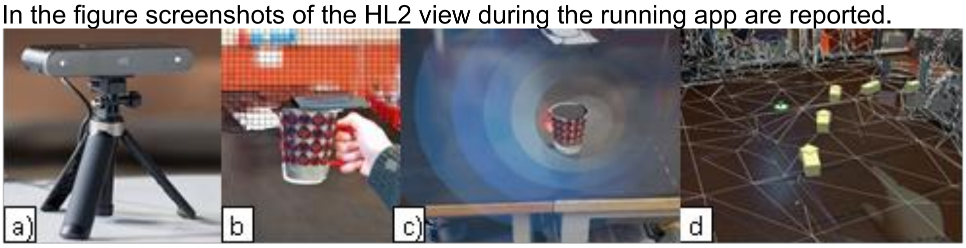

Figure 1. a) 3D scanner; b) and c) tracking and matching of the real cup with the 3Dobject; d) example of objects fixed (yellow arrows for direction) in the real world contextualized by the HL2 spatial mapping.

Discussion

The system is still a prototype, yet it provides the assistance needed efficiently, recognizing the environment, and detecting objects around the area. Moreover, HL2 is small, light, and consequently comfortable to wear. The HL2 hardware introduces some limits: the strict field of view and the small RAM. To improve the system, mapping should be built with a scanner in order to obtain a more realistic 3D map. Introducing a prebuild map, the navigation is limited in this environment, while with artificial intelligence algorithm an assisted navigation can be realized in environments unknown to the app.

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Sharing hologram in Mixed-Reality app for occupational therapy in the Metaverse challenge

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Introduction

Metaverse is the new challenge in healthcare [1]. Sharing holograms and the possibility of interacting with them in real-time is the future of the Mixed-Reality (MR) apps. In recent years, several computer scientists, several studios [2, 3] and Microsoft itself have tried to propose frameworks in which a collaborative MR experience is possible. Among them, Microsoft proposed Mesh, but its upgrade to Teams has not yet been released. In medicine a sharing MR experience would be of support in telemedicine, rehabilitation [4] and also in sports [5]. The aim of this study is to show the possibility of sharing a MR experience between two headsets for MR, Microsoft HoloLens2 (HL2), its eventually innovative applications in medicine and its limitations.

Methods

The system proposed involves two HL2. The app is implemented in Unity 3D platform (2020.3.30f) with the Photon 2 asset and MRTK (2.7.3). The app is built and upload on each HL2. The two devices must be connected to the same Wi-Fi. The 3D objects are provided by a Microsoft's example project.

Results

The Figure shows the views of each HL2 during the experience and a photo taken of the two users.

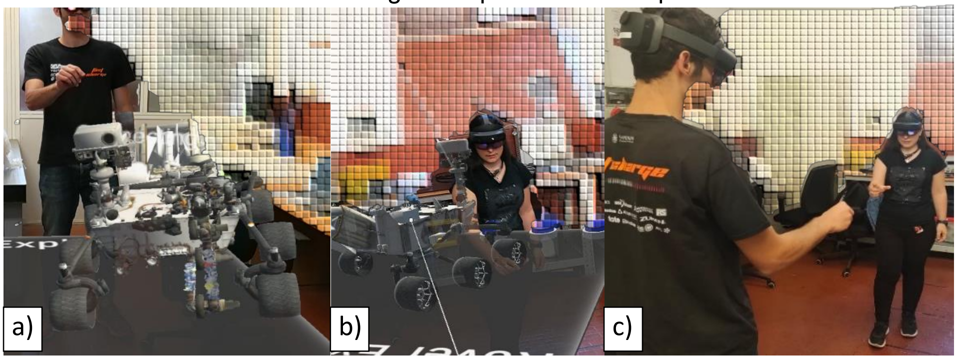

Figure 1. in a) and b) the views of the HL2 users, while in c) the view of a third subject without HL2.

Discussion

In the prototype a prefab provided by Microsoft is used, however it can be replaced by any other 3D object, such as object for an occupational therapy system. Unlike usual experience and also the one presented in [4], where a sharing of the MR experience on the pc monitor was presented for an occupational therapy, this system involves the wearing of a second HL2 by the therapist. An occupational exergame in MR that can be shared in real-time between the patient and the therapist allows the patient to play the exercise while the therapist checks on the performance giving feedback and suggestions. With this integration the system is complete and innovative, as well as exciting and captivating, and it provides feedbacks and therapist supports. Also in sports this system could find applications for anatomical evaluation and interactive training. Some limitations must been highlighted: a powerful internet connection is needed and it must be the same for both devices; Photon 2 is in a upgrading phase as well as Microsoft Mesh so in the future different drivers will be provided; Microsoft Azure, provided to storage during the sharing, is fee-based.

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Variability and correlation analysis of postural stability and plantar pressure parameters in open and closed eyes conditions.

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Introduction

The "Postural Control System" acts through biomechanical strategies and functional neuromuscular adaptations to maintain body balance in static and dynamic conditions [1]. Postural stability and body weight distribution can be affected by external sensory inputs, such as different visual stimuli. Previous studies tried to analyse the influence of visual receptors on stabilometric and plantar pressure parameters in healthy subjects [2]. To the best of our knowledge, no study has investigated multiple correlations between pairs of postural stability and plantar pressure parameters in open (OE) and closed (CE) eyes conditions. The aim of this study was to analyse variability, correlations, and changes in stabilometric and plantar pressure parameters in both visual conditions in healthy subjects.

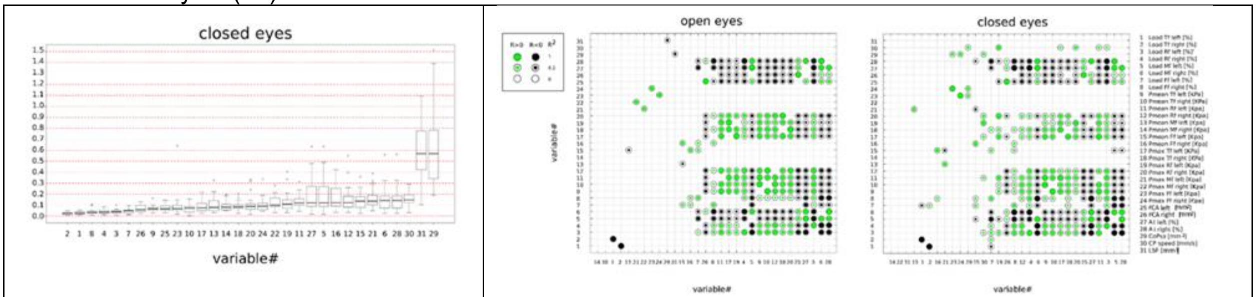
Methods

20 young and healthy subjects were assessed by a 200×50 cm 10.000 sensors/m^2 pressure plate in bipedal standing. Four 30 s stabilometric analyses were performed in OE and CE. 31 clinically relevant stabilometric and plantar pressure parameters were recorded. Pearson's correlation was investigated between pairs of parameters in each condition.

Results

High inter-subject repeatability was found for all plantar pressure parameters and Center of Pressure (CoP)-speed in OE and CE with Coefficient of Variation (CV)<40%, while CoP-sway area and Length Surface Function (LSF) showed larger variability with CV>50% (Figure 1a). The correlation analysis revealed that mean and peak pressures at midfoot and total foot load as the most independent parameters in both visual conditions, whereas the arch-index and the rearfoot load were the most correlated ones (Figure 1b). Limb side significantly affected most parameters and LSF, right forefoot mean and peak pressure were significantly affected by the visual stimulus.

Figure 1a, b. Boxplot of inter-subject Coefficients of Variation (%) (a) and Correlation between pairs (b) of stabilometric and plantar pressure parameters, assessed in open and closed eyes conditions by Pearson's correlation analysis (R^2).



a) b)

Discussion

The present study helped to establish the most reliable and independent stabilometric and plantar pressure parameters for the evaluation of bipedal standing posture in OE and CE conditions in a population of young and healthy subjects (Figure 1a). The association between postural stability and foot load was highlighted via correlation analysis (Figure 1b). Moreover, interesting results about the postural adaptations related to different visual stimuli, the importance of the dominant side and the specific role of the midfoot (in according to previous study [3]) in balance control were reported.

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Biomechanical evaluation with two-year follow-up in patient after iliac crest autograft in osteosarcoma of the cuboid: a gait analysis case report

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Introduction

Osteosarcoma is a rare malignant tumor that affects bone cells and, rarely, some soft tissue outside the bone. In Italy, about 500 new cases of malignant bone tumors are recorded every year and 20-25% is represented by osteosarcomas [1]. The standard treatment of osteosarcoma is based on the combination of surgery with chemotherapy. When conservative surgery is possible, the part of the body that has been removed is replaced with 3D-printed or metallic prosthesis, or autograft.

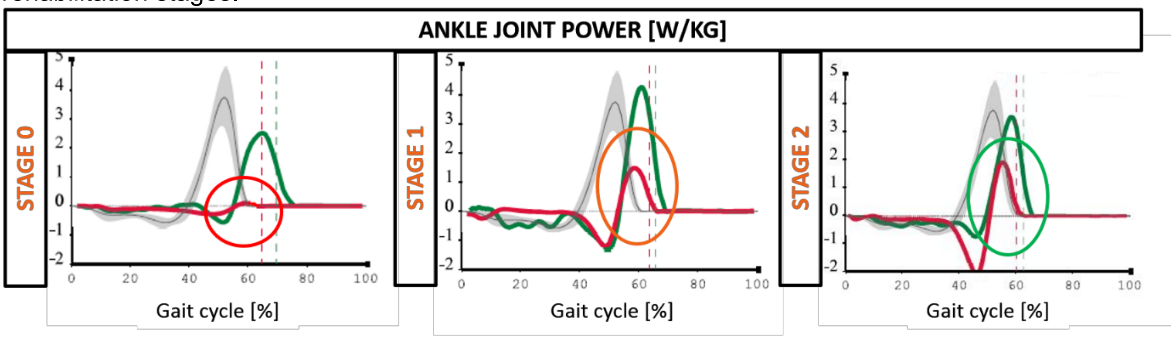
Methods

A young male patient underwent surgical treatment of osteosarcoma of the left cuboid replaced with autograft from iliac crest. Kinematic and kinetic data were acquired using reflective markers positioned according to Davis Heel protocol and two dynamometric platforms. Data were acquired at different stages: after the surgical procedure (stage 0), at one-year follow-up (stage 1) and two-year follow-up (stage 2). The rehabilitation program consisted in physiotherapeutic treatment based on muscle strengthening and gait pattern re-education, with the help of orthopedic shoes with biomechanical sole.

Results

From the comparison between data acquired at different stages, gait analysis documented a better stabilization of lumbopelvic segment during the entire gait cycle with better symmetry on the transversal plane; consequently, a better kinematic pattern of the hips was possible, with a progressive reduction (stage 1 and stage 2) of the hyperextension encountered at stage 0. Progressively, the ROM of the left ankle, which was limited by the outcomes of the surgical procedure, has acquired a better and joint power production, similar to normal gait parameters [2]. The follow-up evaluation performed at stage 2 documented the progressive and continuous improvement of gait kinematic and kinetic parameters, an increase of patient's autonomy during walking and lower level of fatigue in long distance-walking.

Figure 1. Right (green) and left (red) ankle joint power with respect to normality (grey band) at different rehabilitation stages.



Discussion

In conclusion, the use of gait analysis in the evaluation of innovative chirurgical procedure outcomes has proved to be able to supply useful results for clinical specialists in order to plan the most appropriate rehabilitation and choose the best orthopedic aids to accompany the patient in his path after intervention, according to the patient's needs. If applied before intervention, it could represent a useful tool not only to document and monitor the efficacy of the rehabilitation process and orthopedic aids, but also to provide information that allow clinicians to improve surgical procedure.

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A decision support system for the personalization of robotic rehabilitation of the upper limb in patients with stroke outcomes. A feasibility study

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Introduction

Robotic devices have shown effectiveness in treating stroke patients [1]. However, their full potential has yet to be fully realized in terms of personalized rehabilitation and treatment monitoring. In a previous study, we developed an algorithm that predicted patient recovery based on clinical scale scores and robotic system measurements [2], using data collected in a large randomized controlled trial [3]. The algorithm achieved accuracy rates of 60% to 73%. Building on this work, an AI-based Decision Support System (DSS) was developed to assist clinicians through the prediction of the rehabilitation outcome day after day, thus helping in creating effective treatment plans. The current study aims to test this DSS in a pilot clinical trial.

Methods

This study involved 33 stroke patients. They underwent an initial assessment using several clinical scales before receiving a 30-session robot-assisted treatment using the MOTORE robot. The treatment was enhanced by an AI-based DSS called iMotore. The DSS used initial evaluations, demographic, and clinical data to propose a value for three treatment settings (stiffness, weight, and viscosity). The feasibility of the treatment and its effects were evaluated using usability scales, satisfaction ratings, and clinical outcome measures. Also, a "predictor importance" index (called pimp index, ranging from 0, i.e. not important, and 1, i.e. very important) was extracted from the DSS model after training to understand whether demographic, clinical, and serious-game-based kinematic measures were crucial for the DSS to correctly predict the rehabilitation outcome.

Results

The feasibility analysis of the treatment showed a usability score, evaluated using the SUS, of approximately 80/100 for both therapists and patients. The average satisfaction rating was 8.7 points for patients and 7 points for therapists. The TAM questionnaire revealed average scores of around 6 points (out of a maximum of 7) in all evaluated domains. The analysis of treatment effects demonstrated statistically significant improvements in the Fugl-Meyer Assessment (FMA), Motricity Index (MI), Frenchay Arm Test (FAT), Action Research Arm Test (ARAT), Box and Blocks Test (BBT), and Modified Barthel Index (MBI) scales ($p<0.001$ for FMA, MI, and ARAT; $p<0.05$ for FAT, BBT, and MBI). Pain and spasticity did not show significant changes. Additionally, there was a non-significant trend toward improvement in the Physical Component Summary (PCS) and Mental Component Summary (MCS) subscores of the SF-36 questionnaire. Furthermore, among all variables used in the DSS input set, the most relevant in the rehabilitation outcome prediction process were the age (pimp index equals to 1) and stroke latency (pimp=0.72) variables, followed by the task completion time (pimp index = 0.53), the precision of patient's work (i.e. the amount of force correctly employed towards the task target, pimp = 0.42), the cumulative distance covered by the robot in assistance-mode (pimp index = 0.41), and the average patient's hand speed (pimp index = 0.38).

Discussion

The treatment using the MOTORE robotic device and AI-based DSS has confirmed its usability and has shown effectiveness in improving upper limb functionality and performance in a group of stroke patients. This study confirmed the usefulness of rehabilitation outcome forecasting to improve the rehabilitation design process and to extract new knowledge about which data, measured by the robotic platform, were relevant to understand the motor recovery direction. Regarding this point, features extracted from kinematic and kinesiologic data were among the most relevant and could be a breakthrough in designing more engaging rehabilitation tasks. Future studies should evaluate its efficacy by comparing it with a "standard" robot-assisted treatment without AI mediation.

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Neuromuscular assessment of balance in chronic ankle instability

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Introduction

Chronic Ankle Instability (CAI) is a condition usually developed after a first ankle sprain injury and it is featured by recurring episodes of ankle sprains and giving-way, typically accompanied by pain, weakness, reduction of the joint range-of-motion, and of the self-reported function during daily and sporting activities [1]. The aim of this study was to investigate balance performance and muscle synergies during Single-Limb Stance (SLS) in individuals with CAI and control subjects.

Methods

We enrolled in the study 20 CAI patients and 20 controls. Each individual tried to maintain SLS balance, for at least 30 s, while standing on a force platform with their injured (CAI) or dominant (control) lower limb. The electrical activity from 13 muscles of the standing limb, hip, and back was recorded by means of surface electromyography. Muscle synergies during SLS were extracted through Non-Negative Matrix Factorization (NNMF) [2].

The balance performance of the two groups (CAI and controls) were compared in terms of: (*i*) the number of SLS epochs, (*ii*) the epoch duration, (*iii*) the Root Mean Square (RMS) reaction force in antero-posterior (AP) and medio-lateral (ML) directions, and (*iv*) the number of muscle synergies expressed during unipedal stance.

Results

Overall, a reduced neuromuscular performance was found in CAI patients with respect to controls. The main outcome measures estimated are reported in **Table 1**.

Table 1. Comparison of CAI and control patients.

	CAI patients	Controls
Number of SLS epochs	3.9 ± 0.3**	3.3 ± 0.2**
SLS duration (s)	72.6 ± 5.4****	91.2 ± 1.2****
Force AP RMS (N)	9.2 ± 0.8****	4.8 ± 0.4****
Force ML RMS (N)	6.1 ± 0.6****	2.3 ± 0.2****
Number of muscle synergies	4.9 ± 0.2**	5.4 ± 0.1**

Mean ± standard deviation is displayed for each parameter. Statistically significant differences are indicated by asterisks (** $p < 0.01$, **** $p < 0.0001$).

Discussion

While the neuromuscular control during single-limb stance was already analyzed in healthy subjects [2] [3], this is the first study investigating balance alteration in patients suffering from Chronic Ankle Instability. Our finding of a reduced number of muscle synergies in CAI patients supports the hypothesis that a peripheral injury leading to sensory loss and mechanical joint instability, may be related to abnormalities in central organization of movement in the long term.

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Straight-path and U-turn gait biomarkers in PD patients before and after deep-brain stimulation

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Introduction

Clinical gait analysis revealed that turnings are altered, even in the early stages of Parkinson's Disease (PD), with increased turning arcs, time to complete the turn, and a larger number of steps taken to complete the turn. Furthermore, turning/curved walking is more likely to cause gait instabilities and increased variability compared to straight walking. Many studies focus on repeated trials of short intermittent walking bouts, while there is a lack of works considering continuous and prolonged overground walking, that includes both straight-path and turnings. However, this latest approach seems promising to obtain sensitive and reliable gait biomarkers recorded in ecological walking conditions.

Methods

This study enrolled 20 PD patients and 20 healthy controls. PD patients were tested twice: before Deep-Brain-Stimulation (DBS) neurosurgery, and 3 months after it [1]. All subjects were asked to walk for 5 minutes back and forth a straight path, and to U-turn for changing direction at the end of the 9-m walkway. Foot-floor contact events were directly detected by means of footswitches. Besides traditional gait parameters, the percentage of "non-standard" gait cycles was analyzed, i.e., cycles showing a sequence of foot-floor contact events different from the typical one (heel-strike/flat-foot-contact/push-off/swing), normalized with respect to the walking speed [2].

Results

Overall, PD patients considerably improved their gait after DBS, as represented in **Figure 1**.

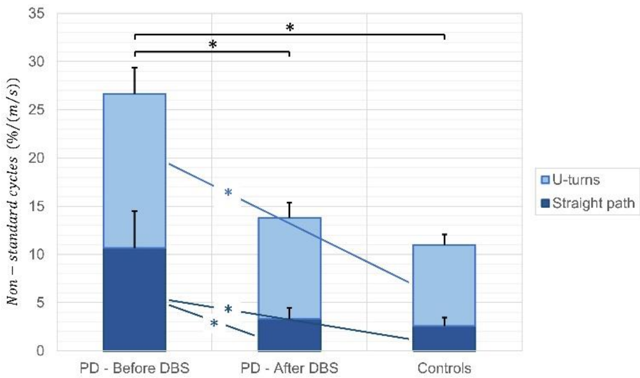

Figure 1. Stacked bar diagrams of the normalized percentage of "non-standard" gait cycles in the more affected side of PD patients (before and after DBS) and in the dominant side of controls. Asterisks represent statistically significant differences (p-values < 0.05). Error bars represent the standard errors.

Discussion

The percentage of "non-standard" gait cycles (also called "atypical" gait cycles) already proved to be an accurate biomarker for quantifying subtle gait dysfunctions in PD patients, correlated with the clinical score UPDRS-III [2]. The present work demonstrated the validity of this parameter in the evaluation of the effects of the DBS, at 3 months after the implant. The segmentation of straight-path and U-turning epochs [3] provided supplemental information, that can be useful in the management of PD patients. While the PD neuromuscular control after DBS was already analyzed in a recent work [1], this is the first contribution presenting original gait analysis data on this cohort of patients.

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Cortical processing of ankle joint proprioceptive afference during active and passive conditions: an EEG study

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Introduction

Proprioceptive stimulation modulates specific cortical sensorimotor rhythms (e.g., β-band from 14 to 32 Hz) that can be quantified by phase-locked EEG responses to the stimuli (i.e. induced responses) that are thought to be a measure of cortical activation and excitability. The state of the cortex might change under particular circumstances due to the execution of specific tasks (e.g. from passive to active) or as effect of ageing or neurological diseases such as stroke or Parkinson's disease [1]. These alterations might reflect important changes in the cortical processing of the somatosensory afference that is worth monitoring e.g. in stroke [2]. We hereby use induced EEG responses to evoked ankle joint rotations to evaluate how the cortical proprioceptive processing is affected by voluntary muscle activation.

Methods

25 young, healthy volunteers (14 males; 28.8 ± 7 y.o., mean ± SD) were recruited. Participants' right ankle joint was stimulated through alternated dorsiflexions and plantarflexions (peak angular velocity: 30 deg/s, movement range: 4 deg) for a total of 100 repetitions (ISI: 4 ± 0.25 s). Two conditions were tested: with voluntary activation of isometric plantar flexion torque of 5 Nm (active condition) and the ankle at rest (passive condition). 30 EEG signals were recorded through a wireless and miniaturized amplifier [3]. Induced responses were quantified by means of the temporal spectral evolution method [4] on 4 s epochs (from –1s to 3 s with respect to the stimulus). A Wilcoxon signed rank test was used to examine whether peak amplitudes differed between conditions.

Results

19 out of 25 participants showed significant β modulations at the level of the electrode site corresponding to the foot area of the sensorimotor cortex (i.e. Cz). Figure 1 A depicts the baseline-normalized grand average induced responses. Figure 1 B shows time-frequency representations and topographies across participants for both conditions. The active condition led to a larger β suppression and a weaker β rebound with respect to the passive condition (respectively $p<0.01$ and $p<0.05$).

Discussion

The differences in β-band modulations between the conditions could be due to different state of the sensorimotor cortex. The stronger β suppression (i.e. higher excitability) and weaker β rebound (i.e. lower inhibition) during the active condition compared to the passive one most likely reflects the activation of the motor cortex and stronger intra- and inter-hemispheric inhibition in the sensorimotor neuronal networks involved in the cortical proprioceptive processing. Our findings demonstrate that the induced responses allow tracking the effects of an altered state of the cortex. We thus provide further support for the use of these measures as neurophysiological markers to investigate adaptations in cortical processing of proprioception.

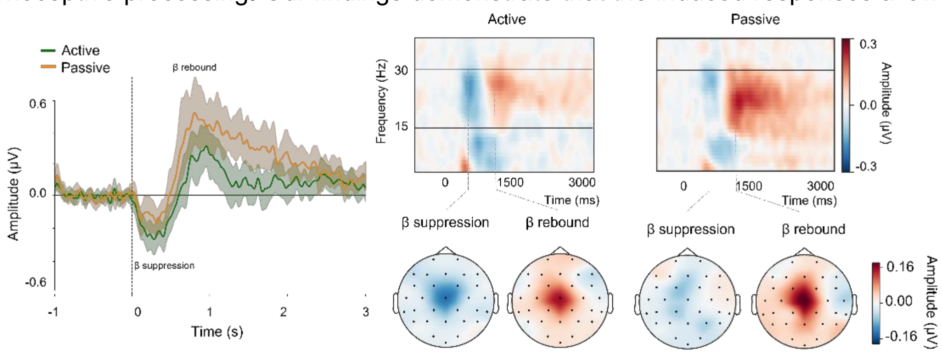

Figure 7. Grand average induced responses (n=19). A) β band power modulation for active (green traces) and passive (orange traces) conditions. B) Time-frequency representation of 4 s epochs and topographies at 300 ms and 900 ms representing β suppression and β rebound.

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A wireless, miniaturized EEG acquisition system optimized for dynamic recordings

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Introduction

EEG motion artifacts overlap with the physiological cortical signal of interest, thereby complicating the correct interpretation of the brain signals during dynamic activities [1]. Motion artifacts are mainly determined by three elements of the biopotential acquisition system. First, the input features of the amplifier used for the recordings. Second, the triboelectric effect caused by the relative movement of conductors inside cables connecting the electrodes to the amplifier. Third, the relative movements of the electrodes with respect to the scalp. We recently developed a wireless, and miniaturized EEG amplifier that was validated under static tasks in [2]. In this study, we aim at demonstrating its robustness also for dynamic applications. To this end, we developed a custom-made EEG electrodes system to disentangle the possible causes of motion artifacts and to focus only on the amplifier-related one. We therefore isolated the first cause from the other two by minimizing both the triboelectric effect and the relative electrodes movements that otherwise would have been non-negligible confounding factors for the interpretation of the results.

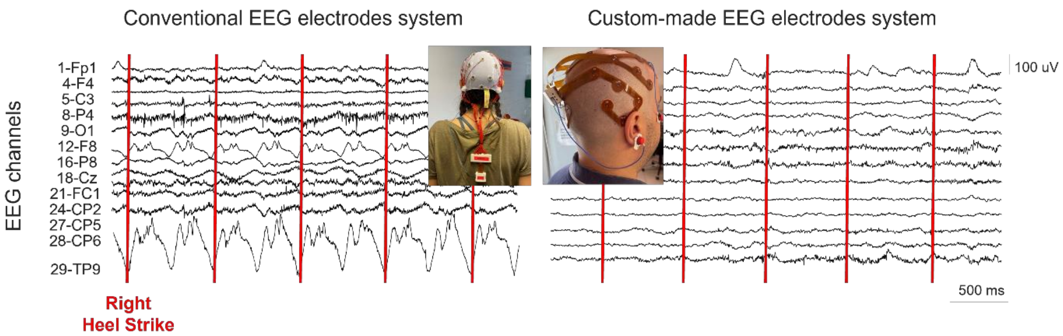
Methods

The developed custom-made EEG electrodes system is characterized by the absence of freely moving cables and adhesive electrodes. It is a flexible printed circuit (Polyimide, 80 μm thick) with 30 electrodes of the same size and shape (area 50.27 mm^2), placed according the 10-20 standard electrodes system. We performed a preliminary test collecting 30 EEG signals on three bald subjects walking overground on a straight path for 1 min. The grid of electrodes was attached on the subjects' scalp using a biocompatible adhesive to minimize the electrodes movements with respect to the skin. A footswitch was positioned under the right heel to identify the heel strikes allowing to inspect gait-related artifacts in the EEG traces.

Results

Preliminary analyses on the collected signals demonstrate negligible EEG motion artifacts during overground walking when compared to a conventional EEG electrodes system detection using the same EEG amplifier (Figure 1).

Figure 1. Figure 1 - EEG traces during 4 s of overground walking. Conventional (left panel) and custom-made (right panel) EEG electrodes system. Red vertical lines indicate the right heel strike instants identified from the footswitch signals.



Discussion

In the present study we assessed the robustness to motion artifacts of a recently developed wireless EEG acquisition system. In order to focus on the amplifier contribution to motion artifacts, we minimized the effect of non-amplifier-related sources (i.e., triboelectric effect and electrode-skin movements). The robustness of the developed EEG acquisition system against movement artifacts was then demonstrated by the absence of relevant gait-related artifacts. This result, although preliminary, confirms the validity of our EEG acquisition system design based on a lightweight, miniaturized and wireless device.

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The potential role of kinematics and electromyography on rehabilitation treatment and follow up in adults with peripheral neuropathy of upper extremity: case series.

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Introduction

Peripheral neuropathies of the shoulder and upper extremity are uncommon injuries that may affect the young athletic and adult population, resulting in significant pain and impairment. Dynamic electromyography and kinematics, measured by 3D upper limb motion analysis, can potentially increase understanding of scapulothoracic movement and muscle weakness. We present three cases characterized by impairments of shoulder range of motion, muscle performance and level of disability: two patients affected by Parsonage-Turner syndrome and one with a paralysis of trapezius after traumatic lesion of spinal accessory nerve.

Methods

We analyzed 3D scapulo-thoracic kinematics and muscle activation with surface electromyography during specific motor tasks at 2 (T1), 6 (T2) and 12 (T3) months follow up. In the same follow up periods, we quantified upper limb impairment with Disabilities of the Arm, Shoulder, and Hand Questionnaire (DASH) and shoulder function with Constant–Murley score (CMS). Patient underwent a specific rehabilitation treatment (2 session/week) from 2 to 12 months after diagnosis.

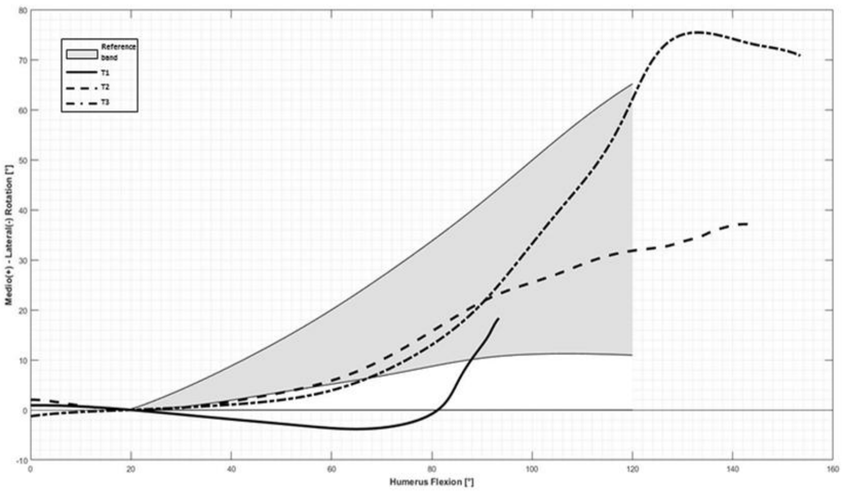
Results

In the first evaluation, patients presented a reduction of range of motion in humerus elevation and humerus abduction, combined with alteration in scapulo-thoracic kinematics and muscle activity. DASH and CMS showed impaired upper limb function. At 6 and 12 months follow up, instrumental data underlined an improvement in range of motion associated with the reduction of compensatory mechanism such as scapula posterior tilt and medio-lateral rotation, during humerus elevation (Fig 1).

Discussion

This study gives us information about the potential contribution of the scapulo-thoracic joint and muscle activity for patient with peripheral neuropathies of the shoulder. Kinematic analysis combined with clinical evaluation and functional scale could be useful to individualize treatment planning and to evaluate outcomes after rehabilitation treatment.

Fig 1. Changes in scapula medio-lateral rotation, during humerus flexion.



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Comparing vertical ground reaction force in patients with Parkinson's disease and healthy subjects walking on a circular path

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Introduction
Curvilinear walking represents a challenging task, due to the cognitive and balance involvements [1,2]. It is known that high-functioning patients with Parkinson disease (PwPD), showed changes in gait parameters during curved trajectories compared to age and speed-matched healthy adults (HS) [3]. Indeed, PwPD diminished the stride length, increased the time spent in double support and had higher variability of swing, single and double support phase during curvilinear paths [3]. However, little it is known about the vertical ground reaction forces (vGRF) in high-functioning PwPD during curvilinear trajectory. The present study aims to compare the vGRF of PwPD and HS during both linear and curvilinear trajectories. We hypothesized that, even when walking at similar speeds, alterations of GRF and their time-course may occur in high-functioning PwPD, especially during curvilinear trajectories.

Methods
We studied a cohort of 18 well-treated PwPD (age 71.4 ± 8.0 years; Hoehn-Yahr range 2-2.5) compared to a group of 18 age and sex-matched HS (age 72.7 ± 7.6 years). HS were purposely selected if walking at the same spontaneous linear speed of PwPD. Participants performed linear and circular walking (1.2 m radius, clockwise and counter-clockwise) at self-selected speed and at random order. Both feet were instrumented with pressure insoles Pedar-X system. We analysed the vGRF of both feet, separated for Foot-In and Foot-Out, during the entire stance normalised as percentage of body weight (%BW) and its time-course expressed in percentage of stride time. The respective coefficients of variation (%CV) have also been analysed.

Results
PwPD showed similar walking speed of HS during curved trajectories ($p=0.48$). vGRF at heel strike and at toe-off was higher in linear than in curved walking in both groups. At mid-stance, vGRF for both Foot-In and Foot-Out was higher than for linear foot in both groups. No differences in vGRF were found between the two groups in both trajectories. The toe off time-course of PwPD was significantly reduced in both Foot-In ($p<0.01$) and Foot-Out ($p=0.05$) compared to HS. No other differences of the time-course variables were found between groups and trajectories. The toe off time-course variability was significantly higher in PwPD in both Foot-In ($p<0.005$) and Foot-Out ($p<0.05$). No differences of force %CV between groups were found.

Discussion
To the best of our knowledge, this is the first study which compares vGRF in PwPD vs HS along curved paths matching the linear speed. Although we found that linear and curved walking speed are superimposable, both groups show a modification of the force profiles during curved walking. With respect to the straight path, the vGRF profiles of both feet show a decrease of the first and second peaks, in force and time-course, and an increase of force during the trough corresponding to mid-stance. Further, when compared between feet during curved walking, the time course of the toe off and its variability are significantly affected in both feet in PwPD. These findings reflect the more complex task of curvilinear trajectories [4]. The increased temporal variability can be interpreted as a disturbed rhythmicity that cannot simply be attributed to inconsistency of force production [5]. The variability of toe off times in PwPD was significantly increased compared with HS for both feet. This could be explained by the minor toe lift [6] or by the diffused dyskinesia characterised by the hallux extension [7]. The lack of differences between the force profiles in Foot-In and Foot-Out also describes the need of both groups to walk avoiding adopting the inner foot as a pivot, as showed in young HS [8]. This is because the ability of pivoting requires good dynamic balance [9].

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Psychometric properties of the Balance Evaluation Systems Test in people with neurological diseases: a systematic review and meta-analysis

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Introduction

Balance impairments are common in people with neurological diseases, resulting in an increased fall risk and a reduction of patients' mobility, functional independence, and quality of life [1]. Thus, since balance evaluation appears to be crucial for fall risk prevention, standardized measuring instruments able to monitor balance regardless of disease are required. The Balance Evaluation Systems Test (BESTest) scale [2] is deemed to be the most comprehensive postural control scale able to assess individuals with different postural control capabilities. Therefore, the aim of this meta-analysis and systematic review was to investigate the measurement properties of the BESTest in people with neurological diseases.

Methods

A systematic literature search of Embase, MEDLINE, Embase, ScienceDirect, Scopus and PEDro databases was conducted to identify studies assessing the psychometric properties of the BESTest in adults with neurological conditions. The COnsensus-based Standards for the selection of health status Measurement INstrument (COSMIN) Risk of Bias checklist was used to assess the methodological quality of included studies [3]. Criteria for good measurement properties were applied and the quality of evidence was graded by measurement property for each distinctive type of measurement.

Results

Twenty-four studies encompassing eight neurological populations (N=1193) were included in this systematic review. Reliability was assessed by 11 studies and was rated as “sufficient”, with moderate evidence (Table 1). The criterion validity, which was evaluated in seven studies, showed “sufficient” ratings, with high levels of evidence. On the contrary, the structural and the cross-cultural validity were both analyzed by only two studies of poor methodological quality; therefore, the structural validity was rated as “insufficient”, with very low evidence, while the cross-cultural validity was rated as “indeterminate”, so the level of evidence was not graded.

Table 1. Summary of results and quality of evidence of the measurement properties of the BESTest.

Measurement property	N° studies	Results	Quality of evidence
Reliability	11	Sufficient	Moderate
Criterion validity	7	Sufficient	High
Structural validity	2	Insufficient	Very low
Cross-cultural validity	2	Indeterminate	-

Discussion

This systematic review demonstrated that the BESTest has moderate to high levels of evidence for good reliability and criterion validity. However, the methodological quality of studies assessing the structural and cross-cultural validity is not optimal. Further studies are necessary to strengthen the evidence on validity and to assess the methodological quality of the psychometric properties not already investigated in this review.

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Typicality of Neuromuscular Parameters and Energetic Commitment in Sprint: Acceleration, High Speed and Deceleration

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Introduction

The energetics of locomotion in sprint conditions is a crucial topic for sports performance [1,2]. The aim of this study was to detect the differences among acceleration, high speed and deceleration of a neuromuscular parameters and energetic commitment.

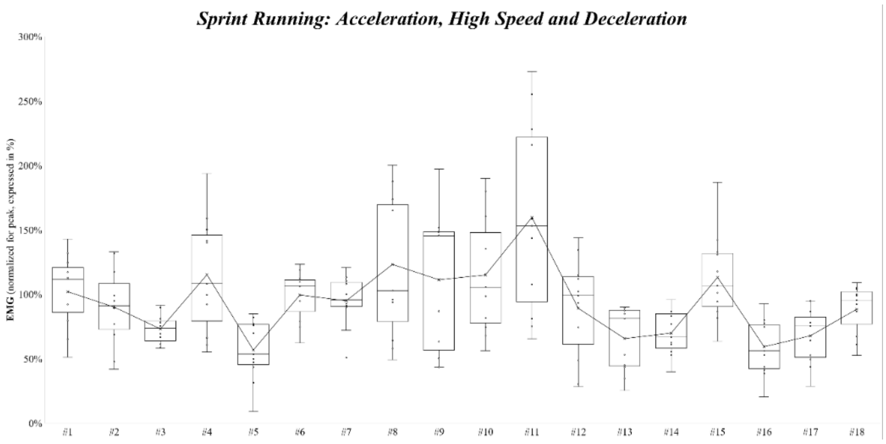
Methods

The data were acquired, during 30m linear sprints, in 18 elite U17 soccer players (mass 64.83kg±3.77, height 174.72cm±5.03) with GPS-IMU Spinitalia v2 and EMG Myontec M-Body 2 resampled at 100 Hz, with electromyography (EMG) signals of quadriceps, hamstrings and gluteus. EMG was normalized respect to the peak value in accordance with Kyröläinen H. et al. 2005 [3]. For the study of accelerations, splits sectioning into 5 thresholds (with percentage change of the target parameter of ≈10% as *cut-off*). For the phase in high-speed running, qualitative peak analysis was considered using a *delta* of no more than Δ3 Km/h (relative to the absolute peak). For the study of decelerations and their splitting, splits were divided into 5 thresholds (of ≈ -10% as *cut-off*), of the speed loss [1,2,3,4].

Results

From maximum acceleration up to loss 10% of acceleration, we obtained 98.95% of EMG value (expressed in % of peak EMG), 10-20% was 110.23%, 20-30% was 117.29%, 30-40% was 123.15%, 40-50% was 126.99%. In high-speed running was 106.16% of EMG value. While, from maximum speed phase up to loss of -10% of speed, we obtained 90.75% of EMG value, to -10 at -20% was 78.74%, to -20 at -30% was 64.38%, to -30 at -40% was 58.96% and to -40 at -50% was 55.30%.

As of maximum acceleration up to loss of 10% of acceleration, we obtained 18.73 for GPS and 49.64 for EMG on energy cost (expressed in $J \cdot kg^{-1} \cdot m^{-1}$), 10-20% was 15.76 GPS and 37.79 EMG, 20-30% was 17.37 GPS and 26.61 EMG, 30-40% was 18.31 GPS and 20.89 EMG, 40-50% was 16.62 GPS and 17.53 EMG. In high-speed running was 6.65 GPS and 7.82 EMG of energy cost. While, from maximum speed phase up to loss of -10% of speed, we obtained 5.15 GPS and 6.79 EMG of energy cost, to -10 at -20% was 5.47 GPS and 6.77 EMG, to -20 at -30% was 6.50 GPS and 6.11 EMG, to -30 at -40% was 7.31 GPS and 6.42 EMG; and to -40 at -50% was 8.11 GPS and 6.60 EMG.



Discussion

From the preliminary data collected, a great typicality of the three types of action seems to be assumed, characterizing different mechanical and energetic implications. However, there seems to remain highly individualized variability.

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Low back pain in powerlifting athletes: an electromyographic assessment of the injury risk

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Introduction

Powerlifting is a maximal strength performance sport including three disciplines, namely squat, bench press and deadlift. Athletes generally undergo high strength training volumes in the pre-competition period, that expose their spines to a mechanical overload, postural compensation and, consequently, low back pain (LBP). In this context, considering the long period out-of-competition due to low back pain, prevention plays a key role. In recent years, in addition to physical examination and medical imaging (X-rays, MRI), innovative tools, such as inertial sensors (IMU) and surface electromyography (sEMG), play a key role, to perform a detailed postural assessment. In particular, the evaluation of the "flexion-relaxation" phenomenon is indicative of an abnormal distribution of the load on the spine and of rigidity of the lumbar area that represent a risk for LBP. [1] Thus, aim of this study is to use motion analysis to evaluate the presence of lumbar muscle activation abnormalities for a personalized diagnostic approach minimizing the injury risk and to reduce recovery time.

Methods

FREEEMG (BTS Bioengineering, Italy) instrumentation and its related "Flex-Relaxation" functional protocol were used to test 41 athletes (Group A) and 33 controls (Group B). The athletes were adults, males and females, with more than 3 years of agonistic experience. The controls, on the other hand, were adults, males and females, practicing regular physical activity, but not engaged in any strength sports. After the application of 4 surface electromyography probes on the lumbar spinal erector muscles at L1-L2 and L4-L5 level and of an inertial sensor placed on 10th dorsal vertebrae level, the subjects were asked to perform an anterior trunk flexion movement, to keep the flexed position for 5 seconds, and to return to the initial position. The collected data were then processed by the EMG analyzer (BTS Bioengineering, Italy) software providing two indices (FRP, flex-relaxation phenomenon and FRR, ratio between energy supplied by muscles during the eccentric contraction and residual energy in retention phase). Moreover, information such as sex, age, weight, height, dominant limb, dysmorphism, previous injuries, chronic diseases, current symptoms, type of occupation (sedentary or not), competition experience, workouts per week, total hours of training per week, personal bests were collected. Statistical analysis was performed using SPSS® software (29th version).

Results

FRP and FRR were more frequently altered in group A compared to group B (FRP: 68,29% vs. 39,39%, p=0,013; FRR: 90,24% vs. 51,52%, p<0,001). Moreover, FRP and FRR showed a moderate association rate, with a contingency coefficient of 0,39 and Cramer's V of 0,43. Furthermore, we found a correlation between FRR and dysmorphism (p=0,003). Among athletes the most altered signals were associated with L4-L5 probes (58,54% left probe and 51,22% right probe) in comparison with L1-L2 probes (41,46% left probe and 39,02% right probe).

Discussion

Competitive Powerlifting could expose athletes to overuse injury. On the other hand, squat, bench press and deadlift are increasingly being recognized as principal exercises in the development of an individual's strength and contribute greatly to lumbar spinal erector muscles hypertrophy, playing a role for both moving and stabilizing the spine. [2] Despite all these benefits, heavy weights, overtraining, and suboptimal training frequency, intensity and volume, could represent a risk factor for low back pain. [3] In this context motion analysis may represent a useful tool to identify, in a pre-clinical phase, those subjects with higher risk of low back pain development for a tailored program of prevention.

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Evaluation of patient slipping in intensive care unit articulated bed: contact pressures and kinematic in healthy volunteers

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Introduction

Patient migration toward foot during stay in intensive care unit articulated bed (bed from now on) leads to abnormal sacral soft tissue loading and pressure injuries [1]. Contact pressure ulcers in bedridden patients cause suffering and costs to society. The main goal should be to reduce pressure at the interface between the patient's body and the mattress by frequent replacement or specific mattress and bed design and articulation [2]. Some solutions have been developed for bed articulation; the most recent is the Patient Anti Slipping System (PAS) patented by Malvestio spa, but its effects on patient migration remains unclear. The present study aimed to investigate the impact of different configurations of bed and mattress on patients' migration and on the contact pressure distributions.

Methods

Three setups were tested: 1. bed with PAS and not-integrated air mattress 2. bed with PAS and integrated air mattress, 3. traditional bed with not-integrated air mattress. Ten healthy volunteers (5 females and 5 males, mean±sd age and BMI respectively: 39.6±10 years, 23.5±4 kg/m^2) were recruited and asked to lay down on the bed while an operator was moving the head of bed in the following subsequent positions: 0°-30°-45°-30°-0°, 0°-45°-0° and 0°-60°-0° inclination degrees. The test was repeated 3 times and the different sequence of inclinations randomly assigned (Fig. 1-top). Level of comfort (questionnaire), pressure distribution (X3display and PX100 mat, Xsensor, Canada) (Fig. 1-bottom right), and 3D hip trajectories (marker on the great trochanter prominence – GT, registered with 4 GoPro Hero 7 cameras and tracked with TrackOnField, BBSoF srl, Italy) were measured in the three setups. Peak and mean pressures, center-of-pressure, contact surface and force data were derived by the pressure distribution. Linear displacement, differences between initial (0°-), intermediate (eg. 45°) and final (-0°) conditions and total path were derived by the 3D trajectories of GT. Comparison among the 3 setup were performed through paired t-test with Bonferroni correction, after evidence of normality.

Results

The GT displacement in setup 2 was significantly lower than the other two setups (Fig. 1-bottom left), as well as the peak of pressure (1. 12±0.8 kPa, 2. 10±0.4 kPa, 2. 14.3±0.8 kPa, p<0.001), while the contact surface was significantly higher in setup 2 (1. 3496±130 cm^2, 2. 4101±114 cm^2, 3. 349±143 cm^2).

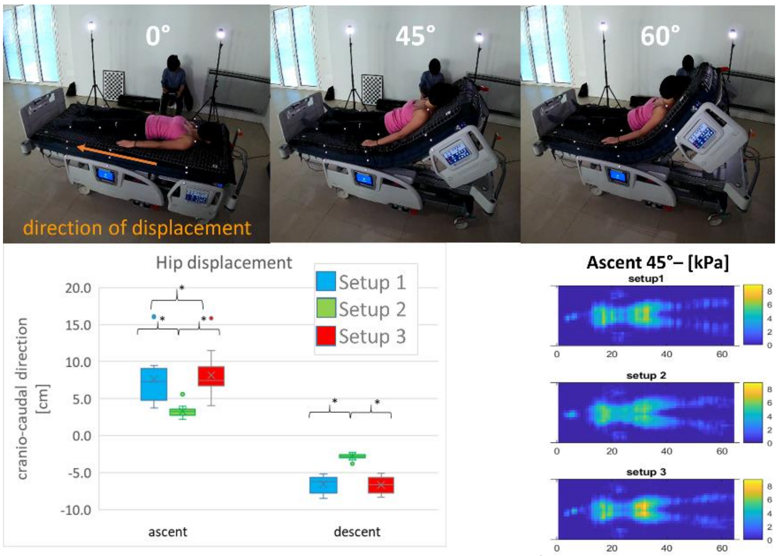

Figure 1. Top: Bed setup and movement. Bottom left: Hip displace-ment in ascent and descent movements with the 3 setups. Bottom right: average pressures maps for the 45° ascent movement.

Discussion

A protocol for assessing the impact of different bed-mattress configurations toward comfort, patient slipping and localized excessive pressure was proposed and applied to test different mattresses-bed configurations. Results showed that setup 2 recorded both lower pressures and migration, associated with an increased contact area. This solution could be effective for reducing uncomfortable slipping in bed and pressure injuries.

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Comparison of sensor fusion algorithms for applications in posturography using MIMU sensors

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Introduction

Balance impairment is a problem that characterizes several pathologies (i.e. neurological disorders, musculoskeletal disorders, diabetes) and can be associated with aging. Posturographic analysis is one of the most common approaches to detect balance alterations through the analysis of center of pressure (COP) or center of mass (COM) displacement [1]. The gold standard instrumentation for posturographic analysis is the force plate, which can be very expensive and cannot be not easily adopted in daily living or ambulatory conditions. However, in recent years magneto-inertial measurement unit sensors (MIMUs) were proposed as a compact and portable alternative [2]. Sensor Fusion Algorithms (SFA) combine two or more types of data from MIMUs in order to make them more reliable, and provide the orientation of MIMUs in 3D space. To date, the main use of MIMU in posturography follows the approach reported in [2]. The purpose of this study was to compare the impact of different SFA, for the reconstruction of body orientation, on posturographic parameters.

Methods

Thirteen healthy subjects (4F-9M, mean±sd age and BMI respectively: 27.5±4.3 years and 22.5±1.8 kg/m^2, shoe size 41.4±1.8) stood for 60 seconds in upright position with open and closed eyes (arms along the body, feet 30° apart assured by through a cardboard triangle, looking at a target at eye level, 5 meters away). Data were simultaneously acquired through a MIMU sensor (Muse, 221e srl, Italy, 100 Hz) applied on the L5, assured through an elastic band, and through a force plate (Bertec corp, FP6040, 200 Hz) as reference gold standard [1,3] and a stereophotogrammetric system (SMART-D, Bts srl, 200 Hz). After a calibration refinement, MIMU data were processed as in [4] for the estimation of the orientation and 10 SFAs applied. Afterwards, the COM and the center of gravity (COG) were computed as in [5]. The root mean square distance (RMS) between the estimated COG and COP trajectories (antero-posterior and medio-lateral separately, Fig.1-top) was calculated in order to find the optimal parameters of the SFAs algorithms and to compare the COP evaluated with the different algorithms. Once the best SFA was found, defined in terms of reliability with respect to the gold standard, the Sway Area and the Sway Path Length [1,6] of the estimated COG position and of the COP were calculated. A timing test was also performed to assess the computational cost of each SFAs.

Results

The LIG algorithm which implements a Kalman filter, resulted in the best solution in terms of RMS, followed by MCF and VAC that are complementary filters. The other SFAs have quite similar performances, the three which recorded the highest RMS, were MCF, EMKF and SEL. The timing test showed that complementary filters were quicker than Kalman ones in general. LIG, MCF, MKF and EMKF resulted in the slowest ones. Taking this also into account, VAC represented the best compromise between reliability in terms of estimation and speed for real-time applications.

Discussion

This study confirmed that carefully choosing the value of each parameter is essential to ensure satisfactory performance for each SFA. At the present stage, the best SFA, in terms of RMS, are also those that require the longest time (LIG and MCF). This could represent a significant limitation for real time applications.

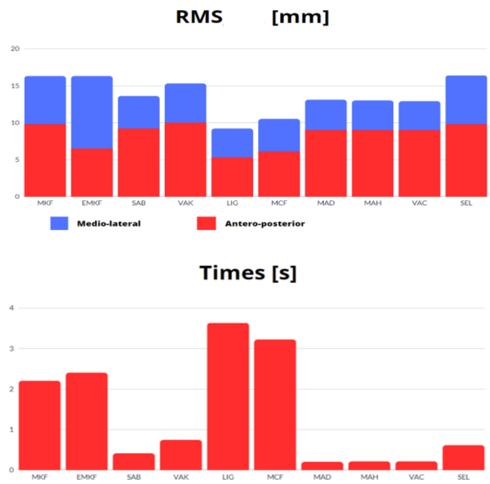

Figure 1. RMS with respect to COP in the 2 directions (top) and computational time (bottom) of the 10 SFAs. Acronyms are reported in [4].

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Multi-parametric monitoring in stroke unit: correlation between EEG based brain networkvariables and actigraphic parameters.

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Introduction

EEG-based brain networks experience complex changes following ischemic stroke. These modifications influence the brain overall balance between local specialization and global integration, known as "Small-worldness" (Sw). However, these specific network changes do not correlate with NIHSS movement subscores. Actigraphy is a tool used to describe limb motor activity. In our previousstudy we demonstrated that some actigraphic parameters, namely Motor Activity (MA) and AsymmetryIndex (AR), correlate with stroke severity [1]. Furthermore, AR can be useful to describe different clinical conditions during the evolution of the acute phase of stroke, throughout the patient's entire stay in the sub-intensive stroke unit [2]. The aim of this study is to verify if the efficiency of motor performance as measured by actigraphy may depend on the specific characteristics of functional cortical network.

Methods

We enrolled 48 stroke patients (22M, 26F; mean age, 72.7 ± 13.4 years) during their Stroke Unit stay for an averaged period of 6 days. Motor activity of both arms were continuously recorded using a programmable actigraphic system (GENEActiv Original, Kimbolton, UK) integrated inside a watch-like case. For each patient the actigraphs were bilaterally positioned on wrists. We calculated the mean values of MA of both arms and AR in the first hour after patient's admission to the stroke unit and everysubsequent hour. We considered for our statistical purpose the mean values of MA and AR in the first hour after admission (T0) and in the last hour before the discharge (T1). The EEG recording (BRAIN QUICK® LTM - SD LTM PLUS 32, Micromed, Italy) was performed with eyes closed in resting state condition for 20 minutes at T0 and T1. Electroencephalographic signals were recorded from 32 electrodes and the sampling rate frequency was set up at 512 Hz. To evaluate the functional cortical network, we calculated mean weighted clustering coefficient (Cw), mean weighted characteristic path length (Lw) and the functional integration Sw in delta, theta, alpha1, alpha2 and beta bands. We used Spearman test to calculate the correlation between brain network variables and actigraphic parameters.

Results

Comparing brain network variables and actigraphic parameters at T0 we found a statistically significant correlation between AR and Cw and Sw in delta band (p=0.037 ρ=0.322 and p=0.030 ρ=0.334, respectively). At T1 we found a statistically significant correlation between AR and Cw in delta band (p=0.039 ρ=0.317). Moreover, at T1 we found correlations between connectivity parameters in delta band and MA of the paretic arm (Cw p=0.005 ρ=-0.434, Lw p=0.002 ρ=0.460 and Sw p=0.002 ρ=- 0.475); between connectivity parameters in alpha1 band and MA of the paretic arm (Cw p=0.018 ρ=0.367, Lw p= 0.009 ρ= -0.403 and Sw p= 0.013 ρ=0.383) and between Lw in beta band and MA ofthe paretic arm (p=0.024 ρ=-0.352). Finally, we found a statistically significant correlation between MAof the non-paretic arm, Lw in delta band (p=0.027 ρ=0.338) and Sw in delta band (p=0.021 ρ=-0.350).

Discussion

Our results demonstrated that motor performance measured by actigraphy is related to specific changes of brain connectivity. During the acute phase of ischemic stroke, higher motor performance is associated with increased local specialization and global integration in physiological alpha band while,in pathological delta band higher motor performance is associated to reduced local specialization and reduced global integration. These findings give new insight on the hypothesis that after an acute stroke,the brain cortex reacts by diffusely modifying its small-worldness in a frequency-dependent modality and that those changes have a role in promoting motor recovery.

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Evaluation of lower limb muscle forces using the Hill-type model and wearable sensors

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Introduction

The estimation of the forces produced by muscles is an aspect of great interest in various fields, such as rehabilitation, human-machine interface or sports, where it is essential to estimate the muscle forces performed on the human movement control system. Since muscles are the engines of human motion, several researchers are studying methods to model muscles in order to simulate human motions (1). The Hill-based muscle model is the most widely used computer model for human movement modeling; it consists of four overall components: the element (CE) represents the active properties of the muscle, the serial elastic element (SE) represents the elasticity of the actin-miosyn crossbridges, the parallel elastic element (PE) represents the passive elastic properties of the muscle fibers, and the tendon (T) captures the elastic properties of the tendon and the aponeurosis combined (2). In our preliminary study, we had the aim to estimate the force of three modelled muscles of the right and left lower leg using surface electromyography and the iFeel technology, a wearable whole-body perception system developed by the Artificial and Mechanical Intelligence (AMI) laboratory of the Italian Institute of Technology, which consists of a network of wearable devices, a pair of sensorised shoes and an AI-based estimation algorithm.

Methods

A healthy subject performed a simple task of dorsi-plantarflexion while electromyographic activity of the tibialis anterior, lateral, and medial gastrocnemius muscles bilaterally was acquired using a wireless surface electromyography system (FreeEMG 1000 System, BTS). We also developed a model of the leg which includes these muscles and whose inverse kinematics was solved from inertial sensors, called nodes, of the iFeel technology arranged bilaterally on the foot, leg and thigh in the sagittal plane. From here we calculated the variables necessary to estimate the muscle forces, in addition to other parameters reported in the literature, following this equation [3]:

$$F^M = \left(aF_0^M F_L^{CE} F_V^{CE} + F_0^M F_L^{PE}\right) \cos\left(\alpha\right)$$

where a is the muscle activation, F_0^M is the maximum isometric muscle force, F_L^{CE} and F_V^{CE} represent the force-length and force-velocity relationships of the contractile element, while F_L^{PE} is the force-length relationship of the passive element. α, instead, represents the pennation angle of the muscle.

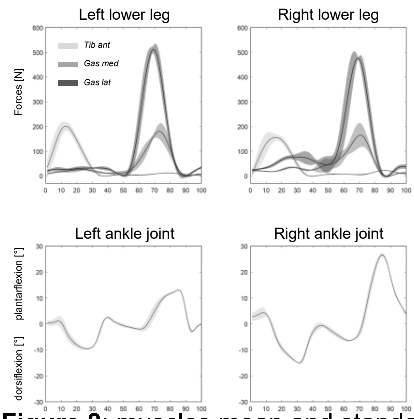

Figure 8: muscles mean and standard deviation forces and joint ankle angles.

Results

Figure 1 shows, for the right and left lower leg, the mean and standard deviation of the forces of tibialis anterior, gastrocnemius medialis and lateralis muscles during three dorsi-plantarflexion cycles. When the tibialis anterior contracts during dorsiflexion, we can see that its force increases, and the ankle angle decreases. Plantarflexion, on the other hand, causes the two gastrocnemii to contract and their forces to increase, while the ankle angle increases.

Discussion

By using wearable sensors, we were able to model the muscles of the lower leg and estimate the forces exerted by them during this preliminary experimental procedure. This first result is important because knowing the muscle forces allows us to estimate also the torques acting on the joints that cause movement.

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Acknowledgement. *The paper was supported by: INAIL ergoCubProject; Italian Ministry of Research NRRP "Fit4MedRob" number PNC0000007; project "RAISE-Robotics" and AI for Socio-economic Empowerment" (European Union NextGenerationEU). The opinions expressed are those of the authors alone and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.*

The influence of the neuropsychiatric symptoms on gait initiation in Parkinson's disease

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Introduction
In recent years the spectrum of non-motor disorders associated with Parkinson's disease (PD) has been fully recognized. Non-motor symptoms include neuropsychiatric symptoms such as depression, anxiety, psychosis, apathy, impulse control disorders. These symptoms occur in the majority of patients with PD [1]. Recent evidences suggest that emotional disturbances may affect anticipatory postural adjustments (APA) and gait in PD [2]. From a motor point of view, it is widely demonstrated that subjects with PD have increased reaction times and reduced displacements of the center of pressure (COP) during APAs [3]. The APA alteration compromises the physiological execution of walking. However, the relationship between these motor deficits and neuropsychiatric aspects has been poorly investigated. Therefore, this study aims at investigating the relationship between APAs and neuropsychiatric aspects in PD.

Methods
Twenty-two subjects with PD (H&Y 2-3, 13 without FOG and 9 with FOG) stood on a dynamometric platform and were asked to initiate gait in response to neutral, pleasant and unpleasant auditory stimuli. As baseline condition, a neutral voice saying 'Start' was used. The experiment took place during the "on" state. The reaction time and COP displacements during the imbalance and unloading phases were calculated from the ground reaction force data [3]. Alexithymia, anxiety, impulsiveness and apathy were assessed by the Toronto Alexithymia Scale (TAS-20), the State-Trait Anxiety Inventory Y Form (STAI-Y TRAIT Dimention), the Barratt Impulsiveness Scale (BIS-11), and the Dimensional Apathy Scale (I-DAS), respectively. Higher scores of these scales indicate greater alterations. Correlation analysis was performed between APA parameters and clinical scales using the Spearman test.

Results
The reaction time to the unpleasant stimuli showed moderate to strong positive correlation with TAS-20 (rho = 0.62, p<0.01), BIS-11 cognitive complexity item (rho = 0.50, P = 0.02) and I-DAS (rho=0.44, P = 0.04) (Figure 1). In the sagittal plane, during the imbalance phase, COP displacement showed moderate negative correlations with the TAS-20 (rho = 0.50 P =0.03), STAI-Y2 (rho = 0.54 P = 0.01) and BIS-11 motor impulsiveness item (rho=0.57, P = 0.01) after the listening to the unpleasant stimuli.

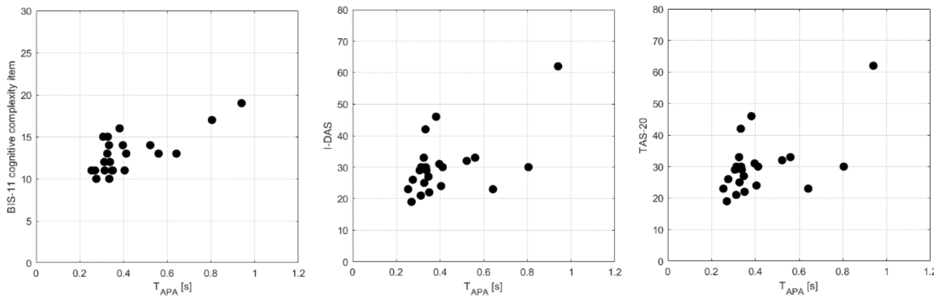

Figure 1. Scatter plots of reaction time and BIS-11 CC item, I-DAS and TAS-20.

Discussion
The main deficits of subjects with PD during APAs, i.e. the increased reaction time and reduced COP displacements, showed good correlations with the neuropsychiatric symptoms, the higher motor alterations the higher neuropsychiatric symptoms severity. In particular, our findings highlighted that an altered understanding and regulation of emotions, increased anxious traits and greater inclination to act without thinking have negative effects on reaction time and COP movements during the gait initiation in PD. The results of this study suggest that a combined approach on motor and non-motor symptoms treatment could be more effective to improve walking deficits in PD.

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Outcome assessment in musculoskeletal tumors and tumorlike lesions: a case-study investigation through a sensor-based mobility assessment

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Introduction

Sarcomas are rare malignant tumors that affect bones and soft tissues [1]. The different body areas in which sarcomas arise (mainly the lower limbs), and the different limb salvage procedures make sarcoma patients highly heterogeneous [2]. Hence, a standard rehabilitation protocol might be less effective in this population. To monitor the recovery of the patient's mobility after intervention, clinicians make large use of qualitative questionnaires [3]. Objective measurements obtained through wearable inertial measurement units (IMUs) can be easily embodied in the clinical routine, offering the clinicians an in-depth patient' description and supporting tailored rehabilitation protocols. In this study, we aimed at exploring the use of an IMU-based protocol to support the pre/post assessment of a patient undergoing lower limb salvage surgery.

Methods

The patient was a 25-year-old female affected by a squamous cell carcinoma of the foot sole, treated with a wide excision. The patient was tested preoperatively (Pre) and 6 months after surgery (FU6). A set of 15 wearable sensors (OPAL, APDM Inc., 128 Hz) was used to track motion during three motor tasks: a linear 10m walking test performed at a self-selected speed, a Timed Up&Go test (TUG), and a posturographic test. Spatiotemporal parameters for walking trials and typical TUG and posturographic parameters (see Figure) were extracted using the Moveo Explorer® software.

Results

The 10m walking test parameters in Pre and FU6 conditions displayed similar results. Results of TUG and balance tests are reported in Figure; values are represented as a percentage difference regarding the available mean normative values (grey line corresponding to 0%). In brackets, Pre and FU6 absolute values of the test parameters.

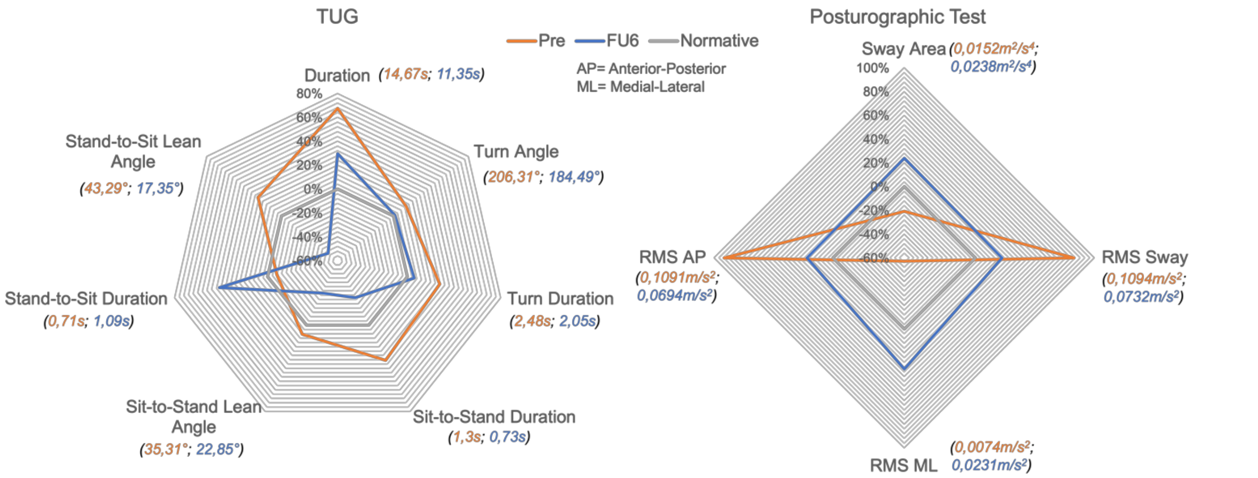

Figure. TUG and posturographic results plots. A higher positive percentage with respect to reference values (grey line) describes a worsening in mobility outcome results.

Discussion

While walking data doesn't exhibit changes after limb salvage surgery, TUG results show a general improvement, except for the stand-to sit duration. Observed together with the great reduction of the stand-to-sit lean angle, it might refer to a different motor strategy characterized by a better control of the chair sitting phase. Balance results show a partially restored normal pattern without the AP/ML asymmetries observed in the Pre condition, and attributed to changes in foot support after surgery.

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Innovative motor and cognitive dual-task for mild cognitive impairment early detection

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Introduction

Alzheimer's Disease affects circa 47 million individuals and is projected to increas. Mild cognitive impairment (MCI) is an intermediate stage between healthy and pathological aging, with a high risk of progressing to dementia. Due to its potential as a target for pharmacological and cognitive intervention, early detection of MCI has become crucial. While cognitive impairment is the primary clinical characteristic of MCI, patients may also experience motor dysfunctions [1]. This study aims to identify clinical markers for the early detection of cognitive decline by expanding the standard motor and cognitive dual-task (MCDT) framework and examining the impact of increasing cognitive loads (CLs) on the dual-task (DT) performance of cognitively normal adults (CNA) and MCI patients.

Methods

36 older adults were included in this work (19 MCI and 17 CNA). The alternate tapping of the index and middle finger on the thumb (ALFT) was used as an alternative MCDT, performed both in single and DT condition. In the DT condition, participants simultaneously performed the ALFT task while counting backwards by 1, 3, and 7 (referred to as cognitive loads CL1, CL2, and CL3). We used wearable inertial modules to record the signals and extract kinematic features from the wrist and fingers [2]. We extracted 14 kinematic parameters (*e.g.*, number, velocities, and amplitudes of the taps) and 2 cognitive parameters (number of answers and errors). By comparing the performance under different conditions, both between and within groups, the dual-task cost (DTC) for each CL was calculated [3], obtaining DTC1, DTC2, and DTC3, using the parameters from CL1, CL2, and CL3.

Results

CNA and MCI subjects were paired for age (Mann-Whitney U test, $p = 0.76$) and for gender (χ^2 test, $p = 0.49$). Kinematic parameters of CNA and MCI were compared across all DTCs. Statistically significant differences were found: i) at DTC1, between the number of taps of the index and the middle finger ($p < 0.05$, Cohen's $d = 0.75$ and 0.91); ii) at DTC2, between the number of taps of the middle finger ($p < 0.05$, $d = 0.70$); iii) at DTC3, between the interquartile range (IQR) of the opening velocity of the middle finger and the median amplitude of the middle finger tapping ($p < 0.05$, $d = 0.76$ and 0.69). At DTC2, the number of taps performed with the index finger, although not statistically significant, showed a medium effect size ($d = 0.62$) between groups. Regarding the number of cognitive answers, CNA subjects performed significantly better than MCI subjects ($p < 0.01$ at CL2 and CL3, $d = 1.06$ and 1.68). Although not reaching statistical significance at CL1, there was a trend indicated by a medium effect size ($d = 0.73$). However, the number of errors across the CLs did not differ between CNA and MCI.

Discussion

Quantitative differences in motor performance between MCI subjects and CNA resulted from this study. At CL1 and CL2, MCI individuals performed a lower number of taps than CNA, whereas at CL3, taps were equal but MCI subjects significant increased variability in tapping velocity and decreased movement amplitude. Also, MCI subjects cognitively performed worse than CNA and the gap between groups widened as the CL increased. Notably as the CL increased, the number of cognitive responses decreased for both CNA and MCI. However, for MCI, there was a substantial gap between CL1 and CL2, while between CL2 and CL3 there is a sort of floor effect. At CL3 MCI subjects showed a stable number of taps if compared to CL2. This effect potentially indicates a motor plateau. However, the cognitive system overload, indicated by the lower number of cognitive responses, affected the movement characteristics. In conclusion, our aim was to expand the MCDT framework by exploring alternative approaches to the standard protocol for identifying individuals at risk of developing dementia. Compared to the gold standard MCDT walking test, the proposed protocol makes the MCDT more accessible to bedridden subjects and applicable in various clinical and experimental settings. Therefore, incorporating simpler tasks and modulating their cognitive and motor difficulties could help identify a sweet spot for early identification of cognitive impairment.

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Overground exoskeleton for gait training in children with cerebral palsy: a pilot study

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Introduction

Cerebral Palsy (CP) is the most common cause of chronic motor disability in children [1], affecting 2.11% of new-borns [2]. Neuromotor rehabilitation is the main intervention for CP as it stimulates the learning of specific motor functions. Robot-Assisted Gait Training (RAGT) has been widely employed as a rehabilitative treatment of neurological adults: however, literature on the paediatric population lacks. [3]. The aim of this pilot observational study is to assess the effects of RAGT based on a paediatric overground exoskeleton in children with CP, assessed by Gait Analysis (GA).

Methods

The study includes 5 subjects with the following inclusion criteria: diagnosis of CP; age 4-12 years; Gross Motor Function Classification System (GMFCS) level from I to IV; ability to understand instructions; and informed consent signed by parents. Exclusion criteria: severe osteoporosis; compromised skin integrity; hip and knee flexion >20°; absence of medical permission for loading at standing position. Every patient conducted 6 sessions of RAGT with a pediatric overground exoskeleton (ATLAS 2030, Marsibionics, ES). The participants were assessed before (T1) and after (T2) the treatments with a motion capture-based GA (Smart-DX, BTS Bioengineering, IT). The primary outcome of the study is the Gait Deviation Index (GDI), a parameter that represents the overall gait pathology in patients with spastic CP [4]. The secondary outcomes are: % of double support, swing, and stance phases; average speed (m/s); step width and length (m); hip and knee Gait Variable Score (GVS) [5]. At T2, a technology satisfaction questionnaire is administrated to the therapist, parents and participants.

Results

Three patients were recruited (GMFCS=3.33±1.15) of which 2 are still in treatment. The results of the child who concluded RAGT are shown in *Table 1*. At T1, the GDI was 78.03±0.85 (right) and 83.11±2.65 (left). The spatiotemporal parameters registered a reduced walking speed, a high % double support phase, reduced step length, and high step width. At T2, the GDI (right: 84.08±0.38; left: 85.13±1.82) and the step length increased, while the step width decreased. The knee GVS registered an improvement on the right limb only while the hip GVS in both limbs. The technology satisfaction questionnaire showed a positive feedback.

	GDI dx;sx	Stance phase dx;sx [%]	Swing phase dx;sx [%]	Double support phase dx;sx [%]	Average speed [m/s]	Step width [m]	Step length dx;sx [m]	Knee GVS dx;sx [deg]	Hip GVS dx;sx [deg]
T1	78.03±0.85; 83.11±2.65	76.56±1.09; 77.94±2.52	24.06±0.47; 22.06±2.52	26.2±0.5; 27.11±2.18	0.2	0.23±0.01	0.36±0; 0.36±0.01	19.5±0.9; 13.5±1.5	12±0.7; 14.4±2.9
T2	84.08±0.38; 85.13±1.82	74±0.43; 79.29±0.42	26.42±0.1; 24.17±2.84	25.21±1.56; 25.52±0.23	0.2	0.18±0.02	0.37±0.02; 0.38±0.01	13.3±0; 17.6±1.7	8.1±0.4; 6.5±0.3
Normality	**>100**	**57.97±1.93**	**42.03±1.93**	**12.4±2.21**	**1.2±0.2**	**0.08±0.04**	**1.13±0.01**	**<7**	

Table 1. *Gait analysis results*

Discussion

This pilot observational study is the first attempt to assess the effects of RAGT based on a paediatric overground exoskeleton in children with CP. The primary outcome showed improvements in gait kinematics: the GA parameters evidenced greater stability at the end of the RAGT. The patient well-accepted RAGT and showed great motivation during the treatment. The analysis of further subjects will help to understand the feasibility of RAGT in the paediatric population with CP.

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Instrumental gait assessment in early-stage multiple sclerosis

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Introduction

Multiple Sclerosis (MS) is a neurodegenerative disease characterized by various symptoms, including gait deficits and fatigue perception. These symptoms are often reported by individuals even in the initial stages of the disease. The aim of this study is to identify gait parameters that differ between controls and people with MS who have an Expanded Disability Status Scale, EDSS <= 1.5. Additionally, the study aims to determine which of these gait parameters have prognostic value in predicting disease progression at 1 year follow-up.

Methods

Twenty-five controls (HC) (15 females, average age 27; 10 males, average age 33.9; overall average age 30) and 22 MS patients (15 females, average age 36; 7 males, average age 36; 3 individuals with Baseline EDSS=0, 9 with EDSS=1; 10 with EDSS=1.5) performed the six-minute walking test on an instrumented treadmill (C-mill *Motek*). The patient group assessed at baseline (T0) repeated the tests after one year (T1). The test was performed with a pelvis-worn triaxial IMU (*Gyko, Microgate*) placed at the L5 level. Vertical force, moments and center of pressure coordinates (Fz, Mx, My, COPx, and COPy) were acquired. Functional calibration movements and synchronization signals were acquired at the beginning of every trial. Stride segmentation of inertial signals was performed using Zijlstra algorithm [1]. Signals were split into 1-min segments. The following features were computed for each minute: root mean square for each variable (RMS), stride regularity (Ad2) (variability domain), improved Harmonic Ratio-iHR, step regularity (Ad1), symmetry index (Sym) (symmetry domain), MultiscaleSampleEntropy (MSE, complexity domain), LyapunovExponent (LyE, instability domain), median frequency for Acceleration and Fz signals, median Fz power, total power (Ptot) and frequency quotient (FQ) for each variable (frequency domain).

Results

We observed significant differences in HC vs MS at T0 (p-value=<0.05) in: MSE calculated over mediolateral acceleration, Fz, COPx, COPy RMS, Ptot and FQ for Fz and anteroposterior acceleration; statistically significant differences in comparing HC and MS at T1 in the following metrics: LyE, RMS for COPx, acceleration in the 3 directions and for acceleration modulus, Sym, Fz median power, Ptot, FQ . Our instrumentally-extracted parameters showed statistically significant differences in MS patient at T0 vs T1: LyE, RMS for COPx, COPy, acceleration in the 3 directions and for acceleration modulus, Sym, median Fz power, median Fz frequency, Ptot, FQ [Figure 1]. Among patients at T1, only one person showed a clinically significant increase of EDSS.

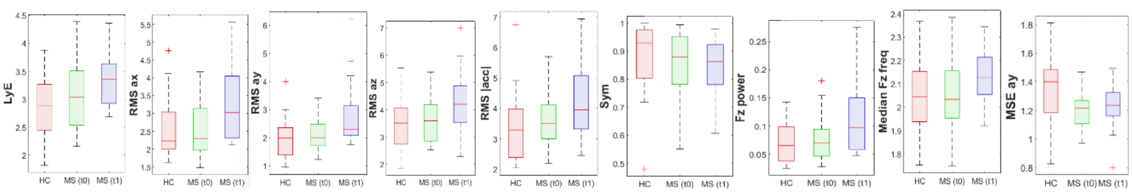

Figure 1. Box plot of significant parameters computed for minute 4. Red=HC, green= MS at T0, blue=MS at T1.

Discussion

Despite that clinical assessment by EDSS was not able in detecting a clinically relevant decline in this group of patients, the instrumental one confirmed a statistically significant deterioration at T1. Moreover, differences between MS and HC were significant at T1 and for some of the parameters at T0. These preliminary results, which are in line with earlier findings in this field on more severe MS patients [2] encourage our research in this direction. Our next steps will involve the investigation of instrumental-derived parameters that can explain a deterioration among patients. This will be done by retrieving additional information about the patients' clinical assessment and analyzing biomechanical parameters at T0 that can be candidates for prognostic prediction.

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Role of the flexion-relaxation phenomenon on the risk of low back pain in powerlifters: a proof-of-concept study

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Introduction

Powerlifting is considered as a discipline of competitive weightlifting, which places the column under continuous stress; it is suggested that excessive back arching could subtend to low back pain. In this scenario, the flexion relaxation phenomenon (FRP) commonly refers to the paraspinal muscles' myoelectrical silence during full trunk flexion. This phenomenon has been extensively reported in asymptomatic individuals, but it is absent in low back pain (LBP) [1]. This study aimed to evaluate the risk profiles for LBP via the role of flexion relaxation phenomenon in subjects undergoing powerlifting.

Methods

Healthy male professional powerlifters (93kg category) with at least three years of competitive experience without acute LBP were included in the study. Then, we stratified the sample as high-risk for the subjects with an anamnestic history of LBP. As an outcome, during 1 repetition at 85% 1RM bench press, the arched back was measured with video-captured open-source software (Kinovea v0.9.5) to obtain the distance between the bench and the lumbar spine. Moreover, the trunk flexion-relaxation was performed by asking the participant to slowly flex the trunk forward to full flexion, pausing, and then returning to the starting position. The sEMG signal coupled to an inertial sensor was collected to quantify the flexion-relaxation ratio (FRR), dividing the maximal sEMG data during flexion by the sEMG during maximum voluntary flexion (MVF); moreover, we assessed measure arched back (ARCH).

Results

We included 18 male powerlifters, mean aged 28.4±12.1 years, with weight of 86.00±5.05 kg. Out of them, 11 were at high risk and 7 at low risk of LBP. Main results were represented in Table 1.

Table 1. Characteristics of participants

	Low Risk (n=11)	*High Risk (n=7)*	*p-value*
ARCH	6.47±0.6	7.51±1.2	*0.113*
MVF	6.78±1.3	4.42±0.5	***0.025***
FFR	10.29±1.82	8.63±2.1	*0.062*

The group at low-risk of LBP reported an overall ARCH of 6.47±0.6 cm compared to the high-risk group (7.51±1.2 cm) with a not significant mean difference (p=0.113). In turn, the MVF was significantly different in the two groups (Overall: Low risk= 6.78±1.3 µV versus High risk= 4.42±0.5 µV; p=0.025). Curiously, no significant differences were reported in the FRR ratio between the two groups (Overall: Low Risk:10.29±1.82 versus High Risk:8.63±2.1; p=0.062). Moreover, lumbar arched back measurement data did not report any association with low back pain risk index (p=0.642). Regarding the MVF value, there is a linear relationship with the presence or absence of LBP risk (p=0.023); in parallel for the FRR ratio, there is a significant correlation with the risk (p=0.021)

Discussion

Taken together, our findings reported a strong activity in maximal trunk flexion in the two groups, as both reported the upper threshold at 3.2 uV [2]; conversely, the FRR indices were higher than 9.5 [2], considering the presence of the protective phenomenon, exclusively for the low-risk group. This could suggest that although there is no significant myoelectric silence in MVF, the powerlifter's trunk still manages to compensate for the flexion gesture by achieving a protective FRR. Furthermore, it does not appear that an arched back affects the risk of low back pain, such as the absolute MVF value or especially the FRR ratio [3]. In light of these findings, future prospective studies could focus on the compensatory effects of the powerlift with respect to no myoelectric silence in maximal flexion, but a protective ratio of flexion relaxation in athletes with low risk of LBP.

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Neuromodulatory contribution to muscle force is reduced after 10 days of unilateral lower limb suspension

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Introduction

Skeletal muscles disuse has a profound impact on the health of the neuromuscular system. The primary consequence of muscle disuse is a loss in muscle force generation capacity. While numerous alterations in muscle properties occur after disuse, several authors suggested that neural factors have a major role in the loss of strength [1]. However, little is known about the changes in neural drive after disuse. The objective of this study was to investigate the adaptations in neuromodulatory input due to a short-period of unilateral lower limb suspension and after an active recovery period based on resistance exercise training. Persistent inward currents (PICs) are an intrinsic property of motoneurons responsible for prolonging and amplifying the synaptic input proportionally to the level of neuromodulation [2]. We hypothesized that muscle disuse associated with unilateral lower limb suspension would reduce the level of neuromodulatory input as expressed by PICs amplitude.

Methods

In 10 young adults, we first assessed the maximum isometric voluntary contraction (MVC) pre- (LS0) and post-10 days of unilateral lower limb suspension (LS10), and following 21 days of active recovery (AR21). At each time point, we also recorded high density surface electromyographic (HD-EMG) signals from vastus lateralis (VL) during isometric ramped contractions at 25% of MVC. Then, we decomposed the HD-EMG signals into motor units discharge times using the validated convolutive blind source separation technique [3]. PICs were estimated from motor unit firing rates using the paired motor unit technique [4], by measuring the difference in firing rate behavior (ΔF) of lower threshold control units at recruitment and derecruitment of higher threshold test units. Linear mixed models and post hoc tests were used to examine the effect of each condition (LS0, LS10 and AR21) on MVC and ΔF.

Results

Compared to LS0, MVC decreased at LS10 (-29.77%, $p<0.001$) and returned to LS0 values at AR21. The values of ΔF were reduced at LS10 with respect to LS0 (-31.27%, $p<0.0001$) and AR21 (-30.03%, $p=0.0001$), while the AR21 period was sufficient to reestablish the values at LS0 (Fig. 1).

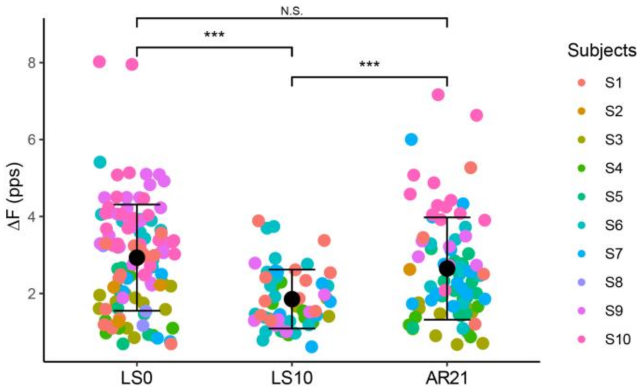

Figure 1. Each colored dot represents the ΔF value (in pulse per second, pps) of an individual test unit at LS0, LS10 and AR21. When considering all participants, the linear mixed model revealed a significant decrease ($P < 0.0001$) in ΔF from LS0 to LS10 and from AR21 and LS10. Means (black dot) and standard deviations are also indicated.

Discussion

These results suggest that the level of neuromodulatory input, as expressed by PICs estimates (ΔF), is reduced by muscle disuse. The consequent reduction in motor unit discharge frequency may in turn contribute to the loss of force production. Further studies may address whether treatments targeting the neuromodulatory system could attenuate the negative impact of muscle disuse in several conditions, such as ageing, prolonged hospitalization due to injuries or diseases, or as a consequence of space flight in astronauts.

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Study of neuroplasticity by high-density EEG in post-stroke patients following robot-assisted upper-limb rehabilitation

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Introduction

Stroke is the second leading cause of death and the leading cause of disability in the world. Robotic therapy is a well-established approach for upper limb rehabilitation, contributing to an increase in the amount and intensity of therapy and standardization of treatment [1]. In recent years, an increasing number of end-effector robots have been developed for the treatment of the upper limb [2], while only a bilateral exoskeleton, which allows a choice between unilateral treatment on the paretic limb and bilateral treatment, is currently available. In addition to clinical assessment, monitoring of brain electrical activity, using Electroencephalography (EEG), has emerged as a widely accessible and versatile tool for longitudinal assessment of patients with stroke outcomes. The proposed study is an RCT aimed at evaluating recovery in patients with stroke outcomes after unilateral or bilateral robot-assisted upper limb rehabilitation using a quantitative index based on high-density EEG (hd-EEG).

Methods

Nineteen patients with ischemic stroke in the subacute phase (mean time since stroke onset 3±1 months) were recruited. Subjects underwent a 30-session upper limb neurorehabilitation program using the Arm Light Exoskeleton Rehab Station (ALEx RS). Each patient was randomly assigned to the experimental group (bilateral treatment) or the control group (unilateral treatment). In addition, evaluation was performed by hd-EEG at the following time points: before the start of the first game session (T0), immediately after the end of the first game session (T1), at the end of the 30 treatment sessions (T2), and at the 1-week follow-up (T3).

From the acquired EEG data, the Brain Symmetry Index (BSI), one of the most widely used electroencephalographic parameters in research for the purpose of stroke prognosis, was calculated [3]. The BSI is a metric that quantifies the symmetry of Power Spectral Density (PSD) between the two cerebral hemispheres.

A statistical analysis was conducted on the whole group of patients to assess the changes in brain activity induced by rehabilitation treatment. Specifically, BSI index values obtained before (T0) and after (T2) the intervention were compared by a two-way repeated measures Analysis of Variance (ANOVA), with time (2 levels: T0 vs T2) as the intragroup factor, and treatment group (2 levels: unilateral vs bilateral) as the intergroup factor. The analysis was performed considering the eyes open and eyes closed conditions, separately.

Results

Statistical analysis showed an increase in the symmetry between the cerebral hemispheres (injured and healthy) following rehabilitation treatment in both the eyes open and eyes closed conditions (p=0.006 and p=0.01, respectively). This trend showed no difference in the two groups (unilateral vs bilateral), being the *timeXgroup* interaction factor statistically non-significant in both conditions (p=0.499 and p=0.997, respectively).

Discussion

The results show a progressive "normalization" of symmetry between the two cerebral hemispheres (injured and healthy) following robotic rehabilitation treatment. This balancing of interhemispheric symmetry is also accompanied by a clinical improvement in the upper extremity. The results, therefore, show the change in the index over time following the intervention, suggesting its use as a means of investigating the mechanisms of neuronal plasticity involved in stroke rehabilitation.

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Assessment of rehabilitation treatment efficacy in multiple sclerosis patients using wrist mounted IMUs: preliminary results during daily living activities.

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Introduction

Multiple sclerosis (MS) is one of the major causes of disability among young and middle-aged adults [1], leading to different motor disorders. Among these, upper limb impairments can significantly impact the ability to perform daily life activities (ADL), with important consequences on the quality of life. In this context, the identification of optimal rehabilitation treatments is fundamental to slow disease progression and preserve motor functions. To this end, inertial measurement units (IMUs) can be used to quantify the eventual progresses due to a rehabilitation treatment, helping the clinician in assessing its efficacy in real-life. This study aims at exploring the feasibility of an innovative protocol based on the use of IMUs to detect mobility changes during ADL in MS patients treated with different rehabilitation interventions, and to evaluate the efficacy of a functional treatment with respect to the others.

Methods

Eleven MS patients (4 male; 41.3±11.5 years old, EDSS 2–3.5) were equipped with three IMUs positioned on the lower back and right and left wrist. The motor assessment involved the execution of six activities of daily living in a predetermined sequence (wash floor, transfer light, laundry, meal management, clean a surface, and climb stairs), in two sessions (before and after undergoing the rehabilitation intervention). Specifically, four patients underwent a comprehensive intervention including both muscle reinforcement and functional exercises; the remaining underwent either only muscular strength or cardio training, or a combination of both (referred to as *Others*). Activity segmentation was automatically performed for each session using the lower back IMU; then, for each activity, five parameters were extracted from wrist-IMUs data to quantify right and left upper limb mobility: Standard Deviation of acceleration peaks (STD), Peak per Second (PPS), Mean Peak Acceleration (MPA) [2], Log Dimensionless Jerk (LDLJ) [3]. For each parameter, inter-session variations were quantified as the difference between the values obtained before and after the treatment ($V_{post} - V_{pre}$). A threshold of 0.30*V_{pre} was used to determine, for each activity and subject, if there was a consistent improvement. Finally, the average number of improvements was computed across the subjects of each group for each activity and parameter. In addition, statistical analysis was performed to detect significant differences between the two groups for each parameter-activity case.

Results

Results are shown in Figure 1. STD showed improvements in all activities in the functional group and in four tasks in the *Others.* PPS exhibited improvements in four activities only for functional group, while Peak Ratio showed improvements in only two activities for the *Others*. LDLJ did not show improvements for both treatments, whereas MPA showed improvements in all activity in both groups. Statistical analysis evidenced a significant difference between the two groups only for clean surface task in STD parameter.

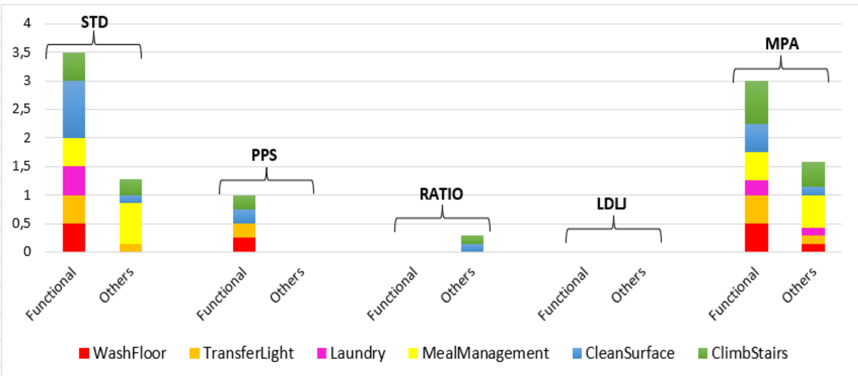

Figure 1. Comparison of functional group and *Others* in terms of averaged improvements for each parameter-activity.

Discussion

The here-presented preliminary results support the feasibility of the proposed protocol for an ecological evaluation of upper limb mobility during ADL using IMUs on MS patients. As expected, functional-based treatment contributed to improvements in more activities, especially in STD, PPS and MPA parameters. However, a statistically significant difference was observed for one activity only, probably due to the limited number of observations. Further analysis on a larger number of subjects is required to confirm these findings.

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Identification of asymptomatic neuropathy in diabetic patients from static posture data

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Introduction

Diabetic neuropathy is a common complication of type-2 diabetes, affecting peripheral sensory perception, thus impairing motor stability and capabilities during static and dynamic tasks [1]. The early identification of the presence of neuropathy is valuable in order to enact timely therapeutic strategies. Static posturography is widely used in clinical contexts since it can be easily performed also by patients affected by neuro-musculoskeletal diseases, providing valuable insights on motor control strategies and functional disorders. Here, a machine learning based procedure is presented for recognizing asymptomatic condition of diabetic neuropathy, based on center of pressure (CP) recordings.

Methods

For this study 36 non-neuropathic diabetic patients (NND) and 36 neuropathic asymptomatic diabetic patients (ADN) were enrolled. Presence of neuropathy was assessed by the motor and sensory nerve conduction velocity [1]. Patients maintained balance (eye closed) for at least 120 s. From CP anterior-posterior (CP_{AP}), medial-lateral (CP_{ML}) components, and the statokinesigram (CP_{SK}), three feature sets were extracted: the balance descriptors (UNF) reported in [2], the stabilogram diffusion function indexes (SDFF) [3], and the recurrence quantification analysis (RQAF). Then, classification performances of each feature set were tested for C_{AP}, C_{ML}, and CP_{SK} through a *k*NN classifier. In the first step, for each feature set, the CP component that gave the best classification results was retained for further analyses. As second step, a backward feature selection was applied to each selected feature set. Finally, a majority voting approach was used: final decision was based on the output of the three *k*NN classifiers, fed by the three best feature sets selected from the first step. Leave-one-subject-out was used.

Results

For each feature set, classification accuracy showed the best results when CP_{SK} was considered, providing a 77.8%, 76.4%, and 79.2% accuracy for UNF, SDFF, and RQAF respectively (Fig. 1). Feature selection retained 2 features from the UNF and SDFF sets, and 4 features from the RQAF set, enhancing the performances of the *k*NN classifier (Fig. 1). The ensemble of the three *k*NN models provided 93.1% accuracy when feature selection was applied (Fig. 1).

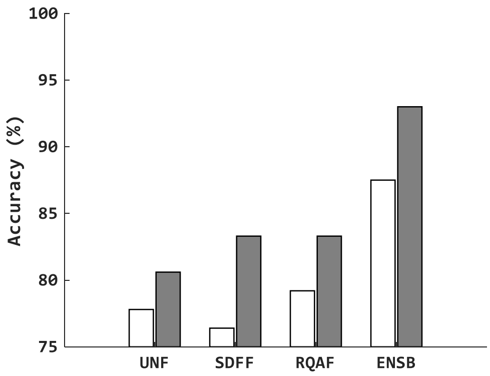

Figure 1: Classification accuracy for the three features sets and the ensemble method. The features were computed on the CP_{SK}. White bars indicate accuracy without the backward feature selection whereas grey bars report the accuracy when feature selection procedure was employed. ENSB indicate ensemble methodology.

Discussion

Outcomes showed that CP_{SK} provides the best information, irrespective of the feature set, for distinguishing between NND and ADN patients. Furthermore, the ensemble of the three classifiers trained on the three proposed feature sets dramatically improved the classification performances (Fig. 1), with only 3 ADN and 2 NND being misclassified (sensitivity 91.7% and specificity 94.4%). The proposed solution can be useful for supporting the early diagnosis of diabetic neuropathy in a non-invasive way, relying on a simple motor task that does not require cumbersome instrumentation or prolonged recording sessions.

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Rhythmic acoustic stimulation reduces gait variability in elderly subjects: a network-based analysis

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Introduction

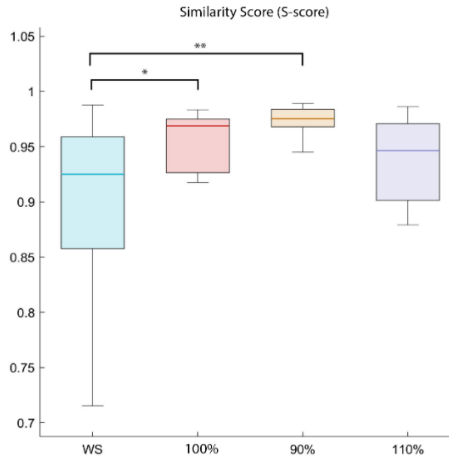
Ageing brings impaired motor control and consequently increased variability of gait kinematics, which in turn leads to a high risk of falling. There are numerous studies investigating strategies to improve motor control in the elderly. Among these, rhythmic acoustic stimulation (RAS) seems to have an important effect, although further investigations are needed. A study by Minino et al. (2021) analysed the gait of the elderly subjects with different frequencies of RAS, showing that RAS with stimulation frequencies based on the average cadence of the subjects has a positive impact on dynamic balance [1]. However, the study, did not show difference in the gait variability, in terms of spatio-temporal parameters. Therefore, the aim of our study was to assess whether a RAS was able to reduce gait variability in a group of elderly subjects, taking the whole body into consideration, through a network analysis-based approach.

Methods

12 healthy individuals from 65 to 85 years old were recruited. The 3D-GA data were acquired through a Stereophotogrammetric system, and 55 passive markers were positioned on anatomical landmarks of the whole body. We recorded the participants' walking in 4 experimental conditions: simple walking (SW); walking with RAS at a frequency corresponding to 90%, 110% and 100% of the mean cadence of the single individual. Considering the body as a network, whose nodes are represented by anatomical landmarks and connections are determined by the level of kinematic synchronisation between each pair of nodes, we constructed subject-specific covariance matrices (i.e., kinectomes) [2]. For each participant, we correlated the kinectomes of the gait cycles within each experimental condition separately, resulting in a similarity score. Subsequently, the experimental conditions were compared to SW, using Friedman's test, and Wilcoxon signed-rank test.

Results

The comparison of the Similarity Score (S-score) between the different experimental conditions showed significant differences. In particular, the S-score of the experimental conditions of the RAS with 100% and 90% of the average cadence were statistically greater than the S-score of the SW ($p = 0.018$ and $p = 0.007$, respectively). No statistically significant difference was found in the comparison between SW and the RAS at 110% of the average cadence ($p = 0.07$).



score of SW with the 100%, 90% and 110% RAS frequencies. p value:

Discussion

The results showed that the S-scores of the experimental conditions are higher than the SW. Indeed, although the RAS at 110% of the average cadence did not statistically differ from SW, we observed a statistical trend. This suggests that RAS induces a reduction in movement variability. This finding seems to be in disagreement with the literature [3].However, the spatiotemporal parameters do not take into consideration the relationship of the different parts of the body, but only the motor output relative to the lower limbs, losing information. In conclusion, this preliminary study emphasises the importance of new methodological approaches to assessing movement variability, taking into account the whole body and not just parts of it, both in physiology and in movement impairment.

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Distribution of plantar pressures during stance and gait in patients with incomplete spinal cord injury

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Introduction

Spinal cord injury (SCI) can affect postural stability due to lesions of either or both motor and sensory pathways leading to a significant limitation in ambulation. It is well known that in healthy subjects (HS), during gait, plantar pressure is unevenly distributed under the footsole with higher pressure at the metatarsal bones and heel [1]. We have shown that in HS foot pressure distribution is similar during quiet stance and gait [2] suggesting that it is possible to estimate pressure distribution during gait from their distribution during quiet stance. In the present study, we have assessed foot pressure distribution during quiet stance and gait in patients with SCI (PwSCI) and compared the results with those in HS.

Methods

We enrolled 22 PwSCI (5 women) with incomplete lesion (AIS D), aged 57.8±14.7 years and 22 age- and sex-matched HS, aged 58.0±14.9 years. All PwSCI were capable to walk autonomously without aids. Plantar pressure was recorded during quiet stance and gait with a 4-m long baropodometric walkway (P-walk, BTS, Italy). Each subject performed two trials for each condition (quiet stance with eyes open, EO, and closed, EC; and gait). Surface of the centre of pressure (CoP) ellipse and path length of CoP were recorded with EO and EC for 30 s. Foot plantar pressure was recorded from 10 areas of the footsole: T1, big toe; T2,3,4,5, toes 2 to 5; M1, metatarsal 1; M2, metatarsal 2; M3, metatarsal 3; M4, metatarsal 4; M5, metatarsal 5; MF, midfoot; MH, medial half of heel; LH, lateral half of heel. Mean peak plantar pressure (kPa) of both feet were extracted during quiet stance and gait. Within each group, changes in foot pressures were assessed through a 2 (quiet stance and gait) x 10 (areas) repeated measures analysis of variance (rmANOVA).

Results

Under quiet stance, both with EO and EC, mean surface of the CoP ellipse and mean CoP path were significantly ($P<0.05$) larger in PwSCI than HS. Regarding plantar pressure distribution, mean peak pressure was similar in HS and PwSCI across all regions of the footsole. In both groups, the highest pressure occurred at MH and LH, significantly higher than at the toes (rmANOVA, $p<0.05$).
Gait speed was significantly ($P<0.05$) lower in SCI than HS. In both groups, plantar pressure distribution was similar to that during quiet stance, except for the absolute values that were higher (rmANOVA, $p<0.01$) during gait across all regions of the footsole. The highest pressures were found in M2 and M3 areas ($p<0.01$). In both groups, a significant correlation was found between corresponding areas of foot pressure during gait and quiet stance: HS, $y=2.1x+62.9$, $P<0.005$, $R^2 = 0.73$; SCI, $y = 2.1x + 47.51$, $P<0.005$, $R^2 = 0.75$.

Discussion

Results show that peak plantar pressure and its pattern of distribution at the footsole during quiet stance and gait are similar in PwSCI and HS. This finding suggests that the observed balance and gait disorders in PwSCI are not completely explained by abnormalities in plantar pressure values and distribution. This result is at odds with those by [3] and might be in part explained by the fact that in our study PwSCI showed incomplete lesions and were capable to walk independently without aids. During quiet stance, both groups loaded more on heels, while during gait pressures were higher at the metatarsal areas. This finding is presumably connected with the forward propulsion of the centre of mass during gait. The similarity in the distribution of plantar pressure suggests that also in PwSCI, as in HS [2], it is possible to estimate rather accurately pressure distribution during gait from its distribution during quiet stance.

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Effect of botulinum toxin injection on clinical and instrumental measures of walking ability in post-stroke patients with equinus foot deviation. A prospective cohort study.

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Introduction

Equinus foot deviation (EFD) is the most frequent lower limb acquired deformity in stroke survivors. It affects ankle stability during the stance phase of gait and hinders foot clearance during swing, increasing the risk of falling and reducing both participation and quality of life. EFD may result from several factors, including the presence of triceps surae spasticity. Botulinum toxin (BoNT-A) is the first-line treatment for spasticity and is typically associated with adjuvant (rehabilitation) treatments to potentiate its effect [1]. This study aims to describe the effects of BoNT-A injection alone at the triceps surae of post-stroke patients with EFD on ankle ROM and spasticity, loading and propulsive abilities during gait, and on the patient's overall walking ability.

Methods

Prospective cohort study. Inclusion criteria: hemiparesis consequent to a first stroke, >1 y from the lesion, age <80 y, ability to walk for at least 10 m without help, Modified Tardieu Scale (MTS) ≥ 1 at the calf muscles, treatment by BoNT-A at the triceps surae with no physiotherapy thereafter. Exclusion criteria: cognitive barriers, orthopaedic pathologies at the lower limbs, ongoing antispastic therapy (e.g., Baclofen, Diazepam). Patients were assessed 1 week before and 4-6 weeks after BoNT-A injection. Clinical assessment included: ankle maximum passive dorsiflexion with the knee extended and flexed (pDF_KE, pDF_KF), MTS score and spasticity angle, walking speed, FAC, WHS and RMI. Dynamic loading ability (DLA) and dynamic propulsive ability (DPA) were computed from ground reaction force (GRF) data [2]. DLA is the mean value of the vertical component of the GRF. DPA is the mean value of the positive part of the fore-aft component [2]. The Wilcoxon test was used to compare paired variables before and after treatment.

Results

Twenty adult patients with chronic stroke and EFD, 4F/16M, age 42 (15) years were included. At the baseline assessment pDF_KE was -4 (7)°, pDF_KF was 4 (8)°, median MTS score was 2 in both conditions (KE, KF), spasticity angle was 9 (5)° at the gastro-soleus complex (KE) and 9 (7)° at the soleus (KF). FAC ranged between 3 and 4, WHS between 3 and 6 and RMI between 5 and 15.

On average, pDF_KE and pDF_KF did not vary after treatment (p=0.15, p=0.54). MTS score and spasticity angle did not vary at the soleus (p=0.23, p=0.18), while a nearly significant improvement was found at the gastro-soleus complex for both MTS score, reduced by 1 point (p=0.065), and spasticity angle, reduced by 3° (p=0.053). Walking speed was 33 (12) %height/s before treatment and 36 (14) %height/s after treatment (p=0.173). DLA minimally increased from 66 (8) to 68 (9) %BW (p= 0.053). DPA remained stable at 3 (2) %BW (p=0.68). FAC, WHS, and RMI did not vary (p>0.78). No modifications in the use of walking aids and orthosis were found. Noteworthy, a subset of patients only had an improvement after treatment, while the remaining subjects did not vary or even worsened. This explains the average lack of statistical significance in our sample. Walking speed improved in 6 subjects, worsened in 3 subjects, and remained stable in 11 subjects. In the sample, the speed variation was correlated with the variations in DLA (r=0.71, p<0.001) and DPA (r=0.46, p<0.05).

Discussion

In our study, walking speed increased in only 1/3 of the patients after treatment, with no or minimum effects, on average, in the sample. On the one hand, this may depend on the lack of adjunctive physiotherapy following BoNT-A, which is instead recommended. On the other hand, a preliminary assessment of calf muscles by sEMG during walking might have modified the treatment selection, as in [3]. Patient recruitment is ongoing to increase the sample size and the consequent statistical power.

Finally, GRF-based indices can be a valid compromise to obtain an instrumental evaluation over time of the effects of BoNT-A with extremely low evaluation times and costs.

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Gait entropy using wearable sensors in patients with stroke during straight and curved gait: correlation with gait quality indices and clinical scales

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INTRODUCTION

Patients with stroke are often affected by gait impairments that limit their movements and quality of life [1]. Combining clinical and instrumental assessment is a useful strategy to better design rehabilitation protocols and monitor their outcomes [2]. Many indices are already widely used for the assessment of gait impairment. Among them, the MultiScale Entropy (MSE) index has been proposed to quantify gait complexity [3]. However, its capacity of discriminating between different stages of a disease and its relationship with gait quality indices describing stability, symmetry, and smoothness, as well as with clinical scales, are still underinvestigated. The aim of this study is to explore these relationships during straight and curved gait in subacute and chronic stroke populations.

METHODS

Twenty-one patients with stroke (7 F; 57±13 y) and 23 healthy adults (HC) (14 F; 52±15 y) performed a 10m walk test (10MWT) and a Figure of 8 walk test (F8WT). Stroke participants were further divided into two sub-groups: 10 Subacute Stroke (SAS) (59.2±14.7 y; 3.6±1.5 months since the event) and 11 Chronic Stroke (CS) patients (55.0±11.9 y; 22.5±26.8 months since the event). The BERG, MiniBESTest, and DGI scales were administered by an expert physiotherapist. Three IMUs (APDM Opal, 128 Hz) were located on the lower trunk (L5) and on both lateral malleoli, the latter used for stride segmentation. From trunk-mounted IMU, MSE and gait quality parameters describing stability, symmetry, and smoothness of gait were computed in the antero-posterior (AP), medio-lateral ML, and cranio-caudal CC directions. To test the effect of group (SAS, CS, HC) and of MSE scale factor levels (τ=1-6) on the results, a mixed model ANOVA was run after verifying for normal data distribution. *Posthoc* analysis was performed using Tukey's correction. Finally, Pearson's correlation between MSE and each gait quality parameter as well as clinical scale scores were tested.

RESULTS

MSE ($\tau \geq 4$) in AP direction discriminated the gait of patients with stroke with respect to HC during straight and curved gait, in particular with respect to SAS. Significant correlations ($p<.05$ and $p<.01$) were found among MSE ($\tau \geq 4$) in AP and ML direction, gait quality parameters, and clinical scale scores.

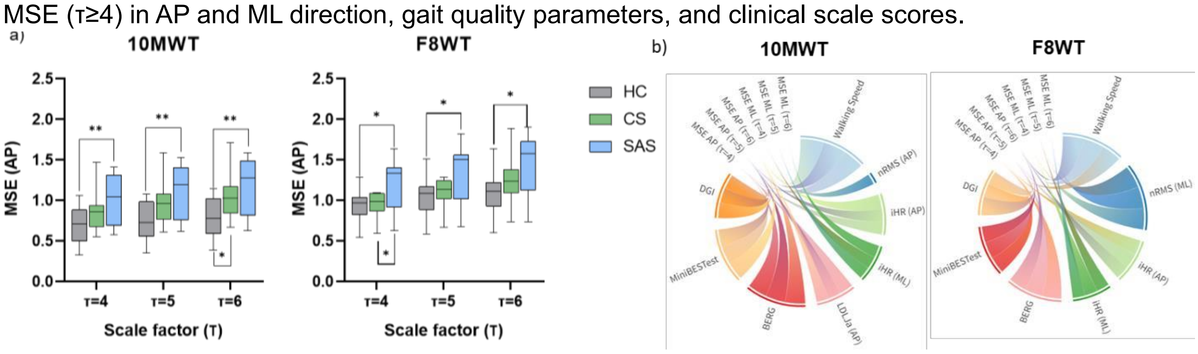

Figure 1. a) MSE ($\tau \geq 4$) for HC, CS, and SAS during straight and curved gait (* $p<.05$; ** $p<.01$); b) Significant Pearson's correlations between MSE and gait parameters and clinical scales.

DISCUSSION

MSE metric with a scaling factor $\tau \geq 4$ can be an appropriate tool to discriminate the dynamic stability of gait between HC and stroke survivors with potential to discriminate between stroke groups in the most challenging task. Significant correlations with stability, symmetry and smoothness indices during dynamic motor tasks and with clinical scales scores were found. The IMU-based quantification of gait entropy using MSE may represent a useful metrics to quantify gait complexity in individuals with stroke.

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The neural bases of sensory reweighting for postural control: a neuro-computational model

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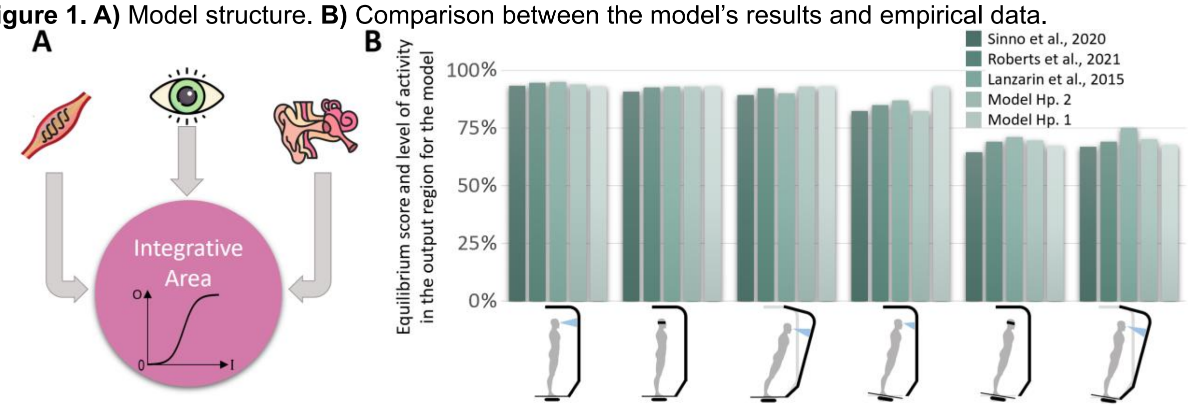
Introduction

Sensory reweighting (SR) involves integrating sensory inputs from various sensory sources, including vision, proprioception, and the vestibular system. The importance of SR lies in its ability to adaptively adjust the contributions of these sensory inputs based on their reliability and relevance in a given context [1], thus allowing the body to respond effectively to changing environmental conditions and sudden disturbances. Understanding SR can lead to advancements in rehabilitation for individuals with balance disorders. Although SR is considered crucial for postural control, the neural mechanisms underlying this process remain unclear. Existing computational models used to investigate SR are mainly "black-box" models [2]. While these models can replicate the behavior of the brain, they do not explain why and how this is happening in the real brain. To fill this gap in the literature, in this work we use a biologically plausible neuro-computational model, to elucidate the neural mechanisms at play in the sensory organization test (SOT), a widely utilized experimental protocol for investigating SR [3]. Considering that the plastic remodeling in the nervous system occurs at a significantly slower temporal scale compared to SR, we put forth the hypothesis that there is no actual reweighting process taking place. Instead, we propose that the adaptive adjustments in the contribution of each sensory modality can be explained by the process of multisensory integration (MSI).

Methods

We implemented a traditional model of MSI [4] (Figure 1A), where an associative integrative area receives as input the activities of all the presynaptic regions, each weighted by a synaptic weight. We investigated two alternative hypotheses to explain the empirical findings in the literature: 1) the six conditions observed in the SOT can be attributed to a reweighting process, and the synaptic weights of each sensory modality adapt based on the amount of information contributed by that modality in a given situation; 2) the variations in the six SOT conditions are solely due to differences in the reliability of the stimuli and the MSI operation, without any reweighting process occurring.

Figure 1. A) Model structure. **B)** Comparison between the model's results and empirical data.



Results

Comparing the model's results obtained in the two sets of simulations with empirical data (Figure 1B), we found that the SR hypothesis cannot account for all six SOT conditions, while the MSI does.

Discussion

Results confirm our starting hypotheses: the adaptive adjustments in the contribution of each sensory modality can be explained by the process of MSI, not by a real reweighting process. We will further validate the proposed model with newly collected experimental data, by analyzing the effect of incrementally varying visual and proprioceptive inputs on both model results and center of pressure-based postural sway measures that are being currently acquired for validation purposes.

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Crouch gait in bilateral cerebral palsy: a validation of markerless video examination of kneeling gait

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Introduction

One of the long-term goals of treating children with Cerebral Palsy (CP) is habilitate independent and sustainable mobility. A common gait deviation observed in CP children, it is the development of the so-called "crouch gait", which means walking with bent knees. Early monitoring of crouching development is very difficult, and the accurately quantitative description of its extent requires instrumental assessment. More comprehensive three-dimensional gait analysis, which can be considered the gold standard, takes time, is only available in a few places in the country and is expensive to carry out.
The aim of this study is to explore the clinical applicability of a validated markerless method [2] based on a single depth camera method for gait analysis in CP patients to lay the foundation to establish a National Cerebral Palsy Follow-up Program Registry.

Methods

We will recruit children with age 6-18 and with bilateral CP type GMFCS I, II and III, between the patients who are followed-up in the ambulatories of ASL TO5 District (province of Turin). The examination will be carried out in the ambulatories of Nichelino (TO). Patients will be asked only to wear colored ankle socks. Markerless video examination will be used to collect data: an RGB-D system (Microsoft Azure Kinect, fs = 30 fps) will be placed laterally at 2.5 m. A 3D subject specific multi-segmental model will be created from four static RGB-D images (frontal, posterior right and left sagittal views) (*Fig.1a*). The 3D cloud point representing the surface of the subject will be extracted by exploiting RGB-D information. The model will be registered with the point cloud of the foreground side using an Articulated Iterative Closest Point algorithm [1] to obtain sagittal lower-limb joint kinematics (hip, knee, ankle and fifth metatarso-phalangeal joint).
Five gait trials will be recorded for each subject, with a required time of 30 minutes approximately.

Results

A graphical representation of the output of each single step of the procedure is reported in Figure 1.
Figure 1*. a) 3D lower-limb subject specific model; b) Dynamic tracking and processing: 1) RGB image, 2) Depth image, 3) RGB-D image, 4) Subject extraction, 5) Model registration.*

Discussion

In this ongoing research we aim to develop and test a gait analysis markerless protocol for children with CP to explore the possibility of an integrated routine assessment for crouch gait in the follow-up of these patients. Thanks to the use of RGB-D technology, it is possible to manage efficiently both the extraction of the subject from the background and the segmentation issues associated to the superimposition between the foreground and background segments. The low cost of the single device (250 €) along with the possibility of simplified experimental set-up, opens new perspectives for the realization of systems for the analysis of movement usable on a large scale.

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Neuromechanical adjustments in human walking with bent posture

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Introduction

Evolutionary and functional adaptations of the spine and trunk are inherently related to an important role of gravity for the mechanisms determining a specific postural tone and body segment configurations, when comparing bipedalism and quadrupedalism [1]. But other than this, gravity has a major impact on specific rules of motion in the gravity field, and foot-support interactions in particular. Here, we looked at the neuromechanical adjustments made by people walking with bent posture that may help us understand the physiological mechanisms and biomechanical regulations underlying our tendency toward upright posture, as well as possible motor control disturbances in some diseases associated with trunk orientation problems.

Methods

Ten healthy young men walked at 1.1 m s^{-1} on an instrumental treadmill. They walked with a natural trunk position, and with an imposed 10°, 20°, 30° and 40° of trunk flexion. The angles were controlled on the sagittal plane by OnForm app. For each condition, participants walked 3 minutes and the last 10 seconds of each session were recorded. The vertical ground reaction force (Fv) under each foot were recorded,as well as the EMG activity of 4 lower-limb muscles (vastus medialis, vasto lateral, tibial anterior, medial gastrocnemius and lateral gastrocnemius). The ratio between the maximal force of the front and the back leg (Ff/Fb) during the step-to-step transition was measured. From Fv, we computed the vertical velocity of the CoM, to determine the begin (Vv,min) of the transition. A one-way ANOVA and Bonferroni post hoc was used to compare our variables. For each condition and each stride, the mean activation and the center of activity (CoA) were calculated. The CoA is the vector's angle that points to the center mass of the circular distribution.

Results

No differences of step length were observed between conditions (p=0.532). The timing of $V_{v,min}$ relative to the foot contact and F_f/F_b were different between conditions (p<0.001): the greater the increase in trunk flexion, the later $V_{v,min}$ occurred relative to FC (p<0.05). Also, as compared to natural walking, F_f/F_b was higher in the 20°, 30°, and 40° trunk flexion conditions (p<0.05). No differences were founded in F_f/F_b between 10° and normal (p = 1.00).

The angle of trunk inclination significantly influences in the muscle mean activation of muscles, especially the extensors. Specifically, the GL's mean activation was higher at 20°, 30° and 40° than during normal walking (p<0.004). The mean VL and VM muscle activity was higher at 10°, 20°, 30°, and 40° compared to normal conditions (p<0.001). The trunk inclination also influences the timing of extensor muscle activation but not of flexor muscle (p=0.054). Also, small change was observed at proximal extensors whereas at distal extensors, the changes were much larger (p= 0.0017).

Discussion

Surprisingly, attenuating extensor muscle activity at the end of stance was one of the main impacts of trunk inclination. During step-to-step transitions, in each step the velocity of the center of mass must be redirected upwards. When walking upright, this redirection was initiated in an anticipatory manner by the trailing leg, propulsing forward and upward the body before foot contact. However, with increasing trunk inclinations, there was a lack of these anticipatory adjustments and the redirection was performed later by the loading limb after the collision with ground. The results are discussed in the context of the biomechanical principles underlying foot-support interactions during step-to-step transitions in bipedal upright walking.

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Identifying the best discriminative gait features to characterize disease progression in Multiple Sclerosis

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Introduction

Digital outcomes identifying gait features through inertial measurement units (IMUs) have been proposed to investigate balance and locomotion disorders in people with Multiple Sclerosis (PwMS) and other neurological disorders [1,2]. Their application has been a beneficial tool to monitor the progress of the disease and for decision-making to enhance clinical outcomes [1-3]. In this perspective, identifying key indicators that could be able to discriminate between PwMS with different levels of walking impairment, could be employed as a tool to characterize walking dysfunction in PwMS. The aim of this study is to explore what specific gait features extracted from IMUs during different walking modalities, best discriminate for disease progression in two grouped classes based on the Expanded Disability Status Scale (EDSS) [4].

Methods

Fifty-seven patients with MS (*Class 1*– greater degree of ambulatory ability, n=32, 21 F, 50.4±9.8 y, EDSS 0–4; *Class 2*– impaired ambulatory ability, n=25, 17 F, 52±10.2, EDSS 4.5–6.5) participated in this study. All participants performed a 10-meter Walk Test (10mWT) and a Figure-of-8 Walk Test (F8WT) [5] while wearing five IMUs (APDM, Opal, 128 Hz) on both lateral malleoli, pelvis, sternum, and head. Stride segmentation was performed from leg IMUs. Spatio-temporal (ST) parameters (stride frequency-SF, stride duration-SD and walking speed-WS) along with acceleration-based features related to stability (Root Mean Square-RMS and Attenuation Coefficients-AC), symmetry (improved Harmonic Ratio-iHR), and smoothness (Log Dimensionless Jerk-LDLJ) of gait were obtained. A Linear Discriminant Analysis (LDA) was performed to identify the best gait features toward the accurate distinction between the two classes with different levels of walking impairment for each motor task.

Results

Discriminant analyses were significant for the 10mWT (Wilk's λ=.559, $\chi^2(4)$=30.81, p<.001) with an R^2-canonical=.440; and for the F8WT (Wilk's λ=.521, $\chi^2(3)$=34.85, p<.001) with an R^2-canonical=.478. The analysis correctly classified 78.9% of the 57 cases in the developmental sample for both walking tasks. A jackknife cross-validation procedure found similar classification scores for the 10MWT (77.2% of cross-validated classifications) and the F8WT (78.9%). Table 1 shows the standardized canonical coefficients and the structure weights for the analyzed used in the analysis.

Table 1. Standardized Canonical Coefficients and Structure weights from the discriminant model.

Task	Gait features	Standardized Coefficients	Structure weights
10mWT	iHR AP	.769	.824
	ACPS ML	.520	.429
	ACPS AP	.208	.450
	iHR ML	.135	.364
F8WT	iHR AP	.742	.783
	ACPS ML	.596	.462
	LDLJ AP	.335	.429

Abbreviations: AC, attenuation coefficient; iHR, improved harmonic ratio; LDLJ, log dimensionless jerk; AP, antero-posterior; ML, medio-lateral; P, pelvis; S, sternum.

Discussion

LDA revealed that iHR in the anterior-posterior component was the gait feature that differs the most among PwMS with different levels of walking severity. Thus, this symmetry index seems the best candidate to monitor walking impairment in patients with MS, providing valuable objective information to clinicians to guide the decision-making rehabilitation process to target functional deficits in tailoring the rehabilitation program [6].

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Age-related gait adaptation strategies during obstacle avoidance in virtual reality

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Introduction

Adaptation of gait in response to obstacles has been extensively studied, as it represents a high-risk situation for falling during activities of daily living, especially with advancing age. Some limitations of previous works on the topic (non-ecological environments or lack of standardization of obstacle presentation) have prevented consistent results on the characterization of the impact of age on motor strategies for obstacle avoidance.

Methods

Eight healthy young (5 females; 23-33 years) and eight healthy elderly subjects (2 females; 58-73 years) underwent an experimental protocol including three sessions of ten walking trials each. Participants walked on a 10-meter walkway: i) in the real world (RW), ii) in a virtual reality (VR) scenario similar to the gait laboratory (VR/A-), iii) in the same VR environment with the addition of a virtual agent (VA) programmed to cross the participant's path in a standardized fashion (VR/A+), according to a published protocol [1]. Briefly, the VA was placed next to the walkway, and programmed to cross the subject's trajectory when the participant reached 3 m from the VA, at a constant speed equal to 1.5 times the subject's current speed. The VR environments were programmed with Unity (version 2018.4.9f1) and navigated by the participants by means of a wireless head mounted visor (Vive Pro, HTC, USA). Kinematics was monitored with a full-body protocol (LAMB) and a six-camera optoelectronic system (SMART-DX 400, BTS, Italy). For the RW and VR/A- conditions, spatiotemporal gait parameters were calculated in the central 3 meters of the calibrated volume. For the VR/A+ condition, the analysis focused on the three strides (modulators: M1, M2, M3) between the onset of VA movement and the return to the preferred speed after the VA transit, as computed during the VR/A- condition. Friedman test was used to examine the differences between the conditions within each group, followed by post-hoc pairwise comparisons (Dunn matched-pairs test). The unpaired Mann Whitney U-Test was used to test differences between groups within each condition (p-value: 0.05, Bonferroni-corrected).

Results

Groups did not show significant differences during the VR/A- and RW conditions (Table 1). During VR/A+, stride time of M1 was longer in the elderly with respect to the young group. Stride length of M1 and M2 decreased with respect to the baseline conditions in the young group, while only M2 stride length decreased in elderly subjects. Velocity of M2 was lower with respect to RW selectively for the young group. Stride time decreased during M3 with respect to the baseline conditions in both groups.

Table 1. Gait parameters. a,b,c,d,e,f,g,h,I,j,k: p<0.05, Dunn test; *: p<0.05, Mann Whitney U test.

	YOUNG					**ELDERLY**				
	RW	**VR/A-**	**M1**	**M2**	**M3**	**RW**	**VR/A-**	**M1**	**M2**	**M3**
stride length (m)	1.27 (1.12-1.34)[a,b]	1.21 (1.07-1.31)	0.41 (0.36-0.44)[a]	0.44 (0.40-0.59)[b]	0.51 (0.46-0.62)	1.26 (1.17-1.35)[g]	1.30 (1.17-1.32)[j]	0.41 (0.31-0.43)	0.39 (0.35-0.47)[g,j]	0.62 (0.48-0.63)
stride time (s)	1.09 (1.05-1.35)[c]	1.12 (1.06-1.19)[e]	0.59 (0.55-0.65)*	0.73 (0.56-0.83)	0.57 (0.46-0.62)[c,e]	1.13 (1.06-1.16)[h]	1.09 (1.07-1.17)[k]	0.81 (0.61-0.87)*	0.76 (0.53-0.81)	0.52 (0.41-0.66)[h,k]
stride vel (m/s)	1.22 (0.98-1.28)[b]	1.08 (0.95-1.23)	0.73 (0.65-0.94)	0.69 (0.46-0.77)[b]	0.92 (0.71-1.37)	1.10 (1.04-1.27)	1.11 (1.08-1.23)	0.65 (0.49-0.75)	0.72 (0.55-1.13)	1.18 (0.97-1.40)
stride width (mm)	0.08 (0.06-0.10)	0.08 (0.05-0.10)	0.09 (0.08-0.24)	0.09 (0.07-0.16)	0.12 (0.06-0.24)	0.09 (0.07-0.11)	0.09 (0.08-0.12)	0.12 (0.09-0.19)	0.16 (0.10-0.19)	0.12 (0.09-0.17)

Discussion

Elderly adults showed preserved capability to adapt their gait in response to the obstacle, with motor strategies similar to the ones of the young subjects. Elderly participants adapted their gait slightly later after the VA start, possibly as needing a longer reaction time in response to the perturbation.

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Comparison of open-source markerless pose estimation methods in measuring gait kinematics: a preliminary 2D study

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Introduction

In the domain of computer vision, advances in markerless pose estimation through deep learning methods are leading to an increase in accuracy and efficiency in the analysis of human movement, with potential benefits in a wide range of fields.

This approach may be particularly useful for gait analysis in clinical settings due to the open-source nature and machine learning techniques, which rapidly reduce the costs associated with multiple specialized cameras and equipment and allow for an accessible method while preserving accuracy. Among open-source software, OpenPose is one of the most popular methods, which, being based on a general pre-trained model, allows a direct extrapolation of human body coordinates [1]. On the other hand, DeepLabCut is a deep learning technique that allows to train artificial neural networks, starting from a pre-trained model, to recognize the position of manually identified landmarks, developing custom-trained models based on a specific dataset [2].

However, despite their increasing application in literature, only a few studies have compared their accuracy in assessing human movement kinematics and, particularly, gait performance [3, 4]. Furthermore, these studies only used DeepLabCut's pre-trained model without implementing a custom-trained model that, conversely, is able to exploit the main strength of the transfer learning of DeepLabCut.

The aim of this study was to evaluate preliminary data on the accuracy of both pre- and custom- trained models of DeepLabCut to detect bodypart location during healthy locomotion in comparison with OpenPose. In addition, the ability of both DeepLabCut models and OpenPose to measure spatiotemporal gait parameters was explored, and the results were compared with a force platform system.

Methods

Fifteen healthy participants walked ten times, at their own pace, along a 5-m indoor walkway, which accommodated four force platforms (BTS INFINI-T, 1000 Hz). The sagittal plane views of the walking sequence were recorded by an RGB camera (BTS Vixta, 25 Hz, 640 × 480 resolution) synchronized with the force platforms.

OpenPose's “Body_25” pre-trained network was employed, generating data for 25 keypoints, while DeepLabCut was implemented using the “Model Zoo Full_Human” pre-trained network, which produced data for 14 keypoints. The custom-trained model was developed by training the artificial network “ResNet-101” with DeepLabCut. For this purpose, 20 frames of each video were manually labeled with 16 keypoints, for a total of 300 annotated images, and a training of 300.000 iterations was performed.

For each participant, the output of the three pose estimation approaches, containing the x-y coordinates of the tracked bodyparts, was imported into a Python script for the analysis. Euclidean distances of common keypoints were calculated for each method, and the gait parameters, such as step length, time, speed, and cadence, were compared with those extracted from the force platforms.

Results

Preliminary findings suggested that the trained DeepLabCut's model proved to be more accurate than its pre-trained counterpart and OpenPose in the reconstruction of bodyparts. By comparing the gait parameters of each approach with the force platforms as a reference system, the higher precision of the trained DeepLabCut's network was confirmed.

Discussion

In conclusion, we found the trained DeepLabCut's model to be accurate for pose estimation of gait kinematics. In the near future, a further development of this study will include the 3D analysis.

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Impact of visual feedback on patient-therapist interaction during robotic gait rehabilitation in individuals with spinal cord injury: a multimodal eye-tracking and HD-EEG study

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Introduction

Patients' active participation to the rehabilitative process is crucial to the achievement of outcomes (1). The growing interest in robotic rehabilitation and its daily employment in clinical practice has been including the robot as a third actor in the one-to-one Physiotherapist-Patient (Pht-Pt) interaction typical of traditional rehabilitation processes. The use of a performance-related feedback (FB) during robotic gait assisted therapy (RAGT) improves the human-robot interaction and helps the patients to adapt their gait patterns (2). The aim of this study was to address the patient's perception of different FB types and the way in which they impact on Pht-Pt interaction during RAGT in individuals with spinal cord injury by means of a multimodal approach including high density EEG (hdEEG) and eye-gaze data.

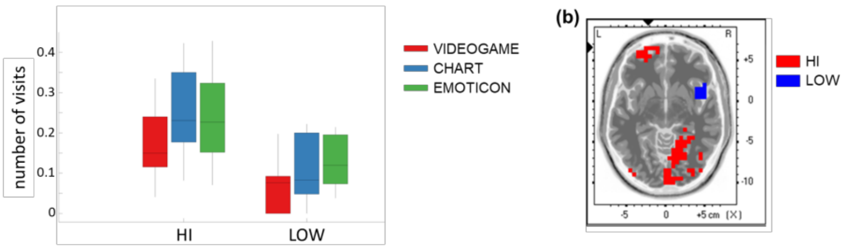
Methods

hdEEG (61 EEG channels, Brain Products, 250Hz) and eye-gaze (Tobii Pro Glasses, 60Hz) were acquired from ten individuals with incomplete spinal cord injury (iSCI) performing a single session of RAGT using the robot Lokomat (Hokoma). During the session two different experimental manipulations were applied: 3 types of FB (chart, emoticon, videogame) and 2 different levels of Pht–Pt interaction (HI -> continuous interaction of Pht and Pt, LOW -> Pt is supported only by the FB without the help of Pht). EEG data were pre-processed and HI vs LOW spectral activations (theta, alpha and beta bands) for each FB were reconstructed by applying Welch periodogram to data localized in the whole grey matter volume by means of sLORETA algorithm. Eye-gaze parameters (number and duration of visits and fixations) were extracted for each of the three areas of interest (AoI) defined (therapist, FB screen and other) for each level of interaction.

Results

Eye-gaze data revealed how the therapist AoI was visited more frequently during the HI with respect to LOW Pht-Pt interaction for all the three FB. However, such number is significantly higher when chart or emoticon FB are used with respect to videogame FB (Fig.1a). HI vs LOW spectral activations in alpha band when emoticon FB was used revealed an involvement of medial pre-frontal cortex and fusiform gyrus in HI condition (in red) while an activation of insula in LOW interaction (in blue) (Fig-1b).

Fig. 1 (a) Number of Visits into Therapist AoI for different FB and Pht-Pt interaction types; (b) HI vs LOW spectral activation maps in alpha band when emoticon FB is used.



Discussion

Results indicate that during the Lokomat based RAGT both the level of Pht-Pt interaction and the FB type have an impact on patients' perception and attention. In particular, the patient tends to fully immerse himself in the exercise when the videogame FB is used, while in the other two cases, being less intuitive, the direction of patient attention is towards the therapist, as testified by activation in areas typical of social processes. Finally, despite performance-related FB is a valuable addition to the RAGT, the presence of the therapist is a crucial point in the collaborative human-robot interaction.

Acknowledgment. *Research supported by the Italian Ministry of Health (GR-2019-12369207)*

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Arm swing reduction in parkinson disease: a study with a network of wearable sensors

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Introduction

Parkinson's disease (PD) commonly manifests with arm swing reduction during gait [1]. Previous kinematic studies using traditional gait analysis have shown decreased arm swing range, amplitude, and velocity in PD compared with controls. The pathophysiology of arm swing abnormalities in PD is still under debate since it would reflect bradykinesia or articular limitation due to rigidity [2][3]. We have recently reported more advanced measurements of reduced arm swing in PD, by using a wearable sensors network in an ecological experimental setting. The first aim is to describe new objective arm-swing features extracted by a frequency-based analysis in patients performing the timed-up and go (TUG) test. A second aim is to correlate the extracted instrumental measures with specific UPDRS subitems for bradykinesia, rigidity, and tremor.

Methods

We recruited 44 PD patients in the early stage of the disease (H&Y<2) and never exposed to L-Dopa (drug-naïve) and 31 age-matched healthy controls. We performed a sensor-based analysis of arm swing during gait. The collected data were FFT transformed, and the frequency content was further analyzed. The Spearman's test was used to correlate specific harmonic features with upper limb clinical scores.

Results

The kinematic analysis demonstrated that arm-swing reduction in PD can be objectively described in terms of decreased amplitude of all harmonics extracted from kinematic analysis of upper limb movements. Specific kinematic features highly correlated with rigidity and, in a lesser extent, with bradykinesia; there was no significant correlation with upper limb tremor.

Discussion

The kinematic analysis based on our wearable sensors network demonstrated arm-swing reduction objectively during gait in PD patients performing a TUG test in an ecological setting. Our findings also suggest that reduced arm swing in PD would more likely reflect the severity of rigidity rather than bradykinesia.

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Implementation of a customized treatment protocol, based on clinical outcomes, for the treatment of the upper limb after stroke using a set of robotic devices

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Introduction

According to the World Health Organization (WHO), stroke is the leading cause of disability and the second leading cause of death worldwide, with a 30% increase expected between 2000 and 2025 [1]. The loss of upper limb dexterity represents one of the major causes of long-lasting disability in stroke patients, which leads to a reduction in autonomy and a serious decline in quality of life [2]. In this context, the benefits of rehabilitation include improved cognitive and psychological functioning as well as the recovery of motor and functional abilities. In the past ten years, robotic equipment designed specifically for the neuromotor rehabilitation of the upper limb has gradually been introduced into clinical practice. [3]. The purpose of the study was to compare the effects of a robotic rehabilitation process, using a set of four robotic devices, before and after the implementation of a robotic treatment defined by clinical outcome.

Methods

At the Don Carlo Gnocchi Foundation facility in Rome, 81 patients with subacute stroke outcomes were enrolled in the study, of whom 32 were assigned to the experimental group (subject to robotic treatment) and 49 to the pilot study group (subject to robotic treatment based on clinical outcome). Subjects underwent a 30-session upper limb neurorehabilitation program using the following robotic devices (Figure 1): Diego, Amadeo and Pablo (Tyromotion GmBH, Graz, Austria) and Motore (Humanware srl, Pisa, Italy). The patients were evaluated before (T0) and after (T1) the rehabilitation intervention using the following clinical scales: Fugl-Meyer Assessment for Upper Extremity (FMA-UE) to investigate the performance of the upper limb, Motricity Index (MI) to measure strength, the Modified Barthel Index (mBI) for activities of daily living and the Numerical Rating Scale (NRS) for pain. In addition to the robotic treatment for upper limb recovery, the patients also underwent daily traditional rehabilitation treatment aimed at improving trunk control, balance and gait recovery. The following procedures were carried out: (a) an intragroup statistical analysis using the non-parametric Wilcoxon test to evaluate the data collected at T0 and T1 separately for the two groups; (b) an intergroup statistical analysis, using the non-parametric Mann-Whitney test, to compare the improvement deltas (T1-T0) between the two groups.

Results

The intragroup analysis revealed in both groups a significant gains in upper limb motor function (FMA-UE Pilot Group: $p<0.001$; FMA-UE Experimental Group: $p<0.001$), strength (MI Pilot Group: $p=0.002$; MI Experimental Group: $p<0.001$) and autonomy in performing activities of daily living (mBI Pilot Group: $p<0.001$; mBI Experimental Group: $p<0.001$). The level of pain remained unchanged (NRS Pilot Group: $p=0.733$; NRS Experimental Group: $p=0.806$). The intergroup analysis on the improvement deltas showed a statistically significant difference in FMA-UE ($p=0.002$) and MI ($p<0.001$), indicating a greater recovery in terms of motor function and upper limb strength in the Group Experimental, compared to the Pilot Group.

Discussion

When compared to the use of robotics without a defined protocol that is inspired by the clinical outcome, the robotic treatment using a set of four robotic devices with the application of a customized robotic treatment protocol that uses the clinical outcome in defining the type of intervention and the modalities of robotic intervention, has shown a superiority in the overall improvement of the strength and functionality of the upper limb in subjects with stroke.

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A novel experimental paradigm to investigate neural and muscular activities during normal gait: proof of concept coupling EEG, sEMG and kinematics measures

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Introduction

Cortico-muscular coherence (CMC) has commonly been used to address the interaction between cerebral cortex and muscle activity and it has been acknowledged as a biomarker of pathology in different diseases [1]. However, there is a paucity of studies using this metric during gait and results ofthese works are rather contradictory; nevertheless, only a few are investigating the effects on the kinematic outcomes or using an elevate number of neurophysiological signals. The aim of the present study is to present a proof of concept that integrates the information collected from the multimodal acquisition of electroencephalogram (EEG), surface electromyography (sEMG), and kinematic measurements giving an accurate and complete overview on neural-to-mechanical interplay.

Methods

One able-body participant (age = 29 years old, height = 1.68 m, weight = 60 kg) took part in the study. The participant was asked to walk barefoot back and forth through the length of the gait laboratory (~ 8 m). An 8-camera stereophotogrammetric system (100 Hz, Vicon) was used to record the 3D marker trajectory of 16 retroreflective markers placed on the shank and foot segments according to the IOR gait protocol [2]. The electrical activity of two lower limb muscles bilaterally (i.e., Tibialis Anterior, Gastrocnemius Medialis) was synchronously collected through an 8-channel sEMG system (2000 Hz, Cometa). A 64-channel EEG system (2000 Hz, ANT Neuro) was adopted to record brain activity and was synchronized with the other systems via a custom-made trigger box (Figure 1A). Pre-processing of the EEG and sEMG data is described in Figure 1B. Heel strike events were used to epoch neurophysiological data in segments of 1s ([-800 +200] ms with respect to the heel strike event) and served as time reference points. Only right strides were analyzed for this study. Signals were averaged across trials (Figure 1B). Cortico-muscular coherence (CMC) was estimated as: $|C_{xy}(f)| = \frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$,
where P_{xy}, P_{xx} and P_{yy} are the cross and auto spectra at a specific frequency f.

Results

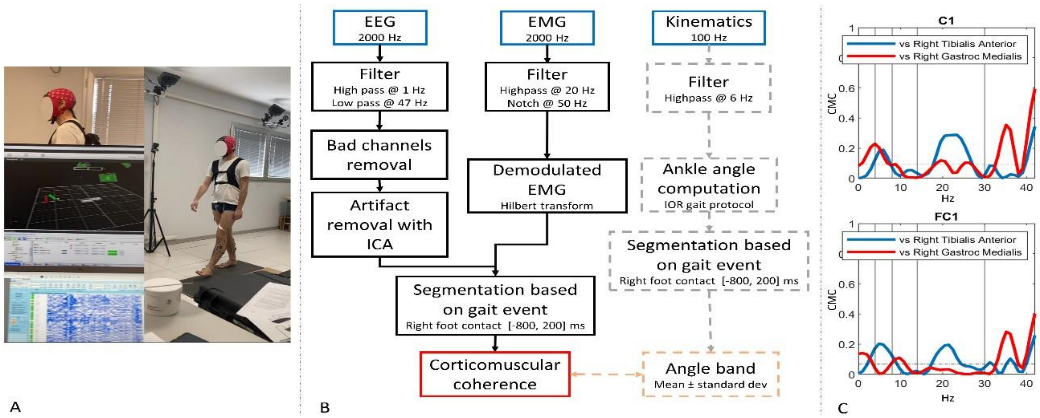

Figure 1. A) Experimental setup. B) Processing pipeline. Solid black lines indicate the implemented processing, dashed gray lines indicate future workflow. C) Preliminary results of CMC.

Preliminary results of CMC estimates between C1, FC1 and Right Tibialis Anterior and Gastrocnemius Medialis are reported in Figure 1C.

Discussion

The framework of this study presents an attempt to overcome some limitations highlighted in the literature by augmenting spatial resolution in the EEG data, increasing the number of sEMG data collected, and using gold-standard measurements to compute joint angles. Future works are needed tolink the estimation of CMC and the kinematic data.

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Balance strategy as consequence of gait perturbation

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Introduction

Technological solutions are expanding the knowledge of the dynamic aspect of function that are useful for its prevention and recovery. The Centre of Pression (CoP) detection employing force platforms demonstrates efficacy in detecting the risk of falls [1]. Despite that, the information given by the CoP do not help to address a therapeutic indication.
Purpose: This study aims to analyze the full body adaptation to a perturbation during natural walking to extract specific therapeutic indications.

Methods

Twelve typically developed young adults and ten children with cerebral palsy walked on a walkway with a camouflaged robotic platform at floor level. The robotic platform was developed ad-hoc in house and controlled in force [2]. The platform descends 10% of the limb length when the participants step on it. This solution was adopted to guarantee the same difficulty for each subject. Was made possible by adapting the stiffness of each participant to their weight and leg length. A 3d motion capture system (Vicon MX, UK) reconstructed the full-body biomechanical model of the participants. A protocol was defined to assess three different conditions, unperturbed gait and expected and unexpected perturbation. Three trials for each condition were gathered for each participant. Data were analyzed using Matlab® tools.

Results

The Linear Fit Method [3] was utilized to detect the statistical differences in the serial time concerning the joint rotation of the body articulation by comparing the three conditions: unperturbed, expected and unexpected perturbation of gait. In such a way, it was possible to analyze the role of the anticipation of the perturbation (expected perturbation) concerning its prediction during the ongoing adaptation to unexpected perturbation.

Figure 1. Anticipatory strategy Predictive Strategy Fully Anticipated

Discussion

It was possible to discern between distal to prossimal strategies. Furthermore, while typically developed participants adapt on the platform in all the conditions using a distal approach (ankle and knee), children with Cerebral palsy also adjust the gait in the half stride after the perturbation with a more distal involvement (pelvis)
Implications: The comparison of the anticipatory and predictive (ongoing) strategies lets to analyze the cause of the risk of falls and define the specific district on which to concentrate the therapeutic indications with specific dynamic treatments

Acknowledgements. *Supported by Pegaso Onlus (Grant numbers: opbg-201603×003858) and by the Italian Ministry of Health (Grant numbers: CO-2011-02351627)*

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From motor control to a rehabilitative tool: a bioinspired orthosis

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Introduction

Robotic wearable orthoses are permeating the rehabilitative processes to respond to the demands of re-education and support of standing and walking functions. Literature revisions on their taxonomy and usage partially address the rehabilitative issues or address only technical aspects of the human-machine interaction [1]. The literature considers mainly biomechanical coupling, wearability, intention detecting, functional coupling, energy autonomy, trajectory definition, and torque expectation. What is missing is the analysis of the scientific rules of interaction able to induce learning processes or support the function. Furthermore, over 30 years of instrumented gait analysis changed the interpretation of human locomotion organization, currently considered a complex dynamic function [2]. Testing technological solutions in pathological conditions lets to consider the necessity to change the research paradigms in this field and the need for low-cost solutions [3]. This study focuses on advanced motor control and learning hypotheses, reversing the current processes, and focusing on rehabilitation. In this study, the prototype is verified on healthy participants to test the possibility of following and modifying natural walking with an ad-hoc built knee robotic orthosis and controller.

Methods

We developed an ad-hoc orthosis with a controller that follows the equilibrium-point hypothesis [4]. Seven typically developed volunteers participated in the test of the orthosis controller (age: 22 – 65 years old, 5 females). A 12-camera (Vicon, Vero, UK) was employed. Three experimental protocols tested the transparency and the gait pattern implicit modification using the orthosis during walking, stepping in place on a compliant platform with 6 DoF (DORIS, Mufy, IT) [4] and while walking on a treadmill. Torque control and imposing phase-dependent target body references was implemented.

Results

The ad-hoc low-cost built bioinspired controller was efficient during unperturbed walking, perturbed walking, and stepping in place on DORIS. Knee flexion-extension time series gathered with gait analysis instruments overlap comparing them with steady gait during the use of the orthosis in transparency mode. Furthermore, while walking on the treadmill, it was possible to dynamically modify the gait kinematic, maintaining the general pattern configuration by changing the current driving the torque of the actuator and selectively changing the final target configuration only during the swing phase. The torque and final angle target worked subliminally concerning the participant's perception but were efficient in changing the maximum knee flexion angle.

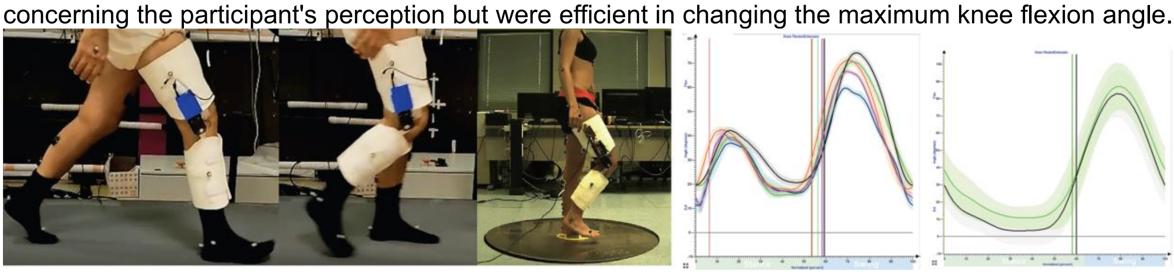

Figure 1. Gait on a treadmill and in place on DORIS trials.

Discussion

From our preliminary data, the phase-dependent control on the final configuration through a force interaction realized the possibility of following the participants' behaviour transparently without any control over the trajectory of the movement. These results match the equilibrium point hypothesis [5]
Interacting with gait patterns through subliminal information opens the path for recovering, when possible, or supporting natural gait, avoiding dangerous interactions that can cause stumble and falls through a low-cost solution.

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The relevance of motion study in the cirrhotic patient: preliminary results of a prospective observational study

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Introduction
Liver cirrhosis is a chronic and progressive disease complicated by several factors such as portal hypertension, hepatic encephalopathy [1], dysbiosis [2], and muscle changes [3] (sarcopenia and myosteatosis) which are responsible for movement disorders. All of these increase the risk of falls [4], mortality, and worsen quality of life. The aim of the study is to investigate the correlation between muscle alterations, movement disorders, falls and mortality in the cirrhotic patient.

Methods
25 cirrhotics were recruited; etiology (alcohol, viruses, Nash, autoimmunity, other), severity of hepatopathy (Child-Pugh and MELD), endoscopic signs of portal hypertension (esophageal varices and gastric varices), presence of spontaneous or iatrogenic portosystemic shunts (TIPS), history of prior encephalopathy, falls, and mortality or liver transplantation were recorded. In all patients, the following assessments were performed: Mini Mental State Examination (MMSE), Psychometric Hepatic Encephalopathy Score (PHES), Animal Naming Test (ANT), SF36, Driving History Questionnaire, Fatigue Severity scale and Activity specific Balance Confidence scale (ABCs-I). The presence of muscle changes (sarcopenia and myosteatosis) was studied by review of lumbar scans (L3) and CT examinations performed within three months (SLICEOMATIC V4.2 software). TUG (timed up and go) and 6MWT (six minutes walking test) were performed for movement study. Through the wireless inertial sensor BTS G-WALK located at L5, spatiotemporal parameters of gait, pelvis kinematics and linear trunk accelerations were recorded through WALK+ protocol of G-STUDIO software from which through MATLAB software the indices were derived: Harmonic Ratio (HR), Recurrence Quantification Analysis (RQA), percentage recurrence (RQA rec), percentage determinism (RQA det) and Lyapunov's maximum exponent (LEE).Telephone follow-up at 3 and 6 months was performed in all patients. Movement study was also performed in a group of healthy controls matched for age and sex.

Results
20 males and 5 females participated: 59.24 ± 9.16 years; etiology of cirrhosis 15 alcohol, 2 HBV, 3 HCV, 3 post Nash and 2 cryptogenic; Child-Pugh Class A11/B12/C2, mean MELD score 12.33 ± 4.17. 11 patients had history of previous hepatic encephalopathy (9 episodic, 2 recurrent and in no patients persistent). 4 patients were TIPS carriers. 7/25 presented at least one fall in the last year (3 without relics, 2 with contusions and 2 with fractures). Hospitalization was required in 4 subjects. 15 patients had minimal hepatic encephalopathy (PHES <-4). 14 patients had sarcopenia (2 women and 12 men); 15 cirrhotics had mysteatosis. Of the 17 patients in whom ABCs-I and Fatigue was administered 2 had a risk of falls and 8 had severe fatigue. During follow-up, 6 of 25 patients developed hepatic encephalopathy; 2 had TIPS; no patients had liver transplantation; death occurred in 3 patients. 4 patients had falls and no patients required hospitalization. Of these none had impaired values at TUG, 3 had impaired values at mediolateral and vertical HR and ΔRQA %rec in vertical, 3 had sarcopenia, and only one patient had both sarcopenia and mysteatosis. At the TUG performed on all cirrhotics 32% had impaired mobility with increased risk of falls. Among the 5 patients with 6MWT, prior hepatic encephalopathy and PHES<-4: in 3 patients HR in anteroposterior direction was < 1.61 and in 3 patients HR in vertical direction was <1.54. In the 13 patients with sarcopenia and 6MWT: in 11 patients ΔRQA %rec in anteroposterior direction >53.21%, in 7 subjects ΔRQA %rec in mediolateral direction >84.50%, in 8 patients ΔRQA %rec in vertical direction >80.81%, in 6 patients ΔRQA %det in anteroposterior direction >64.75% and in 8 patients ΔRQA %det in vertical direction in >85.83%. In the 12 patients with myosteatosis and 6MWT: in 8 patients ΔRQA %rec in anteroposterior direction >61.45%; in 10 patients ΔRQA %rec in mediolateral direction >44.48%; in 7 patients ΔRQA %rec in vertical direction >80.91%. In the 5 cirrhotic patients with prior encephalopathy, PHES <-4 and 6MWT: in 4 patients ΔRQA %rec in vertical direction >82.29%.

Discussion
In the cirrhotic patient, quality of life is compromised by fatigability, the presence of encephalopathy, muscular alterations, and movement disorders which increase the risk of falls and mortality. Therapeutic strategies aimed at improving nutritional status and muscular alterations, together with rehabilitation strategies could improve the prognosis of cirrhotic patients.

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Which is the best instrument to measure anticipatory postural adjustments of reaching movement?

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Introduction

Anticipatory Postural Adjustments (APAs) are involuntary complex activities that allow the body to execute voluntary movements (VM) [1]. APAs are controlled by cortical and deep brain areas [2], and this explains why many neurological disorders present alterations of APAs (e.g., stroke, Parkinson Disease, and Multiple Sclerosis). APAs are necessary for all voluntary movements execution and to handle the external perturbations of the body [2]. However, different instruments are used in different studies to measure APAs, and there is currently no specific recommendation for the choice. Aim of this study is to compare different instruments for the measurement of APAs, also considering the time consumption of the instruments, to facilitate a clinical implementation.

Methods

This study is a secondary analysis of a cross-sectional observational study, in which adult healthy subjects were recruited; inclusion and exclusion criteria are presented in the work of Amici et al. [3]. The study analyzed 4 different instruments: Optoelectronic System (OS) (Smart DX400, BTS Bioengineering) with 29 markers [3]; surface EMG (sEMG) (EMG Free 300 BTS Bioengineering) with 8 probes [3]; an IMU (G-Sensor, BTS Bioengineering) with a belt at sacral level; Force Platforms (FP) (P6000, BTS Bioengineering) one feet on each platform. Each subject was asked to perform an anterior reaching movement under two different starting behavioral conditions, namely external and internal trigger. Outcome of this study were the Delta Time (DT) of each instrument, that is the time from the APA onset and the VM start detected by each instrument. APA onset was calculated using the OS. Another outcome was the time consumption for the pre-acquisition setup of each instrument. Kruskal-Wallis test was used to assess the ability to differentiate between the two starting conditions of each instrument (DT), median test was used to confirm the results of Kruskal-Wallis test. Frequency analysis was used for the time measurements.

Results

Nine healthy subjects were recruited (age: 22±2; 5 males; 9 righthanded), Kruskall-Wallis test was significant for sEMG of Tibialis Anterior (p=0.019), IMU (p=0.000), and FP (p=0.002). Median test confirmed the results for sEMG, and IMU, but did not confirm those of FPs. The time spent for the preparation of each instrument is reported in table 1.

Table 1. Overall time consumption for the preparation of the instruments and subjects.

Time of application	Overall time for the acquisition session (s)	Percentage of time respect to OS
OS	644 ± 69	100%
sEMG	431 ± 53	67%
IMU	172 ± 31	27%
FP	249 ± 20	39%

Discussion

This study provides interesting insights for future study on APAs. It provides suggestions for the choice of the instrumentation and, in particular, it supports the adoption of sEMG, and IMU for this kind of analysis. Moreover, the reported data could be exploited to reduce the time spent for the analysis in clinical context, where the optimization of the time devoted to postprocessing data is important.

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Assessment of IMU-based measurements for routine functional evaluation of patients with rare bone diseases

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Introduction

The early identification of altered joint mobility provides better conservative solutions to patients, possibly avoiding orthotics and delaying surgery, in addition to ameliorating their quality of life and social interactions. Thorough functional assessments are performed by using modern instruments and complex techniques [1], which unfortunately are available only in a few highly specialized laboratories. Monitoring patients' conditions should rather be performed capillary on the territory, in more accessible locations for patients (i.e., community hospitals, nursing/retirement homes, healthcare facilities, etc.). This is particularly critical for patients with rare bone diseases, among which Osteogenesis Imperfecta (OI) is characterized by bone fragility and deformity that impact mobility [2]. This study aimed to assess the exploitability of a commercialized easy-to-use device for more accessible measurements of motor functionality [3-5].

Methods

25 patients with diagnosed Osteogenesis Imperfecta are recruited for clinical assessment, genetic tests, and gait analysis. For the latter, an established stereophotogrammetry-based gait protocol [6] was used to track segments and joints' kinematics and kinetics during the execution of several motor tasks including walking, sit-to-stand, and isolated knee and hip motion. For level walking, about 150 independent parameters were extracted from the time-histories of these biomechanical variables [7]. Additionally, five IMU sensors were used for concurrent kinematics and spatiotemporal analyses. The spatiotemporal parameters obtained from the stereophotogrammetry-based and IMU-based measurements, were compared over the first 7 patients. For each of these sixteen parameters, the maximum intra-subject absolute error was taken for comparison over subject.

Results

Despite the very different technology and algorithms, maximum and minimum values of the intra-subject errors were adequate (8 out of these 16 spatiotemporal parameters in Table 1).

Table 3. The 8 most relevant spatiotemporal parameters - minimum and maximum absolute error.

	Left stance (%)	Right stance (%)	L stride length (m)	R stride length (m)	L cycle time (s)	R cycle time (s)	L speed (m/s)	R speed (m/s)
Min	3.380	2.693	0.062	0.021	0.046	0.040	0.061	0.013
Max	8.203	5.860	0.239	0.229	1.130	0.198	0.191	0.186

Discussion

The results support the hypothesis of IMU-based device's exploitability for initial gait assessments out of highly specialized laboratories. Therefore, the present work is a contribution to take state-of-the-art multi-instrumental gait analysis to more accessible services of functional assessment. This was preliminary developed to address the monitoring of the critical functional conditions of patients with OI. The present tools and analyses are going to be extended to other rare bone diseases, and to other populations with similar functional conditions. These results will also feed a Machine Learning algorithm to classify OI's type.

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Real time estimation of foot displacement using MIMUs attached to the foot

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Introduction

In recent years, the use of virtual-mixed reality (VR/MR) environments in rehabilitation has gained interest, since it may provide both an engaging experience for the patient and an opportunity for monitoring and recording his/her performance for further uses of the clinician. The main requirement for a VR/MR application in motor rehabilitation is the correct tracking of the subject's motion, which can be achieved by using Magnetic Inertial Measurement Units (MIMUs). A Real Time (RT) solution for estimating foot displacement from the measurements of a MIMU attached to it has been presented in [1] and applied to a single subject. The aim of this paper is to analyze the performance of the aforementioned method on a larger group of subjects.

Methods

Nine healthy subjects wearing a MIMU (Shimmer, Dublin, Ireland) attached over each foot were asked to walk along a straight line at self-selected speed for about 15 meters. The same acquisition protocol as in [1] was implemented. A RT initial identification of Heel Strike (HS) and Toe Off (TO) timings was performed as proposed in [2], and the technique explained in [3] was used to refine the identification of these events. MIMU's linear acceleration was then double integrated between two instants identified respectively as: HS + 40% of stance duration, as suggested by [3], and HS + 40% of the duration of the previous stance, assuming the duration of the stance phase of two consecutive steps to be the same. To limit the integration drift, the foot was considered still at the ends of the integration interval [1], the mean value of the acceleration was removed and the ZUPT-DRI technique [3] was applied. Finally, at the end of each gait cycle, the TEADRIP algorithm proposed by Bertoli et al. [4], requiring a minimum of two stance phases, was applied to obtain a more reliable estimate of the foot displacement, which was then used to correct the RT estimate.

Results

The mean difference and its standard deviation (sd) between the original TEADRIP and the RT TEADRIP stride length estimates, both calculated on the total number of gait cycles analyzed for each subject, is reported in Table 1, along with the Mean Absolute Difference (MAD) between the original TEADRIP and the RT-TEADRIP estimates of the foot trajectory along antero-posterior (AP) direction (averaged between left and right side).

Table 1. Stride length mean difference (sd) and MAD for foot trajectory along AP direction between original TEADRIP and RT-TEADRIP estimates.

Original TEADRIP vs RT-TEADRIP	S1	S2	S3	S4	S5	S6	S7	S8	S9
Stride length estimate mean difference [mm]	0 (60)	2 (20)	0 (52)	-8 (48)	1 (39)	1 (71)	-2 (37)	2 (75)	-3 (43)
MAD [mm]	12	12	17	12	13	16	12	15	13

Discussion

The differences between the estimates of stride length and AP foot trajectory obtained with the original TEADRIP and those obtained using its RT version appear to be very limited and since the original TEADRIP was proven to be suitable for clinical use [3,4], the possible additional error introduced by its RT version is not expected to compromise the use of the latter in VR/MR applications, which are known to be characterized by less strict accuracy requirements than clinical applications. The high intra and inter subject variability suggests that a more detailed analysis of the RT estimates of stride length and AP foot trajectory needs to be carried out.

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Acknowledgments. *This work has been developed within the framework of the project eINS-ECS 00000038 funded by the Italian Ministry for Research and Education under the National Recovery and Resilience Plan and funded also by the ISPETTORATO GENERALE DELLA SANITA' MILITARE.*

A serious game to evaluate throwing performance in altered gravity conditions

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Introduction

In recent years, the use of virtual or mixed reality (VR/MR) as a tool to simulate altered gravity conditions has increased, due to the complexity of carrying out experiments in altered gravity environments [1]. In this paper, we present a preliminary study proposing a serious game to analyze the motor performance of subjects throwing a virtual ball towards a virtual target, while exposed to a MR environment featuring three different gravity conditions.

Methods

Three healthy subjects wearing a HoloLens 2 (HL2) and two Magneto Inertial Measurement Units (MIMUs) (Shimmer, Dublin, Ireland) attached over their forearm and hand, respectively, were asked to throw a holographic ball (10 cm ⌀, 30 g) to a holographic vertical round target (1.3 m ⌀) positioned at 3 m distance and at 1.55 m of height, while the virtual ball was exposed to three virtual gravity levels (9.81 m/s^2 [Earth], 1.62 m/s^2 [Moon], 3.72 m/s^2 [Mars]).

Subjects had some familiarity with the use of HL2 and were asked to perform two sets of five throws in each gravity condition. The first set was conducted to let subjects gain familiarity specifically with the task to be performed, while the second set was recorded and resulting data were analyzed.

The MIMUs acquired acceleration and angular velocity (via Bluetooth using MATLAB R2021a). After removing gravity [2], signals were expressed in the HL2 Local Reference System (LRS) and sent to the VR engine (Unity 3D, version 2021.3.14f1) used to design the virtual environment.

For each throw, the acceleration of the hand-placed MIMU was used to detect the ball release instant. The moment of release was assumed to be at the zero crossing of acceleration vertical component preceding the maximum deceleration, identified as a peak in the acceleration norm (15 m/s^2 threshold). The velocity at the release instant, obtained after integrating the acceleration of the hand-placed MIMU, was sent to Unity via UDP, and used to set the ball initial velocity to initiate its ballistic trajectory.

Results

The performance of the subjects was related to their capacity to hit the target. The average distance from the center of the target, is reported in Table 1, along with the percentage of throws that hit the target, in each gravity condition and for all subjects.

Table 1. Average distance from the target center and percentage of successful throws.

	Subject 1			Subject 2			Subject 3		
Gravity levels [m/s^2]	9.81	1.62	3.72	9.81	1.62	3.72	9.81	1.62	3.72
Average distance [m]	0.22	0.55	0.53	0.32	0.59	0.26	/	0.48	0.38
Successful throws [%]	80	60	80	20	80	100	0	60	80

Discussion

During these preliminary acquisitions we observed how the participants were able to adjust their throwing, adapting to the gravity changes. All subjects reported a greater ease in performing the throws in Moon and Mars environments as compared to the Earth, which is in line with the results shown in Table 1. The subjects also reported a visual discrepancy between the expected ball trajectory and the one actually followed by the virtual ball, suggesting the need for a refinement in the ball initial velocity determination. A delay between the release instant as seen in HL2 and the release instant estimated according to the method described above was also observed. Based on the participants' opinion, future game versions should include some form of haptic feedback.

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Acknowledgments. *This work has been developed within the framework of the project eINS-ECS 00000038 funded by the Italian Ministry for Research and Education under the National Recovery and Resilience Plan.*

Feasibility of machine learning algorithms fed with frequency-domain features extracted from inertial signals to classify safe and unsafe postures during lifting tasks

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Introduction

The risk of developing work-related musculoskeletal disorders (WRMDs) is strongly correlated with the safe and unsafe postures during the weight lifting. Recently both the inertial signals - linear acceleration and angular velocity - acquired by wearable sensors and the Machine Learning (ML) techniques have shown to be able to successfully assess the biomechanical risk in the ergonomic filed [1]. The aim of this study was to assess the feasibility of four ML classifiers - fed with frequency-domain features extracted from inertial signals acquired by means of one inertial measurement unit (IMU) placed on the sternum - to classify safe and unsafe postures during weight lifting.

Methods

The study was performed on a study population composed of 4 healthy volunteers (2 male and 2 female) with no signs of musculoskeletal disorders. The study protocol was divided into two trials. Each trial consisted in a task session of 20 consecutive weight liftings. In the first trial, the liftings were associated with a safe posture (squat) while, in the second trial, the liftings were associated with an unsafe posture. The inertial signals were acquired from each subject and then manually segmented in order to extract the regions of interest (ROIs) relating to each lifting. For each ROI, the following frequency-domain features were extracted: Power, Kurtosis, Skewness, Entropy. Four ML algorithms, fed with the extracted features, were implemented, namely Naïve Bayes (NB), Support Vector Machine (SVM) with polynomial kernel, Multilayer Perceptron (MLP) and K-nearest neighbors (KNN). As validation strategy, ten-fold cross-validation was used. Knime Analytics Platform was used to carry out the ML analysis.

Results

The dataset was composed of 160 instances (4 subjects *x* 40 instances), 24 features (4 features *x* 2 signals (acceleration and angular velocity) *x* 3 axis (x, y, z) *x* 1 body position (sternum)) and 2 classes (Safe posture, Unsafe posture). Table 1 summarize the evaluation metrics scores reached by the ML classifiers to discriminate safe and unsafe classes. The best ML algorithm was SVM with accuracy and AUCROC equal to 0.981 and 0.999 respectively with only 3 out of 160 instances misclassified.

Table 1. Evaluation metrics scores of ML models using tenfold cross-validation.

	SVM	MLP	NB	KNN
Accuracy	0.981	0.844	0.812	0.95
F-measure	0.981	0.865	0.815	0.949
Specificity	0.988	0.688	0.8	0.963
Precision	0.987	0.762	0.805	0.962
Recall	0.975	1	0.825	0.938
AUCROC	0.999	1	1	1

Discussion

The four ML classifiers - fed with frequency-domain features extracted from inertial signals - proved to be able to successfully classify safe and unsafe posture using one IMU placed on the sternum. Similar works, such as Conforti et al. [2], proposed similar methodologies using IMUs placed on several parts of the body limiting their use in the workplace. Thus, the presented methodology could represent a valid integration to the procedure already established in occupational ergonomics.

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Position-specific muscle coactivation in human-robot collaboration

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Introduction

The activity of collaborative robots (cobots) is becoming significantly present in work environments as a tool for increasing ergonomic performance and workers level of comfort. In the case of working activities involving repetitive movements of the upper arm, investigating how the robot affects the behaviour and the comfort in realizing a quasi-periodical task is a critical issue. This can help to developcontrol algorithms that can provide an effective decrease of developing musculoskeletal disorders risks.Among the parameters that allow the biomechanical risk quantification, muscular coactivation has beenproposed as a compact index for analysing risk factors associated with excessive muscle activity [1]. Inthis work, muscle coactivation during human robot collaboration has been characterized as a function of the end-effector position, to yield a neuromechanical description of this risk parameter.

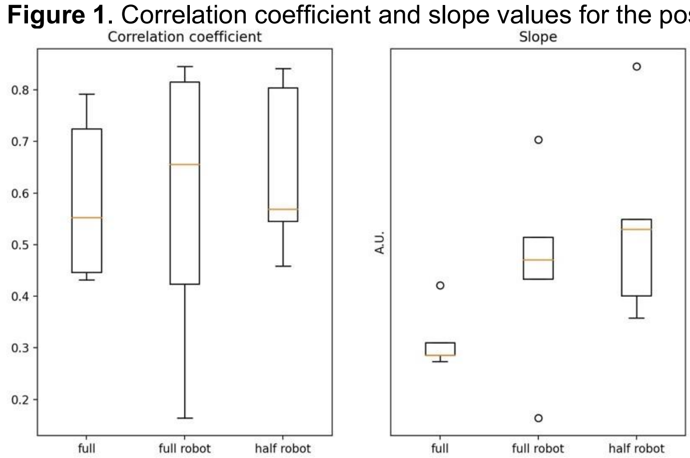
Methods

The analysed task simulates the activity of a cashier that grabs a 1kg package from a loading zone, identify a barcode on it, scans it and finally places the package into an unloading zone. This task has been realized in three different modalities: with no cobot assistance (*full*), with cobot assistance dutingloading (*half robot*) and with full loading and unloading assistance (*full robot*). EMG data has been recorded using five wireless probes on the right forearm (*i.e.,* the loading arm) in a bracelet configuration;kinematic data has been recorded via a motion capture system. The correlation between the distance from the centre of the trunk to the right wrist and the muscle coactivation has been evaluated in terms of correlation coefficient and slope. Five subjects were enrolled in the study, and each experimental trial consisted of 20 handled packages per modality.

Results

Correlation results are shown in Figure 1. A moderate correlation (median values higher than 0.5) canbe observed for all the three tested modalities. As for the slope values, the two modalities in which thesubject must collaborate with the cobot present higher values with respect to the natural task executionwith no external assistance.

Figure 1. Correlation coefficient and slope values for the position-coactivation.



Discussion

The presented results show that, during robot collaborative tasks, the subject needs to increase the level of muscle coactivation to explore more distant regions in space. While collaboration with the cobottypically allows smaller distances to be reached (thus generating an overall lower coactivation index), the higher slopes of the distance-coactivation curve highlights the need to have a thorough optimizationof the relative position of the robotic and human end effectors, in order to achieve a reduction of the effort needed from the human operator.

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Synergy-specific dynamical patterns in sit-to-stand movement

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Introduction

The sit-to-stand task is a widely used clinical test for the assessment of biomechanical performance ina variety of different pathological conditions. The characterization of how the central nervous system controls the movement of the body during this simple task can help in tracking a patient's biomechanicalperformance, as well as improving our understanding of the human neuromusculoskeletal system, evenfor healthy people. Among the motor control theories that have been proposed in the literature, the oneof muscle synergies has been tested for its capability of capturing relevant movement features and facilitating neuromechanical interpretations. In this work, we aimed to seek for synergy-dependent pattern in the centre of mass dynamics, by testing whether the motor control complexity of healthy participants impacts the dynamical patterns during standard sit-to-stand tests.

Methods

13 healthy subjects (2F, 36.9 ± 10 yo, range 24-55 yo, 177.2 ± 6.6 cm, 79 ± 11.7 kg) were asked to perform a 30s sit-to-stand test on an instrumented chair designed for sit-to-stand assessment [1]. The subject centre of mass (CoM) mechanical work has been determined via the scalar product between its 3D velocity (recorded via a BTS SMART DX system) and the total reaction force vector coming from2 force plates (BTS P6000). Muscle synergies were extracted by means of a non-negative matrix factorization from 8 muscles EMG of the dominant leg (BTS FREEEMG 1000); the number of synergiesNSYN has been determined through a modified Akaike information criterion [2]. CoM dynamical trajectories were divided and averaged based on the number of synergies found during the whole trial.

Results

The NSYN characterizing the whole group was 2, 3 and 4 in 23%, 30% and 47% of the subjects, respectively. In Figure 1, the average CoM dynamical trajectories are presented as a function of the number of identified synergies. In general, the higher the number of synergies, the lower energy (*i.e.* the CoM speed by force product) the movement requires.

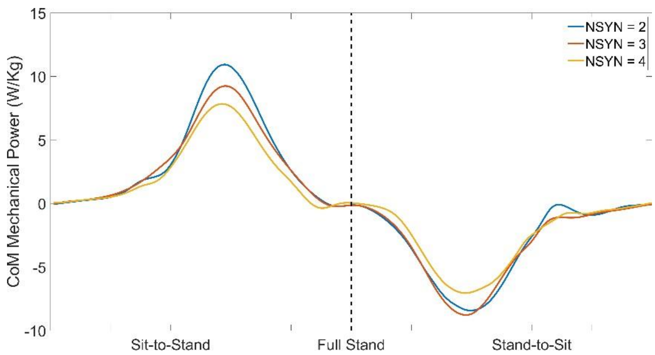

Figure 1. CoM-Work profiles for different numbers of synergies

Discussion

The presented results show that it is possible to find synergy-dependent biomechanical patterns during standardized sit-to-stand tasks. In particular, the complexity of the motor control structures (*i.e.,* the number of synergies) seems to be linked with the energy required to perform the task. While the causalrelationship between those two neuromechanical features is yet to be characterized, it can be hypothesized that using only two synergies for performing sit-to-stand results in a movement pattern that has a more significant inertial characteristic, with high peak values that are needed to start a moreballistic movement of the centre of mass, that involves more feedforward mechanisms; a higher numberof synergies means, in contrast, that the movement is more controlled by feedback mechanism for balance control, resulting in generally lower peak values.

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Validation of a wearable multi-sensor system for characterizing gait under extreme terrain conditions.

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Introduction

Limbed robotic technologies are now being used in real-world environments with diverse and unpredictable terrains, which can pose stability risks for legged systems. By studying human gait in challenging environments, researchers can gain insights into the biomechanics of walking on unstable surfaces and apply this knowledge to develop more robust and stable robotic systems. Wearable systems, offer advantages over traditional laboratory-based systems for studying human gait in challenging conditions, as they allow for data collection in real-world environments that closely resemble the conditions faced by legged robots [1]. The aim of this study is to validate the use of the INDIP system, which is a wearable multi-sensor system including inertial modules, pressure insoles, and distance sensors [2], for characterizing gait in diverse, unstructured terrains.

Methods

Gait data from 10 young healthy individuals were recorded. Subjects were equipped with INDIP and a stereophotogrammetric system (Vicon, Oxford, UK), used as reference. The protocol comprised walking tasks over 5 different terrains [3] I) soft, II) downward sawtooth, III) unstructured, IV) upward sawtooth, and V) overground terrain (Figure 1). Each task was performed at ground level and at 15° of inclination and repeated 4 times, resulting in a total of 40 trials. Due to the irregularities of the surfaces, gait cycle segmentation for the reference system was manually performed, while the INDIP system data were processed using a modified version of a previously method validated on healthy and unhealthy gait [2].

Figure 1: I) Soft, II) Downward Sawtooth, III) Unstructured, VI) Upward Sawtooth, and V) Overground terrain conditions.

Results

Among all conditions, a temporal difference from -0.05 to 0.10 seconds for event identification between systems was obtained. In terms of spatiotemporal parameters on overground terrain, errors of 0.04 meters for stride length, 0.01 seconds for stride time, and 0.04 meters per second for walking speed were found. Regarding the rest of conditions, the mean absolute error ranged from 0.04 to 0.07 meters for stride length, from 0.02 to 0.05 seconds for stride time, and from 0.04 to 0.06 meter per seconds for walking speed.

Discussion

The present study compared the performance of a wearable multi-sensor system against a reference system for the gait events and parameters estimation. The errors in spatiotemporal parameters on overground terrain are acceptable compared to a previous study [2]. Although errors are slightly higher in other conditions, there is no significant difference or variation in errors based on the type of terrain. These results suggest that although the INDIP performance in uneven terrains is worse compared to overground conditions, the system still offers reasonably accurate estimates of stride length, time, and speed across different types of terrain. However, a more comprehensive examination of all spatiotemporal parameters is required to confirm these results.

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A preliminary validation of a 3D markerless method for estimating the kinematics of a two-segment foot model using a single RGB-D camera.

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Introduction

The analysis of foot kinematics is crucial for detecting and quantifying gait alterations. Its estimate is often performed using stereo-photogrammetric marker-based technology (SP), associated with a variety of multi-segment foot models [1]. However, the use of SP inevitably limits the analysis to high cost laboratory settings. Marker-less alternatives based on single RGB-Depth camera have been recently proposed to overcome these limitations. These methods (e.g. Azure Kinect Body tracking SDK, OpenPose, [2]) allow to model the foot as a single segment without articulating the metatarsophalangeal (MTP) joint, which is crucial to guarantee an effective load of the foot and correct progression [3]. The aim of this study is to design a marker-less method based on a single RGB-Depth camera for estimating sagittal ankle and MTP kinematics using a two-segment 3D foot model and explore its clinical applicability on children with foot deformities.

Methods

One eleven-year-old boy affected by Clubfoot was asked to walk in a gait analysis laboratory equipped with an RGB-Depth camera (Azure Kinect, fs = 30 fps) placed laterally to the walkway at 0.6 m. External anatomical landmarks (LM: lateral malleolus; LE: lateral epicondyle, MTP5: 5th metatarsophalangeal joint and TOE) were identified by palpation and marked with a black pen. Four static views (frontal, posterior, medial and lateral) of both feet and five gait trials at self-selected speed for both right and left side were acquired. A two-segment (mid-rear and forefoot foot) 3D foot template was created by merging the static views and calibrated by manually selecting the anatomical landmarks (MTP5, LM, TOE). A depth completion technique, based on a low pass filter, was implemented to reconstruct, during the gait trials, missing depth information by exploiting RGB information. The positions of LM and MTP5 were reconstructed by matching the foot template to the point clouds reconstructed during the gait trials, the TOE was identified as the most distal foot point while LE position was computed as in [3]. Kinematic curves were validated against manually labeled anatomical landmarks on the RGB images and root mean square errors (RMSE) were estimated.

Results

Average RMSE (deg), 10 trials segmented by applying [3]: MTP: 4.2 (R), 4.8 (L); ankle: 3.5 (R), 3.9 (L).

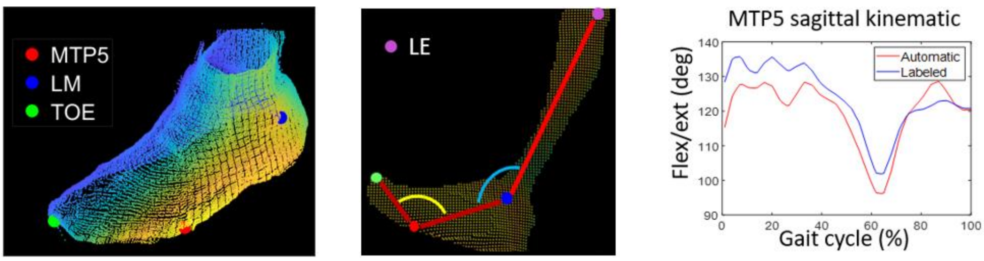

Figure 1. Example of 3D foot model, dynamic LM and MTP5 identification and sagittal foot kinematics.

Discussion

This study presented a two-segment foot model for estimating foot kinematics using a single RGB-Depth camera. The proposed method requires only four views to create the 3D foot model, which limits discomfort during the session. The reported errors are mostly associated with the technological limitations of the RGB-Depth device employed. Inaccuracies in the forefoot fitting were mainly due to the low number of points (forefoot to mid-rear-foot points ratio = 0.26) and missing depth values during foot swing. Considering the rapid technological advancement in depth sensing, the proposed approach seems to be a very promising solution for evaluating gait of subjects with foot deformities. Validation on a larger cohort is ongoing.

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An artificial intelligence based 3-dimensional markerless motion capture system for indoor and outdoor sport applications

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Introduction

Motion capture technologies have always attracted great interest in the sports field. Nowadays, numerous resources are being employed in the development of new markerless motion capture technologies [1], that offer the possibility of overcoming some limitations of marker-based systems [2]. The aim of this study was to assess the reliability and repeatability of a convolutional neural network (CNN_markerless -CNN-) based markerless motion capture system trained with a proprietary dataset of 2D labels according to IORGait [1] marker set acquired in the wild.

Methods

7 healthy subjects (age and BMI respectively 26.3±2.1 years, 21.7±2.5 kg/m^2) were simultaneously acquired through 8 GoProHero® cameras (v3-7, 30-240 Hz) and 6 BTS (60-120 Hz) cameras while performing 3 consecutive bilateral squats within the BiomovLab (DEI-University of Padova). All subjects gave written informed consent to the protocol approved by the local Ethics Committee.

The Deep Learning System takes 2D images as input and returns heatmaps for each available perspective.Then, the CNN creates the 3D trajectories of each anatomical point through which the temporal trends of joint angles are computed. The agreement with the results obtained by stereophotogrammetry and video-based tracking (TrackOnField -ToF-, BBSoF S.r.l.) is assessed through the Root Mean Square Error (RMSE) and the Coefficient of multiple correlation (CMC) [3].

Results

In Tab.1 results of the comparison between joint angles obtained with the different techniques were reported in terms of CMC and RMSE.

Table 1. CMC [3] and RMSE (min < mean < max) normalized (NRMSE) on the peak computed among joint angles from stereophotogrammetry, ToF and CNN data.

	CMC - TOF	CMC - CNN	NRMSE - TOF	NRMSE - CNN
trunk flexion-extension	0,565 < 0,871 < 0,976	0.483 < 0.877 < 0.996	0,262 < 0,501 < 0,889	0.133 < 0.582 < 2.242
hip flexion-extension	0,990 < 0,996 < 0,999	0.973 < 0.986 < 0.993	0,030 < 0,107 < 0,194	0.168 < 0.234 < 0.338
knee flexion-extension	0,994 < 0,997 < 0,9999	0.679 < 0.871 < 0.983	0,020 < 0,083 < 0,152	0.245 < 0.427 < 0.733
ankle dorsi-plantar flexion	0,991 < 0,996 < 0,999	0.906 < 0.936 < 0.970	0,062 < 0,122 < 0,196	0.360 < 0.450 < 0.548

Discussion

This study reveals a good correlation on the sagittal plane joint kinematics accompanied by reduced NRMSE values. The best results were obtained for hip flex-extension. Results are encouraging towards on the field sport applications.

Disclosure. *Niccolò Monaco is the developer of the CNN_markerless system and Federica Cibin is the product specialist at BBSoF S.r.l (spinoff of the University of Padova).*

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Machine learning approach to detect the 3D human posture from a 2D image

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Introduction

Given that musculoskeletal alterations are a leading cause of disability in young adults [1], reliable, non-invasive screening methods can help healthcare organizations to detect these abnormalities early. Recent tech advances propose machine learning (ML) techniques for human motion analysis via 2D images. This technology is being applied in various fields like physical movement quantification, sign language interpretation, and gesture control. Google recently released MediaPipe, a ML technique able to identify 33 body landmarks in Cartesian coordinates. The advantage of ML in motion analysis is its entirely objective evaluations, eliminating potential errors caused by the operator carrying out the measurements [2]. This study proposes an innovative methodology for analyzing human posture using specific ML algorithms.

Methods

We assessed 100 healthy volunteers, 50 males and 50 females, average age 27.4 (SD ± 3.2) years, excluding those with past or current musculoskeletal, spine, and neurological pathologies. Photos were taken from a tripod-mounted camera 2m away from the subject. The images were analyzed using a MediaPipe-based ML algorithm to locate body landmarks and calculate postural parameters.

Results

The algorithm to identify the anatomical landmarks and match 3D front and back images revealed significant gender differences with a medium to large effect size for most parameters (Table 1).

Table 1. Mean value of the 3D matching between front and back images.

	Parameters	**Males mean (SD)**	**Females mean (SD)**	**Sig.+**	**Effect size ++**
Joint angles	Shoulder	16.78 ° (2.20)	13.58 ° (1.55)	< 0.001	1.67
	Elbow	8.32 ° (4.03)	4.89 ° (2.84)	< 0.001	0.97
	Hip	11.45 ° (2.05)	8.62 ° (1.73)	< 0.001	1.48
	Knee	2.75 ° (1.25)	2.29 ° (1.01)	0.064	0.40
Horizontal angles	Head line	2.13 ° (1.25)	1.93 ° (0.73)	0.351	0.20
	Shoulders line	1.41 ° (0.69)	1.55 ° (0.63)	0.316	-0.22
	Hips line	1.19 ° (0.53)	1.13 ° (0.53)	0.577	0.12
Vertical angles	Body imbalance	1.02 ° (0.48)	1.04 ° (0.45)	0.870	-0.03
	Trunk line	10.13 ° (0.73)	9.03 ° (0.71)	< 0.001	1.51
	Leg line	1.89 ° (0.70)	1.64 ° (0.50)	0.054	0.41
Lateral inclination	Neck	13.80 ° (3.95)	15.42 ° (3.61)	0.052	-0.42
	Trunk	2.76 ° (1.99)	2.22 ° (1.83)	0.204	0.27

+ Sig. according to t-test and Mann–Whitney U; ++ Effect size according to Cohen's d.

Discussion

This approach is valid, simple, and accessible. It analyzes joint angles and body alterations, yielding results without requiring expertise for identifying anatomical points in postural assessment. The algorithm accurately identifies these points and measures them. Further studies will investigate the validity of this method in a pathological population with common musculoskeletal disorders.

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Kinematic network changes following the assumption of levodopa in Parkinson's disease.

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Introduction

While three-dimensional motion analysis represents a quantitative and objective approach to assess spatio-temporal and kinematic alterations in Parkinson's disease (PD) [1], [2], it provides segmental information, discarding the whole-body patterns underlying the motor impairment in PD. Borrowing from network theory, the kinectome framework [3] has been developed in order to provide a comprehensive description of the interactions between body elements during gait. In the present study, we investigated how the levodopa (i.e., the gold standard for the treatment of motor symptoms in PD) affects the large-scale movement pattern in PD. To this aim, we built the kinectomes of 23 PD patients before (PD off-state) and after (PD on-state) the levodopa intake. We performed a topological analysis to assess whether the levodopa intake resulted in a change of the synchronization of the kinematic patterns. Finally, we investigated if such topological variations could be related to clinical picture.

Methods

We collected the kinematic 3D-trajectories (trough stereophotogrammetric acquisitions) from several markers applied on bone landmarks of 23 participants. Hence, the level of synchronization between pairs of body segments was estimated through a Pearson's correlation between the time series of the markers' accelerations. Hence, we built the covariance matrices (i.e., the kinectomes) whose nodes were defined by the bone markers, and the links were determined by the level of synchronization between each couple of nodes. Then, we performed a topological analysis to evaluate the large-scale interactions between body elements. To this end we calculated the nodal strength which provide information about the importance of a node (i.e., bone marker) within the kinematic network. Finally, we performed a multilinear regression analysis in order to verify whether the kinectome's topological features could predict the clinical variation before and after the levodopa intake.

Results

PD patients showed lower nodal strength (i.e., lower synchronization) in the upper body in the medio-lateral acceleration while at the "on-state" with respect to the "off state" (p-head = 0.048; p-C7 = 0.032; p-T10 = 0.006). On the contrary, PD patients in the "on state" displayed higher nodal strength (i.e., higher synchronization) of both elbows (right, p = 0.002; left, p = 0.005), wrists (right, p = 0.003; left, p = 0.002) and knees (right, p = 0.003; left, p = 0.039) in the antero-posterior acceleration. Furthermore, the predictive analysis revealed that the nodal strength variations of the arms, due to the intake of levodopa, significantly predicted the clinical variations assessed through the UPDRS ($R2$ = 0.65; p = 0.025) (Figure)

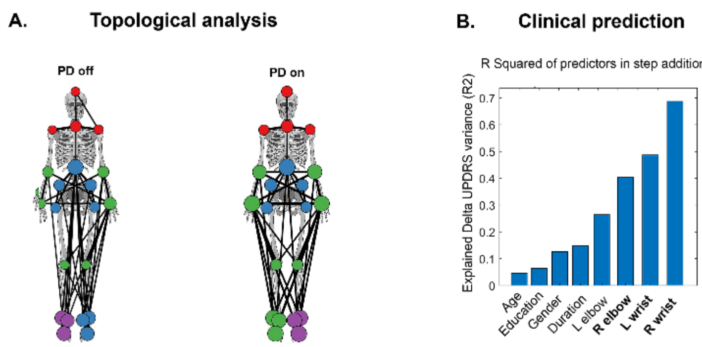

Figure: A. Schematic representation of the kinematic network; **B.** Clinical prediction UPDRS variation

Discussion

Following the assumption of levodopa, we observed increased synchronization of the arms and reduced synchronization of the trunk with respect to the whole body. Hence, the oscillatory pattern of the arms was more in phase with the rhythmic pattern of the legs. As a consequence, PD patients in the "on-state" showed less rigidity during walking, proportional to the UPDRS variation. Finally, we showed that the levodopa intake led to greater harmony of the large-scale kinematic pattern in Parkinson's disease.

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Estimation of temporal parameters using foot-worn inertial sensors for different running speeds

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Introduction

The analysis of stride/step-segmented biomechanical parameters provides valuable information for the description of running performance [1]. Wearable inertial sensors are largely adopted to segment running stride cycles and estimate within-stride phases durations (e.g., contact and swing time). However, the methods proposed in the literature are generally validated on a restricted range of running speeds thus, limiting generalizability across different sports associated with running. The largest range of running speeds tested in the literature is about 10 km/h [2]. The aim of this study is to propose and validate a novel template-based method for the identification of temporal parameters on a wide range of running speeds (about 24 km/h), and compare the performances with previous literature [2].

Methods

A total of 30 runners were enrolled: 1) 11 amateurs running for 400 m on treadmill and track at 8-10 km/h; 2) 10 amateurs running on treadmill at 14 km/h for 6 min; 3) 9 athletes performing 80 m-sprints on track at 20-32 km/h. All the runners were instrumented with two foot-worn IMUs (fs=200Hz for dataset 2, 100Hz for 1 and 3). The reference for the detection of temporal parameters was a motion capture system for dataset 2 and instrumented pressure insoles for dataset 1 and 3. Twenty mid-swing to mid-swing running cycles, extracted evenly from all the datasets and labeled with reference initial and final contacts, were used as a library of templates. The running events for all the other running cycles (more than 43000) were estimated with [2], as minima of mediolateral angular rate, and with the proposed template-based method. The latter was based on the peak sharpening of the inertial signals and the association of each running cycle with a template maximizing the similarity assessed with the dynamic time warping. The running events of each analyzed cycle were then derived from the reference events of its most similar template to calculate stride, contact, and swing durations. The estimates of these durations were compared to the reference values. Friedman test with Bonferroni correction was used to investigate the differences among the obtained errors across the analyzed running speeds.

Results

Table 1 shows the mean absolute percentage errors obtained with [2] and with the proposed method, highlighting the significant differences among results of each temporal parameter across speeds.

Table 1. Mean absolute percentage errors (MAE%) of stride, contact, and swing durations.

	Falbriard et al. 2018			Novel template-based method		
	Stride	Contact	Swing	Stride	Contact	Swing
Speed (km/h)	MAE%	MAE%	MAE%	MAE%	MAE%	MAE%
8-10	1.2±0.4	27.0±4.1	21.2±5.1 *	3.8±1.0	13.2±4.6	9.7±2.9
14	1.0±0.7	17.3±7.0 *	8.9±4.6 *	2.3±1.1	15.8±9.8	7.4±4.6
20-32	2.1±1.0	31.2±12.1 *	20.0±12.1 *	3.8±4.2	20.3±8.1	9.7±3.0

* Comparison across speeds with $p<0.05$

Discussion

In this study, we tested the performances of two methods for the estimation of temporal parameters during running from 8 to 32 km/h. While the method proposed by [2] led to slightly better results in the estimation of initial contacts and stride durations, the proposed template-based method improved the detection of final contacts and within-stride phases durations, where MAE% decreased up to ~13%. Importantly, the performances of the template-based method were not significantly affected by speed, contrary to [2]. This suggests that the template-based method can be a valid solution for estimating running temporal parameters during outdoor running at variable speeds. Its accuracy is expected to further improve increasing the number of templates. Funding provided, in part, by Diadora S.p.A.

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A sensor-based approach for the characterization of mobility in patients affected by soft tissue tumors and tumor-like lesions

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Introduction

Sarcomas, tumours of putative mesenchymal origin, account for nearly 21% of all paediatric and about 1% of all adult solid malignant cancers [1]. Approximately 84% of these are soft tissue sarcoma (STS), while 14% are primary bone sarcoma (BS), each of which has different staging and treatment approaches [2]. Limb salvage surgery, chemotherapy, and radiotherapy could have a detrimental impact on the locomotor system [2,3]. Quantitative and objective assessment of this impact is crucial to properly define personalized rehabilitation treatments and monitor their efficacy. To this aim, the development of ecological protocols to objectively assess gait quality directly in the clinical context is crucial [3]. The purpose of this study was thus to test a full-body sensor-based protocol to characterize digital mobility outcomes of gait in patients with STS and BS.

Methods

Seven patients (2 M, age 46 ± 18 years, 1,64 ± 0,05 m) with STS or BS at the lower body participated in the study. All patients performed three times the 2 min walk test while wearing 15 Magneto-Inertial Measurement Units (MIMUs) (APDM Opal Inc., 128 Hz) located on all body segments according to [4]. The APDM Moveo Explorer software was used to extract the following parameters: stance, swing, and double support durations (StD, SwD, DSD), cadence (Cad), gait speed (GS), stride length (SL), arm swing velocity (ArmV). Joint kinematics was also estimated: flexion-extension range of motion (RoM) of the hip, knee, and ankle joints (HRoM, KRoM, ARoM), as well as of the arms (ArmRoM). Mean values and standard deviation (SD) across the three tests were considered for each parameter.

Results

GS, SL, HRoM, KRoM, and ARoM displayed the greatest differences compared to the normative values (Fig.). As expected, participants showed high variability, particularly in Cad (SD: 13 steps/min), ArmV (SD: 51 m/s), ArmRoM (SD: 12°), and lower limb joint sagittal RoM (SD: 18°, 20°, 78° for HRoM, KRoM, ARoM, respectively).

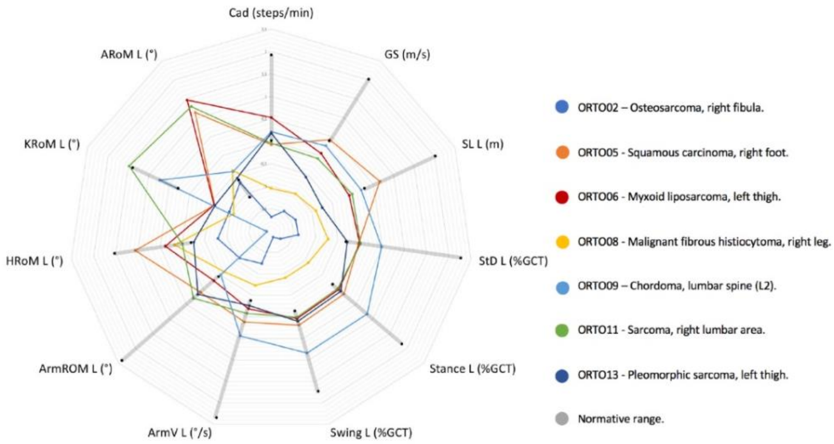

Figure. Spatiotemporal and kinematic parameters in patients with BS and STS. Grey rays indicate normative values [5].

Discussion

The present results suggest that a full-body wearable-based instrumental protocol can be used with patients with STS or BS for the objective assessment of gait quality. As expected, a high variability characterised the tested population and a personalised approach may be used to assess gait impairments which largely vary according to the type and location of the tumour, as well as to the kind of intervention. The potential of the presented protocol to detect changes over time must be assessed together with its accuracy against gold-standard instrumentation [6].

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Muscle activity during passive and spontaneous movements in preterm and full-term infants

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Introduction

Manifestation of muscle reactions at an early developmental stage may reflect the processes underlying the generation of appropriate muscle tone [1] and the emergence of coordinative activity during spontaneous or stepping movements [2,3]. Sensory feedback resulting from interactive and spontaneous movements is instrumental for developing sensorimotor circuits in early infancy, and shorter gestational periods (preterm infants) may have an impact on muscle strength and functionality. Here, we aimed at investigating potential differences between the behavior (movement-related muscle activity) of preterm infants and that of full-term infants.

Methods

Here we evaluated early manifestations of muscle tone by measuring muscle responses to passive stretching (StR) and shortening (ShR) in both upper and lower limbs in preterm infants (at the corrected age from 0 weeks to 12 months), and compared them to those in full-term infants. Passive movements were recorded in a supine position in both left and right limbs, were periodic (typically 4–7 consecutive cycles of flexion/extension) and relatively slow (~1.5 s duration of each flexion/extension). In a subgroup of participants, we also assessed spontaneous muscle activity during episodes of relatively large limb movements (limb endpoint excursion ≥15% of the body height). The rationale for measuring muscle activities during both passive and active movements is that we focused our study on the analysis of movement-related activity, which can be measured in these two important types of movements.

Results

For muscle responses to passive movements, the results showed very frequent StR and ShR, and also responses in muscles not being primarily stretched/shortened, in both preterm and full-term infants. The major finding of the current study was that there were age-related changes in the manifestation of muscle responses in both preterm and full-term infants. The majority of muscles generally showed a significant decline in the expression of reactions with age in both full-term and preterm infants. For active (spontaneous) movements, the appearances of selected episodes of relatively large limb movements were in general similar in full-term and preterm infants. However, the age-related increments in correlations of antagonist muscle activity were notable only in full-terms.

Discussion

Overall, both full-term and preterm infants showed similar characteristics and postterm development of muscle activity during passive and spontaneous movements. A reduction of sensorimotor responses with age suggests a reduction in excitability, and/or the acquisition of functionally appropriate muscle tone during the first year of life. However, the preterm infants showed higher rates of muscle responses to passive movements at 3-6 mo corrected age, and lacked age-related increases in antagonist activity correlations during spontaneous movements. Thus, the alterations of responses during passive and active movements in preterm infants were primarily seen in the early months, perhaps reflecting temporal changes in the excitability of the sensorimotor networks.

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A sensorimotor characterization of the Alzheimer's disease continuum with Linear Discriminant Analysis

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Introduction

In contrast to cognitive deficits, sensorimotor impairments in Alzheimer's Disease (AD) have not received much attention and their correlation with cognitive deficits is still debated. Impairments in visuomotor processing and motor coordination may have a considerable impact on the ability to perform activities of daily life and consequently may worsen quality of life. In addition, a thorough characterization of sensorimotor features in individuals with dementia could help in developing novel diagnostic protocols for an early detection.

Methods

To investigate sensorimotor impairments in the Alzheimer's disease continuum, 20 AD, 20 Mild Cognitive Impaired (MCI), and 20 age-matched healthy control (HC) individuals performed reaching and catching tasks in virtual reality (VR). Kinematic data were recorded with the embedded tracking system of a HTC Vive headset used to render the VR scenario. Spatial and temporal accuracies were computed in both tasks to quantitatively characterize sensorimotor abilities. In addition, the overall task performance (i.e., the number of successful trials) provided a gross metric to evaluate individual skills in VR. Cognitive abilities were assessed with a Mini Mental State Examination (MMSE) and the resulting score was compared with motor performance. Finally, Linear Discriminant Analysis (LDA) was applied to the several kinematic features analyzed in both tasks (reaction time, movement time, speed, accuracy, and performance).

Results

Overall, HC participants achieved a better performance than both AD and MCI groups. In particular, AD participants showed delayed and slower movements. However, AD had similar movement speed in the catching task but were less accurate than HC. MCI participants' performance was in between that of AD and HC individuals. MMSE score was significantly correlated with all metrics used to characterize the sensorimotor tasks, suggesting that sensorimotor impairments may be a valid predictor of cognitive impairments. Finally, a three-way classification (33% chance) performed with LDA on kinematic characteristics of both tasks clustered individuals in each group (i.e., HC or MCI or AD) with an accuracy of 59%, indicating that sensorimotor features can discriminate different levels of cognitive impairment.

Discussion

These findings suggest that sensorimotor features can be used to evaluate cognitive deficits in individuals with dementia. LDA components provide an indicator that could help in classifying individuals even at the early stages of dementia (MCI). Furthermore, the set of tests developed for this protocol indicates that a more comprehensive assessment is needed to examine all the aspects of the disorder. Such innovative approach can set the stage for future studies that explore sensorimotor behavior in relation with AD and MCI. In addition, characterizing sensorimotor deficits could provide an early assessment of the AD continuum through a simple protocol involving both motor and cognitive tasks.

Evaluating the Safety and Efficacy of a Memorized Weight-Shifting intervention designed to help people with Parkinson's overcome freezing of gait

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Introduction

Freezing of gait (FoG) in people with Parkinson's often increases the risk of falling and reduces qualityof life. When preparing to initiate walking people will typically shift their weight to their non-stepping limbto unload and allow the leading limb to move forward, using so-called Anticipatory Postural Adjustments(APAs). However, these unconscious adjustments are often impaired in people with Parkinson's and FoG. In previous studies [1, 2], we used a step-in-place paradigm to induce FoG and showed that a weight-shift (WS) intervention, involving the conscious creation of APAs, could improve step success when initiating forward and turning steps from a freeze. However, due to the nature of this reductionistparadigm, results cannot be generalised to daily life. We therefore aimed to assess the efficacy and thesafety of this WS intervention in a more complex, challenging and ecologically valid context.

Methods

Twenty people with PD and FoG completed the following tasks ON medication. Participants were fittedwith 39 retroreflective markers, placed according to the Conventional Gait Model and a VR headset, which showed a complex domestic scene (cluttered corridors). The dimensions of the virtual environment (VE) matched the size of an instrumented floor made of an array of force plates(3.6m*3.6m). People were instructed to walk in the VE and to stop and turn on a designated spot in thecentre of each corridor. The study had 3 conditions: Baseline, intervention A (WS training) and intervention B - placebo (Attention Control, AC). The order of the two interventions was randomized. Before each intervention, participants were asked to watch training videos co-designed with a Project Advisory Group made of people with PD and clinical experts. Participants then completed the walking task and were instructed that, when attempting to initiate walking, they should try to use the respectivelearned strategies. FoG events, FoG duration and successful/unsuccessful attempts to step from a freeze were identified through the subjective evaluation of video recordings. Force plates and motion capture data were used to extract spatiotemporal characteristics of the APAs [3] preceding successful/unsuccessful steps. The following parameters were calculated for each condition: ratio between successful/unsuccessful steps following FoG, average FoG duration, FoG incidence and APAs amplitude preceding steps. In addition, participants rated the perceived safety and effectiveness of theintervention on a scale of 1 (lowest) to 11 (highest).

Results

For Baseline, Post-WS training and Post-AC we recorded 200, 103 and 83 FoG events respectively. Seven participants experienced FOG in both Baseline and Post-WS training conditions. As only 5 participants experience FoG in the Post-AC condition this condition was excluded from the statistical analysis. The Post-WS training (median±interquartile; range=76%±54%) condition showed a higher percentage of successful steps from FOG compared to Baseline. Similarly, the average APAs amplitude significantly increased from Baseline to the Post-WS condition. Participants reported that they perceived the training as safe (mean score± standard deviation; 8.7±1.1/11) and effective (7.5±2.3/11)at helping them step from FOG, when used in daily life following the laboratory session. FoG incidenceand duration remained unchanged in the different conditions.

Discussion

The WS training had a clear effect in supporting step initiation from a freeze, even during a complex walking task. In addition, participants reported that the strategy felt safe to use. Compared to previousdata, the current results indicate that the increased task complexity may slightly reduce the effective execution of memorised WS strategies. Nevertheless, we suggest that the current observations show the utility of the WS-training in challenging scenarios that require users to adapt the strategy to the required action (forward vs turning steps), and, therefore, highlighting the potential applicability of the WS-training in real life.

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Implementing an immersive virtual reality protocol for functional gait disorders: an experimental study

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Introduction

Functional gait disorders (FGDs) are among the most disabling symptoms that affect patients with Functional Motor Disorders (FMDs) [1]. Multidisciplinary management and rehabilitation are crucial for functional recovery, and literature suggests how some technological tools, such as Virtual Reality (VR), could add value to manage these patients [2]. VR could improve walking disorders [3] and, consequently, quality of life. However, no study has been conducted to explore the effects of VR on FGDs. This study explores how an immersive VR protocol might shape spatio-temporal gait parameters in healthy controls (HC) to collect normative data to compare effects on patients with FGDs.

Methods

In all, 22 HC (age 31 ± 11 years, female 63.6%) underwent spatio-temporal gait analysis during free walk (ST), cognitive (cDT), and visual-fixation (vDT) dual task wearing FeetMe insoles. Tasks were executed in real and virtual environments as seen in Figure 1. We evaluated spatio-temporal gait parameters sensitive to the effects of dual-tasking to quantify changes in low- and high-level gait control markers: gait speed, swing time and stride time variability. The dual-task effect (DTE) of each of these parameters was calculated to assess the interference of concurrent performance of another task.

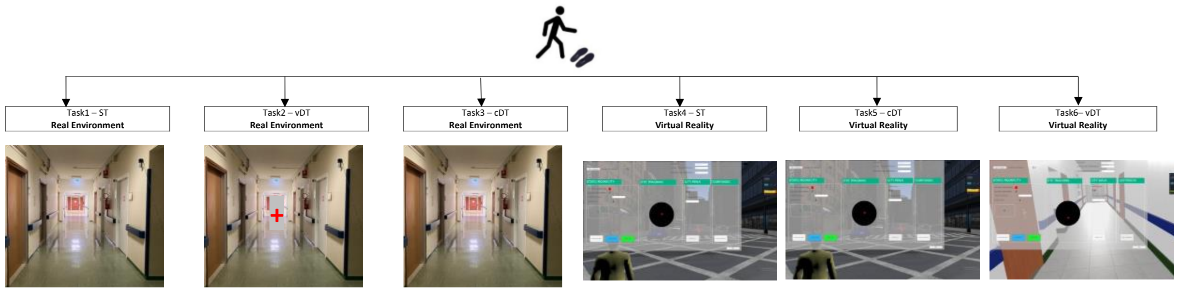

Figure 1. Tasks of the experimental protocol

Results

A non-parametric statistic was applied to analyze data; Friedman test was used to compare spatio-temporal parameters between different tasks and to compare DTE in different conditions. Then, a post-hoc analysis was applied using Wilcoxon test. Gait speed decreased in all tasks compared to ST and vDT in the real environment. Instead, swing and stride time variability worsened only in the cDT in the real environment and VR conditions compared to ST and vDT in the real environment. No significant differences between conditions were found in the DTE calculated for the ST in the real environment. However, the trend indicated a decreased gait speed (negative DTEs) and increased swing and stride time varialibilty (positive DTEs) compared to ST.

Discussion

The vDT task didn't alter gait parameters, indicating that this task isn't sufficient to impact cognitive control that regulates gait. HCs worsened significantly in all parameters during the cDT in the real environment, underlying that this task interferes with the cortical control of gait. Moreover, cDT performed in the real environment is not significantly different from any task performed in VR, showing that the cognitive load between tasks is not different (no significant DTEs). In future studies, focusing attention on FGDs, we assume that the application of the same protocol could get differences in ST and vDT in real environment and the application of VR could facilitate the movement of attentive focus, improving the parameters of the gait in these subjects.

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Real-time lower limb joint kinematics during walking in real-world based on a minimummeasured -input model: proof of concept

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Introduction

Quantification of the kinematic pattern of human gait in real world conditions could open new perspective and determine a paradigm shift in the way motor disorders are diagnosed and rehabilitationinterventions are designed and assessed. The most straightforward and common solution is to equip each segment under analysis with an inertial measurement unit (IMU). However, the use of full body sensor network is often impractical for monitoring free-living activities. In this study, we presented a novel sensor fusion approach that leverages information derived from a minimal number of IMUs and biomechanical joint constraints within the robotic Denavit-Hartenberg (DH) convention. The proposed method allowed to estimate lower limb joint kinematics at hip, knee, and ankle by using only three IMUsattached to the pelvis and feet.

Methods

The lower limbs were modelled using a DH chain with three degrees of freedom for each joint (pelvis rotations, hip, knee, and ankle) (Fig. 1a) [1]. Segments lengths were derived from the anthropometric measurements. The method provides an effective computational framework to impose joint-specific physiological constraints and to bound joint variables workspace compatible with the motor-task underanalysis (e.g. the pelvis must maintain its position within the range defined by the positions of the feet during the forward movement). The kinematics outputs are determined through an optimization process, based on the sequential quadratic programming algorithm, which minimizes the differences between the modelled and measured pelvis and feet segments orientations and feet positions (Fig.1b) [2]. The effectiveness of the proposed method in achieving convergence was tested on preliminary data acquired on one healthy subject equipped with three IMUs (INDIP) placed on pelvis and feet, as done in [2].

Results

The method proposed in this study successfully achieves convergence in about seventy seconds, witheach frame taking an average of forty seconds. The stick-diagram (Fig. 1c) depicts the reconstructed lower limbs kinematics for a specific frame, accompanied by the joint angles.

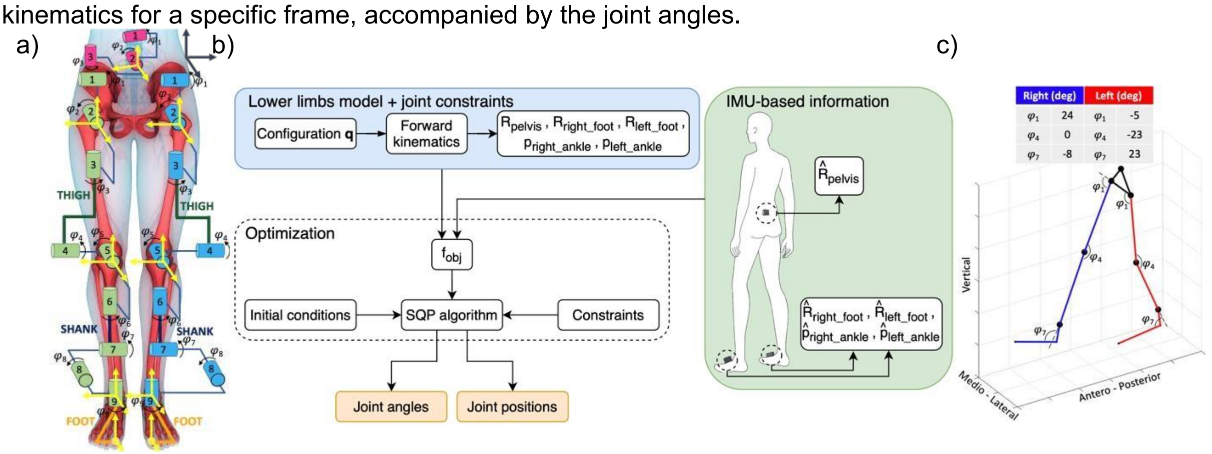

Figure 1. a) DH lower limbs model, b) Optimization framework, c) Stick-diagram and joint angles

Discussion

In this study, the feasibility of an optimization framework for estimating lower limbs kinematics during walking was verified. The proposed method allows to add an efficient mathematical framework to include joint- and motor-task-specific constraints. Although the current implementation does not achieve real-time kinematics estimation, this approach holds promise for enabling real-time biofeedback. In future work, validation against a stereophotogrammetric system on various subjects will be performed.

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How long do motor deficits persist after ACL reconstruction? A long-term quantitative performance assesment

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Introduction

Decision making regarding return to sport (RTS) after ACL reconstruction surgery (ACLR) is subject of debate in the literature. In recent years it has emerged that the time parameter is not sufficient to define the readiness for RTS [1]. The high re-injury rate [2] and the low percentage of return to pre-injury levels [3] show how necessary it is to objectively measure any motor performance deficits to create protocols aimed at recovering motor skills. The purpose of the study is to measure the presence of motor performance deficits in patients at least 9 months after ACLR and comparing the results with those of a control group.

Methods

The sample includes 28 subjects equally distributed in two groups: experimental group A and control group B. All participants underwent a single session assessment of balance with the Biodex platform, proprioception (Joint Position Sense) with X-Sens sensors, vertical jump with the G-Walk sensor and the lower limbs strength with Chronojump Boscosystem dynamometer.

Results

The results show that the subjects in group A present significant deficits compared to group B in the reproduction of the JPS at 60°(p=0,014), in the postural stability with closed eyes (0,039), in the peak of isometric strength in knee flexion (p=0,002) as well as in all plyometric tests Counter Movement Jump (p=0,012), Squat Jump (0,027), Counter Movement Jump with swinging arms (p=0,005).

Table 1. Characteristics of enrolled participants

	Group A	Group B
Participants (n)	14	14
Age (years)	30.8±7.3	27.7±2.7
Gender (female)	4	6

Discussion

The deficits that emerged in group A are elements that altogether represent an indicator of risk of re-injury of the neo ligament. Therefore, it is essential to provide some complete and objective evaluations of the elements that characterize the performance to early intercept these deficits and intervene to restore the correct motor patterns.

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Cervical ataxia in Myotonic Dystrophy type 1: preliminary findings

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Introduction

Myotonic Dystrophy type 1 (DM1) is a multisystemic genetic disorder with clinical hallmarks of muscular weakness, wasting, myotonia, and early-onset cataracts. Weakness typically involves the face, neck, and distal muscles of the limbs. Patients with DM1 have a 10-fold increased risk of falling compared to age-matched controls, and falls have traditionally been considered the result of reduced visual acuity and lower limb muscle weakness. However, recent evidence has suggested that impairments of proprioceptive and vestibular systems may contribute to falls in DM1 [1]. The present study aims to identify whether patients with DM1 have deficits in the cervical position sense and, thus, cervical ataxia.

Methods

This is an observational, cross-sectional study (ClinicalTrials.gov: NCT04712422). From October 2020 to September 2021, 16 patients diagnosed with DM1 and a control sample of 16 healthy adults were recruited. Cervical position sense has been assessed through a head-to-target (HTT) repositioning test. In HTT tests, an operator rotates the head of a blindfolded individual to a target position, and the participant is then asked to reposition the head to the target actively. An optoelectronic system was used to measure the Joint Position Error (JPE), the angular difference between the target position and the actively reached position [2]. The head movements tested were 30° left or right rotation and 25° flexion or extension. Four trials were performed for each direction in randomised order. The repositioning error in the plane of the intended movement (i.e., the horizontal plane for left and right rotations and the sagittal plane for neck flexion and extension) was labelled JPEintended. The repositioning error in the frontal plane, associated with left and right rotations and flexion and extension movements, ideally nil, was labelled JPEunintended.

Results

Both DM1 patients and controls showed greater JPEintended in left (4.57°, 3.346 to 5.80°) and right rotations (5.38°, 4.156 to 6.61°) than in flexion (1.76°, 0.528 to 2.99°) and extension (1.81°, 0.585 to 3.04°; ANOVA direction factor: $F_{3,90} = 14.68$; $p < 0.001$). No difference between groups was found for JPEintended ($F_{1,30} = 0.12$; $p = 0.733$). On average, JPEunintended was about zero in the controls' sample for left (0.17°; 95%CI: -0.53 to 0.87°) and right rotations (-0.22°; -0.91 to 0.48°). On the contrary, in DM1 patients, JPEunintended was about -1° for left rotations (-1.29°; -1.99 to -0.60°) and about +1° for right rotations (0.98°; 0.28 to 1.67°). The ANOVA showed a significant interaction between "direction" and "group" ($F_{3,120} = 5.25$; $p < 0.001$) for JPEunintended. Post-hoc testing confirmed that JPEunintended was different in patients, but not controls, for left and right rotations ($p < 0.001$). In addition, JPEunintended was significantly different between patients and controls for left rotations ($p = 0.028$). These findings indicate increased clockwise and counterclockwise repositioning errors in the frontal plane in DM1 patients but not in controls when the head actively rotates to the right and left.

Discussion

Even if small, DM1 patients showed greater repositioning errors in the frontal plane during right and left axial rotations. These findings open to the possibility that DM1 patients suffer a vestibular impairment and also a proprioceptive one due to the involvement of neck structures. In turn, this impairment could eventually worsen the impairment of balance.

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Processing video-recordings for the assessment of episodes of spontaneous limb movements in preterm infants

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Introduction

We aimed at developing the algorithms for the analysis of spontaneous movements (SMs) from markerless video-recordings in preterm neonates. Manifestation of SMs in early infancy [1-3] may reflect the processes underlying the emergence of coordinative activity. Given that the first months of life represent an extremely important phase of maturation of motor activity, the method may be used for developing the screening tools for the early identification of developmental delays.

Methods

We recorded spontaneous (2D) movements during ~40-60 min in 5 preterm neonates (at 2-3 weeks after birth, GA=28-31 weeks) using the video camera TEC.BEAN T2 at 120 fps with a resolution of 1280x720 pixels. We tracked a total of 6 points (Fig.1A), and 4 of them (right/left hand, right/left foot) were used for the analysis of endpoint movements. We used DeepLabCut version 2.2 [4] to extract the kinematic data for markerless pose estimation. Approximately 20 frames were taken from every video and then selected through k-means clustering for the training data set. Then a residual neural network (resnet50) was trained to reconstruct the whole recording. We analyzed a total of 13 videos.

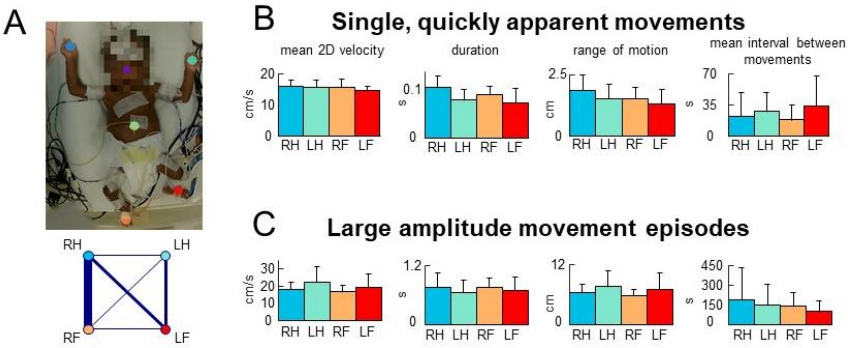

Fig.10. ME analysis. A - experimental setup and evaluation of interlimb coupling, the width of lines refers to ME relative occurrence (as the total timing of MEs). RH, right hand; LH, left hand; RF, right foot; LF, left foot. **B** and **C** - SM characteristics (mean+SD) using first and second algorithms, respectively.

Results

DeepLabCut could successfully reconstruct the endpoint motion in all preterm infants. Two types of movement episodes (ME) have been analysed. For the first algorithm (that detects single quick velocity-related episodes), we adopted an approach based on a 2D velocity threshold [1] (0.1 m/s) (Fig.1B). This method is helpful for detecting jerky movements and grouping four limbs' coordinated behaviour. For the second algorithm, we adopted an approach based on both a velocity threshold and amount of motion. To this end, the MEs were selected according to the following criteria: endpoint 2D velocity > 0.1 m/s, episode duration > 0.2 s, episodes were combined into one if the interval between them < 0.5 s and the endpoint excursion for any of the two coordinates (X,Y) ≥ 2 cm (Fig.1C). The second algorithm is specifically important for the analysis of large-amplitude SMs (excluding small and short movements).

Discussion

The developed algorithms were tested successfully in a group of infants for clustering MEs. This information can be used for the evaluation of early alterations in SM activity during the first few months of life, representing an important observational period for changes in the excitability of the sensorimotor networks for the early identification of the risk of cerebral palsy.

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Gait analysis synthetic indexes as predictors of intensive multidisciplinary neurorehabilitation outcomes in multiple sclerosis: methodological aspects

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Introduction

Multiple sclerosis (MS) is a chronic, degenerative, and demyelinating disease, and one of the primary causes of disability in young adults in Europe and North America. Gait deficiency is one of the main reasons of disability in people with MS, and from the perspective of the patients it is the most challenging symptom. For gait assessment, a 3D computerized analysis may be considered the criterion standard because it provides objective data on kinetic and spatiotemporal parameters. The evaluation of gait deviation in patient with MS (pwMS) represents an important issue in assessing the effectiveness of multidisciplinary neurorehabilitation treatments. Despite the availability of tools and devices for the assessment of the kinematic aspects of gait, there are still some difficulties in interpreting this large amount of data. The introduction of gait analysis synthetic indexes (namely Gait Profile Score (GPS) and Gait Variable Score (GVS) [1]) could help in this perspective.

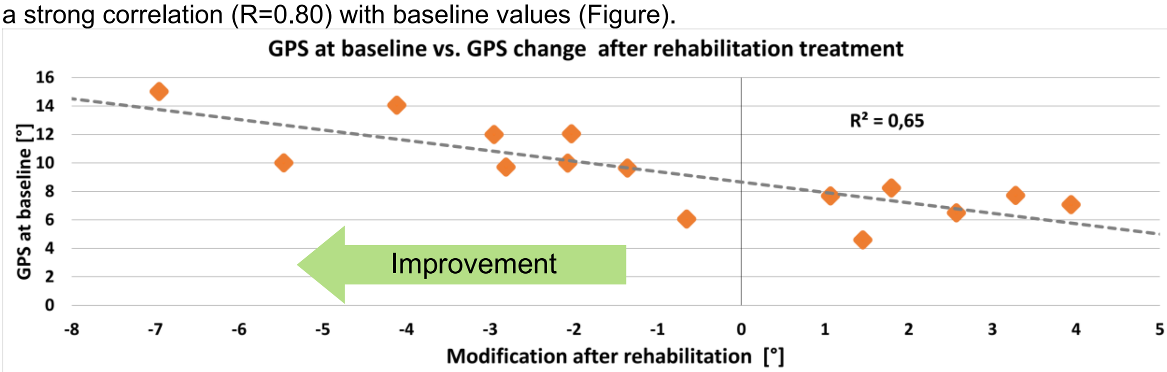
Methods

Patients with MS experienced at least 3 weeks of inpatient intensive multidisciplinary neurorehabilitation (motor and balance exercises plus 9-12 sessions of excitatory (20 Hz) motor cortex rTMS). Clinical characterization was assessed through EDSS (Expanded Disability Status Scale).

Before and after the treatment the kinematic aspect of the gait was recorded. The evaluation was carried out using a 7-cameras optoelectronic system (VICON, Oxford, UK) with a sampling rate of 100 Hz. After familiarization with the environment, the subjects walked barefoot at their own natural pace along a 10-m walkway. Raw data were pre-processed and processed using the Nexus software (VICON, Oxford, UK) to calculate the spatiotemporal and kinematic parameters for each trial performed by the patients. Using a customized script in MATLAB (MathWorks Inc., Natick, MA, US) the kinematic outputs were used to calculate the Gait Variable Scores (GVSs) (one for each kinematic time-series) and the Gait Profile Score (GPS).

Results

15 patients with MS (8 females, 51.40±5.72 years, EDSS 4.70±1.13) were enrolled and performed the rehabilitation treatment and no adverse event were recorded. Correlation between EDSS scale values and GVSs showed significant ($p<0.005$) correlations ($0.4<R>0.6$) for Pelvic Obliquity, Hip Flex–Extension, Knee Flex–Extension and, Ankle Dorsiflexion. The change of GPS before/after the rehabilitation treatment showed a strong correlation ($R=0.80$) with baseline values (Figure).



Discussion

The GPS/GVSs are feasible indexes to investigate pwMS gait alteration: significant positive correlations were found between the EDSS score and four GVS variables, indicating that individuals with higher EDSS scores (more severe walking impairment) had higher GVS values (larger deviation from controls).

GPS analyzed before/after the rehabilitation treatment showed that: higher the baseline values, larger the improvement; under a certain threshold the effects of treatments seem negligible.

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Correlation between biomechanical outcomes and neurophysiological biomarkers in patients with stroke undergoing upper limb motor neurorehabilitation: protocol trial

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Introduction

The scope of this paper is to present a study protocol aimed at the investigation of possible correlation between biomechanical outcomes and neurophysiological biomarkers to characterize and/or predict the results of motor rehabilitation in patients with neurological pathologies (i.e., stroke) involving motor functional deficits of the upper limb. Particularly, using a dry electrodes device, repeated EEG will be acquired weekly to quantify the neuro-motor changes. Moreover, longitudinal modifications in EEG biomarkers will be correlated with patients' clinical data and with kinematic data acquired during specific upper limb motor tasks (i.e., repetitive pointing task).

Methods

For a period of 4-6 weeks in the CCI hospital setting, 32 patients with stroke (<85 years; diagnosis verified through brain imaging; MMSE≥24; latency of the acute episode >2 weeks; clinical evident motor functional deficit of the upper limb) will undergo motor rehabilitation treatments for 5 days a week, at least 45 minutes a day, based on specialist clinical indications. Before and after the rehabilitation period (i.e., T0 and T2), patients will be assessed through clinical tests and scales and EEG and kinematic evaluations during epetitive pointing task performed with the affected upper limb. EEG will be also recorded weekly during resting state and during the execution of repeated wrist extension-flexion movements.
EEG will be assessed with Helmate (ab medica S.p.A., Italy), a Class IIa certified wireless device with dry electrodes characterized by a high usability and a quick setting. This helmet is equipped with 10 dry electrodes including 8 acquisition channels at a sampling frequency of 1024 Hz [1]. After pre-processing the following biomarkers will be calculated: power, latency, and duration of the ERD/S in alpha and beta bands; the ratio between different frequency bands (DAR delta/alpha ratio); the ratio between electrodes from different hemispheres.
To perform the kinematic evaluation, 15 passive reflective markers will be positioned on the trunk and on the affected arm of the subject and will be acquired using a 7-camera optoelectronic system (Vicon, Oxford, UK) at a sampling frequency of 100 Hz. Considering the trajectory of the marker on the third metacarpal, the following metrics will be evaluated [2]: the number of peaks of the velocity profile, the fluidity described by the Teulings index, the normalised jerk, the maximum and average peak velocity. In addition, the joint angles of the upper limb will be assessed, taking into account any trunk compensation. Clinical, neurophysiological and biomechanical outcome measures will be correlated.

Results

After obtaining results regarding the reliability and feasibility of the protocol, we will consider and analyze the modifications of the neurophysiological biomarkers and the correlation between them and the other outcomes. We expect to determine EEG biomarkers specific for stroke and to obtain differences among subjects clinical and biomechanical states. This might be useful for classifying patients and monitoring them along the rehabilitation process.

Discussion

Data-analysis and interpretations on potential benefits will be presented during SIAMOC2023 conference. With this study, we evaluate the possibility to characterize the changes in patients with stroke, over the rehabilitation time, of the EEG biomarkers. We further expect to find correlation results between neurophysiological and clinical and/or biomechanical data able to determine specific predictive elements prognostic in terms of motor recovery. Moreover, we will possibly demonstrate that a wireless EEG with dry electrodes might be used frequently during patients' rehabilitation process due to its low intrusiveness and ease of use. In the next future, the same procedure might be translated in a home scenario, in a perspective of continuity of care and monitoring.

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Changes in anticipatory postural adjustment prior to gait initation after lower limb immobilization

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Introduction

The effects of inactivity and lack of load following a lower limb fracture on motor behavior are well known [1]. Walking and transitional movements such as gait initiation are bipedal activities in which load is progressively transferred between the two lower limbs within a variable base of support depending on the action [2].

The lack of load after a fracture or lower limb surgery results in impaired load management, leading to reduced smoothness in body progression during walking.

This study analyzed the anticipatory postural adjustment (APAs) prior to self-generated gait initiation.

Methods

A group of individuals with non-weight-bearing lower limb fractures was compared to a group of healthy subjects and a group of patients who were allowed early weight-bearing after surgery.

Data acquisition took place at 3 months and 6 months post-fracture (beginning of the period of inactivity), when all subjects had the ability to fully bear weight on both lower limbs.

Kinetic and kinematic data related to the anticipatory postural adjustments (APAs) were recorded in the motion analysis laboratory using an optoelectronic system with 8 infrared cameras and force plates. APAs preceding heel-off were studied, characterizing the displacement of the center of pressure (COP) and the duration of APAs. The subjects were instructed to initiate walking with the limb that had the fracture.

Results

The analysis of the collected data allowed us to identify a reduction in anticipatory postural adjustments (APAs) in the subjects after a period of inactivity compared to the group of healthy patients and the group of patients with early weight-bearing.

Patients who underwent surgery after the fracture and were allowed early weight-bearing demonstrated a behavior similar to that of healthy subjects as early as 3 months post-operation.

Discussion

The study highlighted the impaired load management in the group of patients with lower limb fracture after cast immobilization during the task of gait initiation. Considering that the anticipatory postural adjustment (APA) occurred on the contralateral lower limb, these data support the line of studies [3] suggesting that motor behavior alterations, even in the presence of a fracture or “peripheral damage”, affect central movement control mechanisms.

Furthermore, the study has allowed for the identification and quantification movement strategies that are not otherwise measurable but are only observable in a clinical setting and persist in these patients despite the progressive recovery of weight-bearing.

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Preliminary results of a biomechanical risk assessment of an actual industrial use-case executed with and without a dual-arm CoBot

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Introduction

Industry 4.0 is the implementation of intelligent technologies to increase productivity and reduce the associated biomechanical risks [1]. From a general perspective, the integration of ergonomics and human factors requirements in human-robot collaborative (HRC) systems, such as collaborative robots (CoBots), represents a new option to reduce the physical effort of workers during the performance of manual material handling (MMH) activities and to introduce new ergonomic interventions for the prevention of work-related musculoskeletal disorders (WMDs). As the use of CoBots in manufacturing has recently increased significantly, all potential benefits need to be thoroughly investigated and proven, especially in the MMH activities where the physical interaction of the worker with the CoBot takes place. While the safety in this new hybrid scenario is widely studied, the effects on workers' health are still limited [2]. The present study aims to investigate the biomechanical parameters of workers performing an industrial use case with (wB) and without (woB) a dual-arm CoBot.

Methods

Four participants (all males; age: 27.8±7.4 years; height: 180.2±2.4 cm; weight: 78.4±10.7 kg; body mass index: 22.2±3.7 kg/m2) took part in the study. We reproduced in the laboratory an industrial application case. The apparatus consisted of the CoBot BAZAR, four tables, and one cylindrical load (5 kg) to be moved and cleaned. The task is to move the cylindrical load between the four tables in a predefined order and to clean it with a brush. The video (available at: https://youtu.be/vul8iLO0Sdw) shows the experiment. We carried out a task analysis with and without Bazar. We identified three main phases in which there were relevant differences in the performance of the task i) phase 1: an initial phase where the worker handled the cylinder; ii) phase 2: the principal phase where the worker holds the cylinder with one hand and brushes it with the other; phase 3: the final phase where the worker placed the brushed cylinder in the packaging area. For the assessment, we used the 3D Static Strength Prediction Program (3DSSPP), which reproduces the workers' posture by superimposing an avatar model on a selected frame. The software calculates various biomechanical parameters: percentage of maximum voluntary contraction (%MVC), static (continuous) allowed exertion time and low back spine compression force (L4Ort). The paired sample t-test (the data was normally distributed) was then used to evaluate whether the help of the CoBot had determined significant changes in each parameter. The significance level for all statistical analyses was set at p-value < 0.05.

Results

The results refer only for phase 2, which is the one that best fits the 3DSSPP because it's a static task. We didn't report values for the left upper arm because we didn't find significant %MVC values, which were all below 5% MVC. We didn't find unfavorable parameters when using a CoBot. We found several parameters that support the use of the CoBot. We found differences in orthogonal force at L4/L5 level (585.8N vs 1171.0N, $p \leq 0.01$). We found difference in %MVC of the right arm in favor of CoBot use for wrist flexion/extension (2.5% vs. 44.8%, $p \leq 0.01$), wrist rotation (0.0% vs. 22.5%, $p \leq 0.01$), shoulder humeral rotation (8.0% vs. 55.3%, $p = 0.03$) and trunk flexion (9.0% vs. 19.8%, $p = 0.02$). We found differences in maximum holding time for wrist flexion/extension (1200 s vs. 74.3 s, $p \leq 0.01$) and wrist uln/rad deviation (1200 s vs. 415.8 s, $p = 0.03$), elbow flexion/extension (1200 s vs. 531.5s, $p \leq 0.01$), shoulder humeral rotation (873 s vs. 125.2 s, $p \leq 0.01$) and shoulder back/forward (1200 s vs. 656.9 s, $p \leq 0.01$).

Discussion

Our results seem to support using CoBots in the industrial scenario analyzed. We find benefits for the right wrist, shoulder, and trunk flexion in phase 2. Moreover, it could be possible to automate phase 3. These preliminary positive results should be confirmed and strengthened with a larger sample.

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Measure of Microsoft Hololens 2 accuracy in tracking position and orientation

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Introduction

The use of virtual/mixed reality (VR) headsets as tools in rehabilitation scenarios is gaining momentum thanks to the wide range of sensors they feature [1]. In particular, the HoloLens2 (HL2, Microsoft®) is a mixed reality visor featuring a number of cameras for reconstructing the surrounding space and an embedded MIMU positioned over the subject's forehead. Using proprietary algorithms, the HL2 exploits visual and inertial sensor fusion to enhance the accuracy of the position and orientation of the subject's head in the 3D space. The aim of this study was to measure the system accuracy.

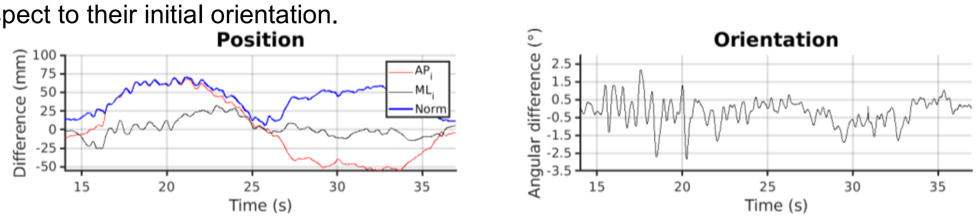
Methods

The position and orientation recorded by the HL2 were validated against ground-truth data acquired by a 8-camera motion capture system (MCS; Vicon, Oxford-UK) during a single trial. Four markers were attached to the HL2 and four virtual spheres of the same size were placed on a 3D mesh of the HL2 in the same locations. The MCS data were streamed to the virtual reality engine (Unity 3D) [2] and recorded at 50 samples/s along with the HL2 position and orientation and the virtual markers position. The recording session started with the HL2 placed on a holder to determine the initial reference frame (AP_i and ML_i: the anterior-posterior and medio-lateral directions of HL2 while on the holder). Then, the subject wore the HL2 and walked to complete an 8-shaped path 13.7 m long (within an area of 5.3 m by 2.2 m). The motion capture and HL2 reference systems were manually aligned at the initial static configuration. The horizontal plane, as identified by the MCS, was considered to be aligned to that of the HL2 as the HL2 uses the gravity vector to define the horizontal plane. A residual offset of the two reference systems on the horizontal plane was determined and taken into account for the further processing (angular offset = 1.47°, linear X-offset = 0 mm, Y-offset = 95 mm). Transferring to the virtual reality engine, data from the MCS was slightly delayed (120 ms) and therefore it was synchronized with the VR engine data in post-processing. The recorded signals were filtered using a third-order Butterworth filter with a cutoff frequency of 3 Hz.

Results

The HL2 tracked the position of the subject's head while walking along the path with a maximal absolute error of 71 mm (at the first U-turn) and a mean error of 42.2 mm (sd 18.0 mm) relative to the MCS data. The maximum error of HL2 measurement of the orientation angle relative to the MCS was 2.8° (mean 0.2°, sd 0.7°).

Figure 1. *Left panel)* The norm (blue trace) shows the absolute difference between the position as recorded by the MCS and the HL2 in the horizontal plane and the projection of the position error along the AP_i and ML_i directions. *Right panel)* The trace shows the difference between the angle measured by HL2 and the MCS with respect to their initial orientation.



Discussion

Our results showed that the HL2 tracks the position and orientation of the subject's head with maximum errors of about 1.3% of the range of motion (mean 0.8%). Thus, the HL2 is capable of reliably tracking position and orientation for most clinical applications and therefore may be used as an alternative “motion capture” system when appropriate.

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Impact of a proprioceptive training in terms of jump performance in volleyball athletes: a pilot study

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Introduction

Volleyball is one of the most popular sports, with 500 million players worldwide, due to its broad age-appropriate accessibility, minimal equipment and cost requirements, and the ability to play indoors and outdoors [1]. The sport implicates constant, prompt lateral action in combination with complex ballistic motions in reaction to outer stimuli [2]. Despite several studies on the risk of injury in athletes focused exclusively on large joints (e.g., knees and ankles), there is still poor evidence on plantar pressure modifications and fat pad atrophy in volleyball players. In this scenario, biomechanics adaptations can be due to changes in foot plantar pressure, that is, an increased load on the medial arch is usually suggestive of foot pronation shifting the sagittal plane kinematics, at the same time, changes in the foot plantar pressure may also cause changes in the foot biomechanics, inclining volleyball players to injuries. Preventive exercises and rehabilitation interventions can protect and strengthen the ankle and foot region from injuries and recently, devices to train proprioception and evaluate plantar pressure have been shown to play a role in physical performance conditioning. However, to date, the impact of proprioceptive mat training has not been adequately assessed yet. Therefore, the present study aimed to evaluate the efficacy of proprioceptive conditioning performed on a specific proprioceptive device on plantar pressure and jump performance in a small sample of volleyball players.

Methods

In this pilot study, we included criteria were: (a) adult males; (b) at least 5 years of volleyball experience; (c) no injuries in the last 12 weeks; (d) no anti-inflammatory therapy in the past 2 weeks. We excluded participants with active plantar infections or disorders or pain when performing athletic gestures and those who followed any additional lower limb-strengthening programs. After assessing the eligibility, all participants were divided through a randomization scheme with a 1:1 ratio of allocation into two groups: the experimental group, undergoing a mat-based proprioceptive and balance training, and the control group, undergoing a sham mat-based proprioceptive and balance training. In more detail, both groups performed a structured protocol in a daily session with active or sham proprioceptive intervention for 5 days a week for two weeks (10 sessions in total). For the outcome, we evaluated the barefoot plantar pressure, performing an analysis on a baropodometric resistive platform. The countermovement jump and squat jump were measured using an inertial measurement unit.

Results

Nineteen subjects were included in the two groups: the active proprioceptive group (n = 10) or the control group (n = 9). The results show a more uniform redistribution of loads with pressure hindfoot relief in the experimental group compared to the control group (p = 0.021, RBC = 0.67). Moreover, we observed a significant increase in peak landing force and high concentric power development in the experimental group compared to the controls.

Discussion

Taken together, the findings of the present pilot study suggest that mat-based proprioceptive training provides plantar pressure redistribution in volleyball players in a pre-season context. Furthermore, the mat-based proprioceptive training increased different sport performance parameters in these athletes. Therefore, a proprioceptive stimulation performed in the inter-seasonal period might be considered as a safe and effective intervention to be added to the comprehensive athletic training of these subjects to improve their sports performance and reduce foot and ankle injury rates.

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Cognitive impairment is associated with gait variability and fall risk in amyotrophic lateral sclerosis

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Introduction

In amyotrophic lateral sclerosis (ALS), gait abnormalities contribute to poor mobility and represent a relevant risk for falls [1]. To date, gait studies in ALS patients have focused on the motor dimension of the disease, underestimating the cognitive aspects [2;3].

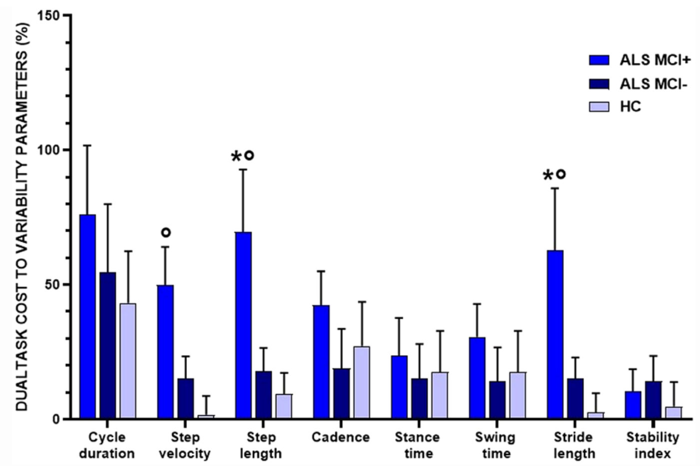
Methods

Using a wearable gait analysis device, we compared gait patterns in ambulatory ALS patients with mild cognitive impairment (ALS MCI+; n = 18), and without MCI (ALS MCI−; n = 24), and healthy subjects (HS; n = 16) under two conditions: (1) normal gait (sin- gle task) and (2) walking while counting backward (dual task). Finally, we examined if the occurrence and number of falls in the 3 months following the baseline test were related to cognition.

Results

In the single task condition, ALS patients, regardless of cognition, displayed higher gait variability than HS, especially for stance and swing time ($p < 0.001$). The dual task condition revealed additional differences in gait variability parameters between ALS MCI+ and ALS MCI− for cadence ($p = 0.005$), stance time ($p = 0.04$), swing time ($p = 0.04$) and stability index ($p = 0.02$). Moreover, ALS MCI+ showed a higher occurrence ($p = 0.001$) and number of falls ($p < 0.001$) at the follow-up. Regression analyses demonstrated that MCI condition predicted the occurrence of future falls ($\beta = 3.649$; $p = 0.01$) and, together with executive dysfunction, was associated with the number of falls (cognitive impair- ment: $\beta = 0.63$; $p < 0.001$; executive dysfunction: $\beta = 0.39$; $p = 0.03$), regardless of motor impairment at clinical examination.

Table 1. In the amyotrophic lateral sclerosis without mild cognitive impairment (ALS MCI+) group the dual task cost was significantly higher compared with the amyotrophic lateral sclerosis with mild cognitive impairment (ALS MCI−) group and healthy subjects (HS) for the step velocity variability, step length variability and stride length variability. The group effect was tested by the Kruskal–Wallis test, while post-hoc comparisons were performed by means of Mann–Whitney U test. *MCI+ versus MCI−; °MCI+ versus HS. Significance was set at $p < 0.006$, according to Bonferroni correction for multiple comparisons (number of comparisons = 8). Post-hoc p was set at $p = 0.05$.



Discussion

In ALS, MCI is associated with exaggerated gait variability and predicts the occurrence and number of short-term falls.

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Classification of Fragile X Syndrome phenotypes based on K-means cluster analysis of biomechanical variables

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Introduction

Fragile X Syndrome (FXS) is caused by pathological expansions of the CGG repeat polymorphic region of the FMR1 gene and represents the leading cause of inherited intellectual disability and autism [1]. This condition is characterized by musculoskeletal manifestations such as flexible flat feet, joint laxity and hypotonia [1] associated with altered joint kinematics and muscle activity during gait [2]. Two different FMR1 allele variations characterize mosaicism in FXS: size mosaicism and methylation mosaicism [3,4]. The aim of this study was to verify the possibility of classifying FXS children from healthy controls and, within FXS children with full mutation, to classify children with mosaicism, based on gait analysis and surface electromyography (sEMG) parameters.

Methods

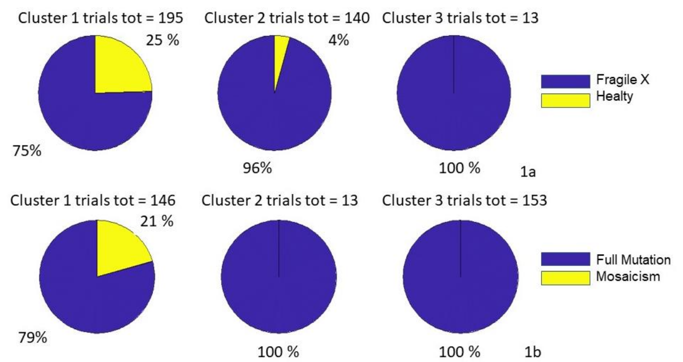
The gait of 59 FXS children ((FX) mean(±SD) age of 9.5(±3.5) years, BMI of 19.2(±3.7) Kg/m2) and 10 controls ((CS), mean(±SD) age of 10(±3.07) years, BMI of 20.4(±4.5) Kg/m2) was assessed. Within the FXS group, 34 children presented full mutation ((FX-FM), 5 methylation mosaicisms (FX-MET), 10 size mosaicism (FX-DYM), 6 premutations and 4 both size and methylation mosaicism. Joint kinematics and sEMG were simultaneously acquired through four synchronized cameras (GoPro Hero7) and an sEMG system (FreeEmg, BTS, 1000Hz) that collected the activity of Tibialis Anterior, Gastrocnemius Lateralis, Rectus Femoris and Biceps Femoris. From sEMG parameters, envelope peak and its occurrence within the gait cycle were computed, sagittal plane kinematics was assessed from video recordings [2]. K-means unsupervised classification was used to partition the considered sample of trials executed by subjects into different clusters, on the basis of the Silhouette score. Two possible databases were considered: FXS with CS and FX-FM with FX-DYM and FX-MET.

Results

The clustering results for the two different solutions are shown in Figure 1a and 1b.

Discussion

Concerning the second solution, FX-DYM and FX-MET subjects were assigned to the same cluster, meanwhile with the first database, one CS with all its trials was associated with a different cluster all the others CS. Future developments will include applying different data mining approaches (i.e., supervised learning approaches and hierarchical clustering).



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Acknowledgment. *This study was supported by FRAXA Foundation*

Pose estimation methods for automatic general movements assessment in infants: influence ofvideo acquisition settings and processing

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Introduction

General Movements Assessment (GMA) is a non-invasive reliable assessment for identifying risk of neurological impairment in infants [1]. General Movements (GMs) are spontaneous movement patternsevident up to 20 weeks of age; they involve the whole body in a variable sequence of arm, leg, neck and trunk movements. GMA is performed through direct or video observation by a licensed operator, resulting in a qualitative description of motor performance of the infants. These aspects limit widespread objective and quantitative evaluations [1].

Recently, technological approaches aiming at automated or technology-assisted GMA have surfaced [2]. Video-based approaches remain authentic to the non-intrusive character of the classic GMA and guarantee potential easy and widespread clinical applications [2]. Video-based automatic GMA generally consists of i) automatic tracking of body segment kinematics, ii) metrics extraction, and iii) performance classification. The proper initial tracking of segmental kinematics is the prerequisite for reliable metrics extraction and resulting classification; unfortunately, when comparing the few availablestudies [2], exploiting mainly state-of-the-art open-source software for automated tracking [2], no standard can be identified for video acquisition and processing.

This work aims to fill this gap, investigating the influence of video acquisition settings (i.e. frame rate and resolution) and processing (e.g. reconstruction model, accuracy thresholding, filtering, and interpolation) on resulting kinematics, as well as on a set of metrics from previous studies [3].

Methods

Experimental protocol: as part of an ongoing research study, 81 infants at risk of neurodevelopmental impairment (preterm newborns with gestational age <32 weeks and/or birth weight <1500 g) were recruited at the Neonatal Unit of IRCCS AOU Bologna (ethical approval n° EM1229- 2020_76/2013/U/Sper/AOUBo). Videos of GMs were collected at term equivalent age, using, ease of use in a clinical setting by clinical staff, a commercial video camera (GoPRO Hero 9), at 240fps, and 1920x1080p resolution. Video collection was performed following GMA guidelines [1].

Data analysis: Kinematics of body segments was extracted using OpenPose [2] (predefined Body25, 25 landmark5, and MPI, 15 landmarks, models) and DeepLabCut [2] (ad-hoc defined 14 landmark model), having been used in previous studies. For the implementation of DeepLabCut ad-hoc model, influence of the number of training iterations was tested for 200k, 400k, 600k, 800k, and 1M iterations.Computational time and percentage of missing reconstructed points were analyzed for basic performance assessment. Percentage of points with confidence above 95%, distance of marker trajectories for increasing number of training iterations, and spectral analysis were performed to assessinfluence of video resolution and sampling frequency, and model training iterations on trajectory reconstruction. Influence of model training iterations, filtering, and interpolation on resulting evaluationmetrics (i.e. range, covered distance, velocity and jerk mediated over 1s windows) was tested for processing assessment.

Results

Due to double processing time and low performance in trajectory reconstruction Open-Pose was excluded from further analysis after basic performance assessment. After 400K iterations reconstructedtrajectories resulted to reach a plateau in terms of stability, completeness, and number of values above95% confidence. Both filtering and interpolation resulted to critically affect evaluation metrics.

Discussion

Preliminary analysis highlighted the critical role of video acquisition settings and processing onreconstructed kinematics and, even more, on the resulting evaluation metrics. The finalization of the analysis will provide evidence-based criteria for the definition of a reliable methodologic approach for the automatic assessment of GMs.

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Correlating Clinical Functional Scales with Gait Analysis and Wearable Inertial Device after one-month Rehabilitation program in a patient with acquired K1 Transfemoral Amputation: A case report

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Introduction
Using a prosthesis after transfemoral amputation improves kinematic gait parameters as well as functional scales, enhancing social participation and self-empowerment [1]. An 81-year-old Caucasian male with right mid-thigh K1 transfemoral amputation (February 2020) due to chronic vasculopathy and Diabetes Mellitus type II was admitted in January 2023 to our Physical Medicine & Rehabilitation Department for one month gait rehabilitation. He worn a propylene modular transfemoral prosthesis with ischial containment and silicon cuff, single-axis knee, and multi-axis foot. Aim of this case report is to correlate clinical functional scales with kinematic parameters using Gait Analysis and a Wearable Inertial Device before and after one-month Rehabilitation program.

Methods
Patient at the beginning (T0) and end of one-month rehabilitation program (T1) has been evaluated with clinical functional scales (Houghton Scale, Barthel Index, Functional Ambulation Categories) and underwent Movement Analysis with two different tasks: a 5-Meter-Walking Test (5MWT) and a Timed Up and Go Test (TUG test). The former task has been performed with a 4-wheel walker and a pair of forearm crutches. 5MWT was performed using an 8-infrared-camera optoelectronic system (Smart DX-4000, BTS Engineering, Milan, Italy). Moreover, TUG test was performed with a wearable inertial sensor (Baiobit, Rivelo Srl, Milan, Italy) in order to assess the risk of fall and spatio-temporal features.

Results
Clinical assessment: Houghton Scale T0 – 4/12, T1 – 6/12; BI T0 – 33/100, T1 – 68/100; FAC T0 – 1/5, T1 – 3/5. Kinematic features are shown in Table 1.

Table 1. Optoelectronic and Wearable Device data

5MWT - OPTOELECTRONIC SYSTEM								
	T0				T1			
	Walker		Crutches		Walker		Crutches	
	Right	Left	Right	Left	Right	Left	Right	Left
Cycle time (sec)	5,01	4,76	5,87	5,75	2,49	2,23	2,41	2,6
Stance Phase (%)	85,28	89,09	84,87	90,97	66,42	82,56	62,47	87,08
Swing Phase (%)	14,72	10,91	15,13	9,03	33,58	17,44	37,53	12,92
Mean velocity (m/s)	0,07		0,06		0,22		0,19	
Cadence (stride/min)	24,6		20,7		51		48	
Stride Width (m)	0,26		0,26		0,22		0,21	

TUG TEST – WEREABLE DEVICE		
	T0	T1
Time Lenght (s)	77,25 (High Risk of Fall)	71,99 (High Risk of Fall)
Standing up phase (s)	3,21	2,41
Sitting down phase (s)	5,67	5,17
Forward walking (s)	19,83	16,43
Return walking (s)	17,94	18,01

Discussion
Improvement of gait sub-items in clinical functional scales well correlate with kinematic data, such as improvement in mean velocity and reduction of cycle time and stride width (in 5MWT); time required for standing up and forward walking (in TUG test). Therefore, instrumental movement analysis of gait cycle and wearable devices are useful tools for clinicians to better describe improvements in gait-correlated clinical scales.

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A machine learning-based pipeline for stride speed estimation with a head-worn inertial sensor

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Introduction

Walking speed is a primary outcome in the field of mobility assessment and an important indicator of individual wellbeing [1]. Activity monitors including a single inertial measurement unit (IMU) constitute an optimal solution for estimating walking speed in real-world conditions, as they allow to minimize costs and encumbrance. Although waist and wrist positionings have been widely explored [2], little attention has been paid to less common locations, such as the head, that allows the integration with smart glasses and virtual reality visors. Only recently head-worn IMU (H-IMU) solutions have been proposed for stride speed estimation [3]. The present study proposes a machine learning-based pipeline for estimating walking speed from H-IMU data in both standardized and real-world settings.

Methods

Fifteen participants (50% female, 26±3 years old) were asked to perform two standardized motor tasks (3X12m-straight walk at three different speeds and 3X24m-double-ring walk), and a 2.5-hour free-living acquisition. Each participant was equipped with the INDIP system [4] - used as reference - plus a H-IMU on the left side of the temporal bone, sampling at 100 Hz. The proposed H-IMU-based pipeline consisted in several steps: i) Filtering of 3D accelerations and angular rates with a 10^{th}-order low-pass filter (f_{cutoff}: 5 Hz); ii) Z-score normalization and partitioning into 2 s – time windows with 1 s overlap; iii) Detection of initial contact (IC) instants using a Temporal Convolutional Network (TCN) that takes the labeled windows as input; iv) Segmentation of signals norms into strides with the detected ICs to obtain nine features in the time and frequency domain; v) Stride speed estimation through a GPR model that takes the derived features as input. Data were split into a construction set (10 participants, used for training) and a test set (5 participants), including both real-world and standardized data. Hyperparameters of the models were tuned via grid search with a leave-one-subject-out cross-validation protocol. The best TCN architecture had 4 residual blocks with 64 kernels of size 7 and a dilation factor that spanned from 1 to 32, while the best GPR architecture embedded a squared exponential kernel with a kernel scale length of 9031.2 and a signal variance of 3.1 m^2/s^2. Features for stride speed estimation were selected through forward wrapper feature selection. After training, the pipeline was applied on walking periods labelled by the reference. Performance of the TCN was evaluated against INDIP system in terms of mean absolute error (MAE) and percentages of missed and extra ICs, while performance of the GPR model for speed estimation was evaluated in terms of Pearson correlation (ρ), root mean squared error (RMSE) and scaled mean squared error (SMSE) i.e. the MSE scaled for the variance of targets.

Results

Percentages of missed ICs and extra ICs and the MAE achieved by the best performing TCN were 2.35%, 6.38% and 0.02 s for standardized data and 7.91%, 6.65 % and 0.03 s for real-world data, respectively. Performance of the best performing GPR model on test data are reported in Table 1.

Table 1. Performance of the best performing GPR model on test data expressed as mean ± STD

	RMSE (m/s)	SMSE	ρ
Real-world	0.1 ± 0.15	0.15 ± 0.31	0.93
Standardized	0.1 ± 0.12	0.14 ± 0.23	0.94

Discussion

Results of the TCN showed small errors in ICs detection. As expected, the number of mis-detected ICs increased in free-living conditions, as real-world gait underlies greater variability. The GPR model showed good performance over the full test set, though it is expected to furtherly improve after outliers removal. Overall, the proposed H-IMU method showed to be promising for the estimation of stride speed. Future analysis will investigate the feasibility of applying the pipeline to pathological subjects.

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Role of customized insoles in improving foot biomechanics and posture in individuals with down syndrome: a scoping review

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Introduction

Down syndrome is a genetic disorder that affects approximately 1 in every 700 births worldwide. It is associated with a number of physical and cognitive challenges, including altered foot biomechanics and posture. Customized insoles have been proposed as a potential intervention to improve foot function and posture in individuals with Down syndrome, but their effectiveness is unclear. To evaluate the evidence on the role of customized insoles in improving foot biomechanics and posture in individuals with Down syndrome.

Methods

Four databases were searched until January 2023. Studies that considered customised insoles were included. All interventions and contexts were considered. No restrictions were applied regarding language, study design and publication type. Grey literature and reference lists of included articles were not identified. The results were presented in numerical and thematic form.

Results

From 32 initial registrations, 5 studies (Table 1) fulfilled the inclusion criteria. The results showed that customised insoles are effective in improving foot biomechanics and improving posture. However, the quality of the evidence was generally low and further high-quality studies are needed to confirm these results.

Table 1. Main characteristics of included studies

Author	Title	Year	Country
L Selby-Silverstein	The effect of foot orthoses on standing foot posture and gait of young children with Down syndrome	2001	USA
Julia Looper et al.	What to measure when determining orthotic needs in children with Down syndrome: a pilot study	2012	USA
Yoshihide Kanai et al.	Relationship between the use of lower extremity orthoses and the developmental quotient of The Kyoto Scale of Psychological Development in children with Down syndrome	2018	JAPAN
Daniele Galafate et al.	Bilateral Foot Orthoses Elicit Changes in Gait Kinematics of Adolescents with Down Syndrome with Flatfoot	2020	ITALY
Yusuke Endo et al.	Influence of a Foot Insole for a Down Syndrome Patient with a Flat Foot: A Case Study	2020	JAPAN

Discussion

This is the first scoping review to provide a comprehensive overview of the topic. Overall, this review provides valuable insights into the potential benefits of customized insoles as a non-invasive and low-cost intervention for individuals with Down syndrome. Customized insoles can improve foot function and posture, but the quality of the evidence is currently limited. Further research is needed to establish the effectiveness of customized insoles in improving foot function and posture in individuals with Down syndrome.

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Abdominal plastic: a postural and biomechanical evaluation before and post-surgery

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Introduction

Patients from plastic surgery after a bariatric path; the way how plastic surgeries and a possible rehabilitation training [1] can define a new and complete pattern.
The aim of this pilot study is to show how an abdominal surgery after a previous bariatic surgery can influence back posture and gait cycle.

Methods

In a sperimental proscpetic study 20/25 patients from Department of Surgery "Valdoni", Unit of Plastic and Reconstructive Surgery, "Sapienza" University of Rome, Rome, Italy, will be evaluated pre-operatively (abdominal surgery) and then approximately 1/2 months after the surgery in order to check their posture and gait cycle. Moreover, after this evaluation will be considered the possibility of starting a new rehab protocol [2] when is clinically noticeable. The biomechanical evaluation will be done at our laboratory: BTS GAITLAB SMART DX 4000 (Davis Protocol) and DIERS formetric 4D.

Results

In the results we are expecting a change in the posture path in terms of lumbar lordosis, thoracic kyphosis and lumbosacral angle and also in the biomechanics of movements.

Discussions

Depending on what the results will be our rehabilitation team would consider a rehabilitation program and project.

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A Myoelectric-based pattern recognition architecture for shoulder movement intent detection: toward a human-machine interface for transhumeral amputees

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Introduction

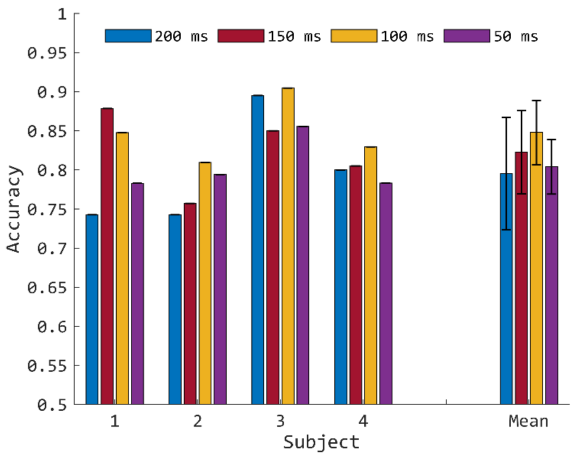
Nowadays, myolectric pattern recognition (PR) is becoming fundamental for the development of assistive technologies and prosthetics [1,2]. Relevant solutions were developed for transradial amputees by exploiting transient electromyographic signal (sEMG) of the forearm [3]. On the other hand, transhumeral amputation (TA) was less studied under this perspective. Literature highlights the opportunity of using shoulder muscle to decode movement intention from the shoulder joint of TA patients to develop myoelectric interfaces [2,4]. Hence, in this study, a cohort of 4 TA patients was considered for assessing the role of transient sEMG signal epochs to decode the shoulder movement intention. Moreover, the role of window length (WL) for feature extraction was considered since it represents a key step toward the implementation of myoelectric PR in real time. To this aim, WL of 200, 150, 100 and 50 ms were respectively considered.

Methods

A total of 5 sEMG probes were placed respectively on the upper and lower fibers of the Trapezius, Rhomboid major, Serratus anterior and Pectoralis minor following standard proposed by SENIAM [2,4]. An accelerometer was placed above the shoulder to segment the data. Accelerometer and sEMG probes recorded data synchronously at 1000Hz. Patients were asked to perform shoulder elevation, depression, protraction retraction, upward and downward rotation alternating pauses and reached configuration for 5s. Accelerometer data were employed to identify transient sEMG epochs. Then, features were extracted at the above-mentioned WL, accordingly with [4]. For each subject the obtained, feature set was split randomly in two folds, i.e. 50% training and 50% testing, and used for feed a discriminant analysis model with gaussian kernel [4].

Results

Figure shows the accuracy obtained in testing for each subject using the 4 WL previously described. For each subject accuracy reaches value greater than 80%. Moreover, PR experiments suggest the use of 100 and 150 ms among patient to boost the recognition of shoulder movements using transient EMG information [3,4].



Discussion

The study shows the possibility to recover intent of upper limb movement from shoulder of TA patients through transient sEMG signals. WL of 100ms shows the best performances among the 4 conditions investigated. This suggests short processing window to highlight motion pattern from transient epochs with respect to 200 ms usually adopted for static sEMG pattern recognition. Further, the study suggests the use of kernel-based architectures with respect to linear PR models to better exploit the information content behind transient sEMG data [2,4].

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Multiscale entropy algorithms to investigate the degree of complexity and variability of trunk acceleration time series in patients with Parkinson's disease

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Introduction

Altered trunk behavior has been shown to characterize gait impairment [1] and it has also been shown that wearable sensors, provide gait indices derived from trunk acceleration that can accurately characterize gait variability in swPD patients [2]. If derived from trunk acceleration, it is possible to extrapolate measures that quantify the variability of spatiotemporal gait parameters. which, however, have limitations in their ability to provide information on the underlying patterns and short-term changes in gait variability [3]. To overcome this, nonlinear entropy measures have been proposed that assess gait variability by providing a measure of the complexity and regularity of a time series, independent of step detection [4]. The purpose of this study was to evaluate the ability of multiscale sample entropy (MSE), refined multiscale composite entropy (RCMSE), and complexity index (CI) to characterize gait complexity in subjects with Parkinson's disease (swPD) and in healthy subjects, independent of age and gait speed.

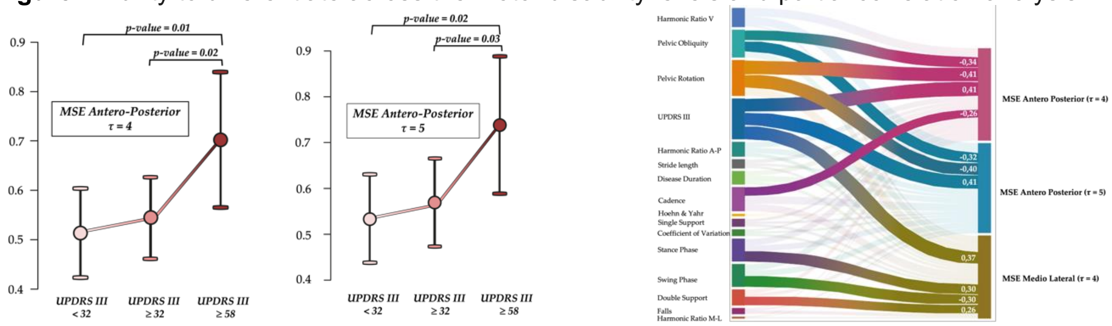
Methods

Trunk acceleration patterns of 51 swPD and 50 healthy subjects (HS) were acquired using a magneto-inertial measurement unit mounted at the lumbar level during walking. The MSE, RCMSE and CI were calculated over 2000 data points, using scaling factors (τ) 1-6. Differences between swPD and HS were calculated at each τ, and area under receiver operating characteristics, optimal cutoff points, post-test probabilities, and diagnostic odds ratios were calculated.

Results

MSE, RCMSE, and CIs showed to differentiate swPD from HS. MSE in the anteroposterior direction at *τ*4 and *τ*5, and MSE in the ML direction at *τ*4 showed to characterize the gait disorders of swPD with the best trade-off between positive and negative posttest probabilities and correlated with the motor disability, pelvic kinematics, and stance phase (Figure 1). Using a time series of 2000 data points, a scale factor of 4 or 5 in the MSE procedure can yield the best trade-off in terms of post-test probabilities when compared to other scale factors for detecting gait variability and complexity in swPD.

Figure1. Ability to differentiate across the motor disability levels and partial correlation analysis



Discussion

The results of the study allow us to consider MSE in the antero-posterior and mid-lateral directions as an age- and speed-independent biomarker of gait complexity in swPDs. The MSE in the AP direction, calculated at τ4 and τ5, and the MSE in the ML direction at τ4, outperformed the other scale configurations in terms of discriminative ability. Our results suggest that higher scaling factors are needed to highlight the gait irregularities caused by Parkinson's disease.

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Unsupervised machine learning strategy and shapley additive explanation to distinguish gait abnormalities through IMU-based gait analysis in movement disorders

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Introduction

Distinct, though related, groupings of neurodegenerative illnesses frequently share common symptoms, implying that the underlying pathogenetic mechanism is likely to overlap. Machine learning (ML) automates the analysis of complex datasets to identify patterns that would otherwise be difficult to find using traditional qualitative methods. When paired with gait analysis utilizing IMU, automated classification of gait disorders using Machine Learning algorithms can enable fast and clinically significant assessment of gait anomalies in persons with gait disorders [1]. Unsupervised methods can be used to classify gait patterns of people suffering from various neurological illnesses [2-3]. Clustering algorithms were assessed in this study to detect patterns and produce insights on sensor data from people with movement problems and healthy subjects.

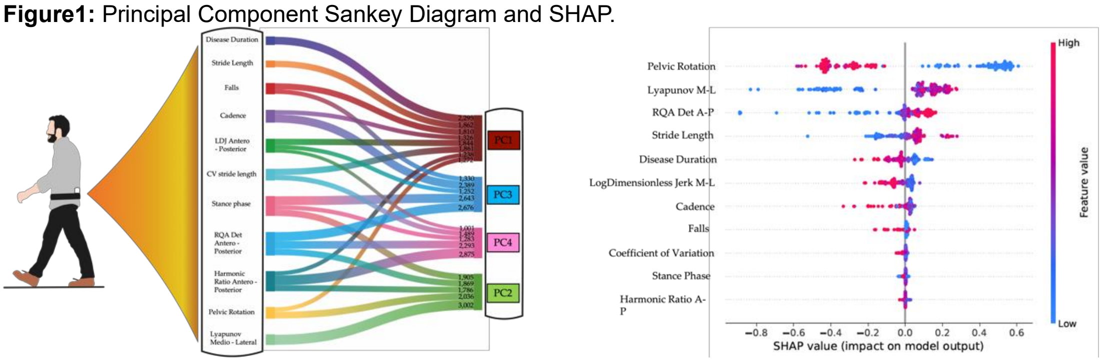
Methods

In this study, 59 subjects with Parkinson's disease, 39 subjects with cerebellar ataxia, and 35 healthy subjects matched for age and speed were included, and through the use of an inertial IMU sensor, it was possible to derive relative spatiotemporal parameters of gait and to calculate, from the measured accelerations, stability indices. Unsupervised machine learning methods such as partitioned clustering (K-Means), hierarchical clustering, and density clustering (DBSCAN) were studied on the initial dataset and on a second dataset obtained by doing dimensionality reduction through feature extraction. Finally, supervised statistical analysis and Shapley Additive Explanations (SHAP) analysis were performed to identify the most impactful set of features for differentiating between movement disorders and healthy subjects.

Results

The results showed us that partitioned clustering performed better than the other algorithms, in metric terms, in differentiating motion disorder in both internal cluster metrics and external metrics, evaluated later. Feature extraction by Principal Component Analysis (PCA) improved internal cluster metrics making them more recognizable and homogeneous while worsening external metrics slightly. On the cluster with the best external metric results, SHAP analysis (Figure1) was performed to assess which features were most impactful for the model, and this strategy showed us the importance of different characteristics from single lumbar inertial data in differentiating the two movement disorders from each other and from non-pathological subjects.

Figure1: Principal Component Sankey Diagram and SHAP.



Discussion

In conclusion, the results of this study demonstrated that when considering gait data from single IMUs mounted at the lumbar level in moderate disease-stage pwCA and pwPD populations, the unsupervised K-Means and hierarchical clustering algorithms can generate excellent insights and classification metrics, and that pelvic rotation plays a key role in differentiating extrapyramidal and cerebellar disorders.

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Articular network synchronization in Parkinson's disease during gait

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Introduction

Joint coordination during gait in individuals with Parkinson's disease (PD) and healthy controls (HC) was examined by the means of network theory [1]. The study assessed the synchronization among range of motion velocities of the joints and evaluated the kinematic organization of the gait pattern in health and disease, through the analysis of the network features. Finally, a potential relationship between the network characteristics and the motor impairment, assessed through UPDRS-III [2], was investigated.

Methods

Twenty-three PD patients and twenty-three age-matched controls were recorded during linear gait using a stereophotogrammetric motion analysis system. For each participant, the network was computed by calculating the pairwise Pearson correlation coefficient of the time series of the velocity of the joints' angles (Figure 1A). The result was an adjacency matrix, whose nodes represented the articulations, and the element of the matrix represented the coordination (Figure 1B). The nodal strength values [3] of the network of the two groups were compared through a permutation test, and the relationship between the network properties and the motor impairment was investigated through a cross-validated multilinear regression model.

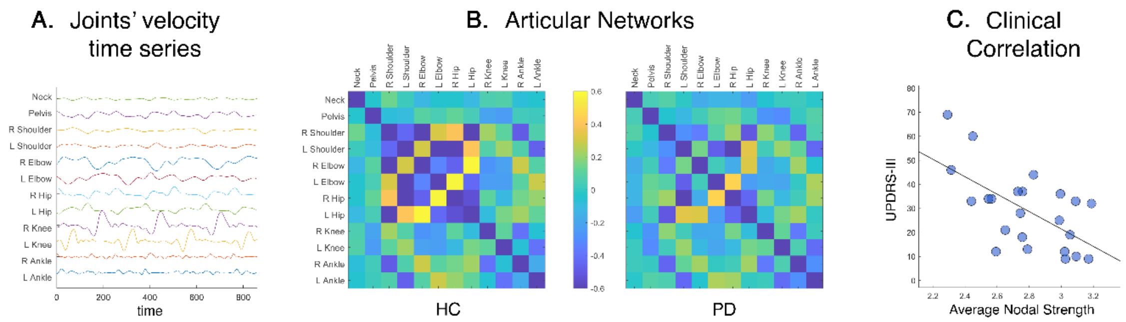

Figure 1. *Joint network and clinical correlation in Parkinson's disease*

Results

The results indicated decreased velocity coordination in PD patients at both global and nodal levels, specifically in the neck, shoulders, elbows, and hips. Furthermore, we found that PD patients' average nodal strength was significantly related to the UPDRS-III (Figure 1C) and predicted it using a cross-validated multilinear regression model.

Discussion

This study emphasizes the potential of network theory for analyzing movement and coordination in PD patients, and its clinical relevance for PD. The network approach can help identify specific joint impairments and evaluate joints' coordination during gait in individuals with PD.

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The Gait Variable Scores as clinically relevant tool for the classification of Myotonic Dystrophy types

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Introduction

Myotonic Dystrophy (DM) is a rare and progressive neuromuscular disorder with genetic transmission.It is one of the most complex pathologies ever known and it is the most common adult muscular dystrophy, characterized by progressive muscle wasting and weakness [1]. Currently, two major types of DM are recognized: type 1 (DM1) and type 2 (DM2). In both, gait and balance can be severely impaired. Focusing on locomotion, weakness affects mostly the distal muscles (lower legs) in subjectswith DM1 and the proximal muscles (pelvis and hips) in subjects with DM2. To date, locomotive functional deficits are investigated through clinical assessment. It is worth highlighting that the interpretation of the huge amount of three-dimensional data generated by gait analysis is not so straightforward. Therefore, synthetic indexes have been made, namely Gait Profile Score (GPS) and/orGait Variable Scores (GVSs) [2]. We aimed to evaluate the applicability of GPS and GVS in individualswith different types of DM. In our hypothesis, GPS and GVS could be considered clinically relevant tools if they result able to detect the differences between DM1 and DM2 kinematics and provide a quantitative measure to a possible rehabilitation scenario.

Methods

Individuals affected by Myotonic Dystrophy were enrolled for this study. The evaluation was carried outat the Motion Lab of CCP using a 6-cameras optoelectronic system (VICON, Oxford, UK) with a sampling rate of 100 Hz. Sixteen spherical retro-reflective passive markers (14 mm diameter) were placed on the patients' pelvis and lower limbs according to Plug-In-Gait model (VICON, Oxford, UK). After familiarization, the subjects walked barefoot at their own natural pace along a 10-m walkway. Rawdata were pre-processed and processed using a customized script in MATLAB (MathWorks Inc., Natick, MA, US) and the kinematic outputs were used to calculate the GVSs (one for each kinematic time- series) and the GPS. Normative reference data employed in the routine use for clinical gait analysis services (MOTION Lab, CCP, Milan, Italy), was used as reference population. Higher GVSs and GPS values, larger the deviations from a physiological gait pattern.

Results

Three DM1 patients (1 Female, 46.7 ± 6.5 years) and three DM2 patients (3 Female, 66.3 ± 11.7 years) were enrolled. Spatiotemporal parameters and GPS, although altered in comparison with normative data, did not reveal anysignificant effect of the pathology, while specific GVSs (distal for DM1, proximal for DM2) were strictly related to DM type (in bold into Table 1).

Table 1. Comparison between GPS and GVS in individuals with DM1 and DM2.

	Parameter	DM1	DM2	p-value
	GPS [°]	12.75 (3.06)	13.88 (3.56)	0.245
	Pelvic Tilt	**14.69 (4.77)**	**19.17 (8.42)**	**0.028**
	Pelvic Rotation	3.57 (1.11)	3.71 (1.33)	0.698
	Pelvic Obliquity	4.64 (2.15)	5.42 (1.17)	0.127
GVS [°]	**Hip Flex–Extension**	**16.74 (5.67)**	**25.24 (8.63)**	**<0.0001**
	Hip Abd–Adduction	3.98 (2.19)	3.11 (1.24)	0.098
	Hip Rotation	19.64 (8.75)	17.26 (7.64)	0.322
	Knee Flex–Extension	13.35 (5.02)	14.60 (1.93)	0.264
	Ankle Dorsiflexion	**12.59 (4.83)**	**6.75 (1.24)**	**<0.0001**
	Foot Progression	**8.98 (3.45)**	**4.60 (1.57)**	**<0.0001**

Discussion

GPS, that takes into account all the kinematic patterns along the gait cycle, candifferentiate DM from unaffected people, indeed, all DM subjects (both DM1 and DM2) showed a value greater than 10°,denoting a general picture of impaired gait.Only a deeper investigation by means of GVSs can discriminate and quantify DM types, identifying alsothe joints more affected by the disease. This could be beneficial in order to track the evolution of the muscular involvement and to guide specific rehabilitation program.

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Assessment and comparison of zero-velocity detectors under variations in running speed

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Introduction

The analysis of running spatio-temporal parameters is crucial in sports science [1]. In-field running can be conveniently assessed using magneto-inertial sensors (MIMUs) [1]. Most of the studies estimating stride velocity and/or stride length based on foot-worn MIMUs uses a zero velocity detector (ZUPT) to reduce the integration interval to a single stride, thus reducing the signal drift [2]. However, the performances of ZUPT detectors are often tested for specific running speeds, and methods generalizability for different running paces is overlooked. The aim of this research was to compare across running speeds (between 8 and 25 km/h) the performances of the most used ZUPT detectors in running [3], which employ fixed thresholds dependent on running speed, and a parametric ZUPT detector [4], that automatically determines the threshold.

Methods

Twelve runners were enrolled: a) 4 amateurs running for 400 m at 8-10 km/h, b) 4 amateurs running at 14 km/h for 6 min, c) 4 elite runners performing a 50m-sprint. All the subjects were instrumented with two MIMUs (fs = 100Hz for a, fs = 200Hz for b and c) and the available reference consisted of instrumented pressure insoles for a and c, and a stereophotogrammetric system for b.
Three different ZUPT detectors were implemented: SHOE method [3] is based on accelerations and angular velocities; ARE method [3] considers only the angular velocities; and the parametric method proposed by Rossanigo et al [4] minimizes the kinetic energy without requiring to set any fixed threshold. The flat foot intervals derived from pressure insoles and stereophotogrammetry data were used as a reference. To perform the integration of acceleration data, integration instants were chosen at 50% of each ZUPT interval. The overlap of the integration intervals (i.e., strides) of the three methods with respect to the reference integration intervals was calculated. To assess the impact of the different ZUPT methods on the velocity estimation, errors on the estimation of the average velocity with respect to the reference running speed value were calculated.

Results

Table 1 shows the evaluation of the implemented ZUPT detection methods, in terms of the overlap of the integration intervals and of errors on average velocity, with respect to the relevant reference values.

Table 1. Percentage overlap (Ov%) of the integration intervals and the percentage mean absolute error (v_{MAE}%) of the estimated velocity, for the different running speeds and methods.

Speed km/h	Skog et al 2010 (SHOE)		Skog et al 2010 (ARE)		Rossanigo et al 2021	
	Ov%	v_{MAE}%	Ov%	v_{MAE}%	Ov%	v_{MAE}%
8-10	96.6 ± 1.2	2.2	92.1 ± 2.8	3.8	94.9 ± 0.8	0.9
14	96.3 ± 3.1	1.2	95.5 ± 2.6	2.7	96.4 ± 3.4	0.6
20-25	95.7 ± 2.7	3.5	97.2 ± 1.0	4.9	95.5 ± 2.0	2.8

Discussion

This study highlights that different ZUPT methods led to comparably good performances for a wide range of running speeds in terms of the detection of the integration intervals. However, larger errors on average speed estimate were found with ARE method, followed by SHOE method. Overall, the best performances were obtained with the parametric solution, which exhibits v_{MAE}% always below 3% and does not require the tuning of ad-hoc thresholds. In conclusion, the parametric method is suggested as most favourable ZUPT detector in running between 8-25 km/h.

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Evaluation of a passive upper limb exoskeleton using high-density surface electromyography

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Introduction

Wearable and/or collaborative robotic technologies are becoming increasingly popular in industry 4.0 [1]. Indeed, using these technologies the immediate and short-term biomechanical effort is reduced. During a prolonged tasks while it is well known that, in the case without an exoskeleton, there are fatigue-related alterations in the neuromuscular pathway (i.e., changes in motor unit (MU) firing, motoneuron excitability, and motor cortical excitability), it is still to be explored how the (CNS) handles the presence of an exoskeleton. In this study, we investigated the muscle activity of the Biceps Brachii caput longum (BBCL) muscle during an overhead work task with (W) and without (WO) the presence of the Comau-XT exoskeleton (a passive exoskeleton for upper limbs). We compared the muscle activity in the two conditions by using high density surface electromyography (HDsEMG) that allows us to individuate the activation of motor units and the estimation of their firing rate [2].

Methods

Seven male participants (27±2 years; mass: 81±8kg; height: 180±7 cm) took part in the study (local ethics committee approval: N. 0078009/2021). HDsEMG was acquired via one 64 channels grid (OT Bioelettronica, Italy) placed on BBCL muscle. Each participant performed three 5-second maximal voluntary contractions (MVC) during which force values were recorded using a dynamometer (DIN ERGO 81-08 PRO X; Centro Italiano di Ergonomia, Italy) that provided instantaneous visual feedback of the force values through a display. Then, participant performed submaximal tasks maintaining values of 40% MVC and 60% MVC for as long as the subject could sustain it and never more than 2 minutes. The two submaximal conditions were spaced by 3 minutes [3]. During MVC and fatiguing task, the participant placed his arm at 90° to his forearm and apply a vertical isometric force, directed from bottom to top, on the dynamometer thrust recording point. The task of maintaining submaximal values was performed, in a random order, under the two conditions (W and WO) with a 2-hour break between the two. Considering each of 59 bipolar recordings from adjacent, nonoverlapping signal epochs of 0.5-s duration, we calculated the Root Mean Square (RMS) values to create a topographical map of BBCL activity and the mean RMS of the whole grid in all the task (RMS_{grid}) and considering 5s at the beginning (RMS_{in}), at the middle (RMS_{mid}), and at the end (RMS_{end}) of the task [3]. Furthermore, the decomposition algorithm [4] was applied for identifying MU, their action potentials and discharge rate.

Results

Figure 1. Topographical map of muscle activity(A,B),RMS values(C),MU with its discharge rate and action potential amplitude(D,E).

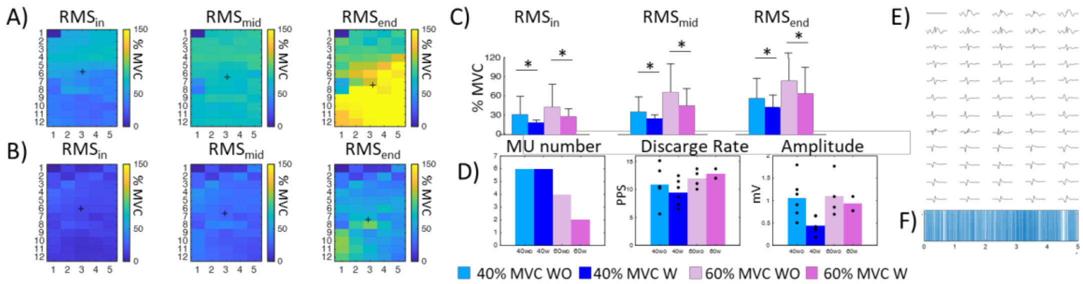

Figure 1 shows an example of a topographical map of BBCL activity created by using the RMS values for each bipolar signal for 60% MVC in the two conditions: WO (Fig. 1A) and W (Fig. 1B) exoskeleton. The Wilcoxon test showed a significant effect of the exoskeleton on the RMS at three times (1C). Furthermore, the figure shows an example of an extracted MU with its discharge rate and action potential amplitude (Fig. D and E).

Discussion

The results obtained in this study show how the passive upper limb exoskeleton can be useful during a static overhead word task. Indeed, when the task is performed with the exoskeleton, there is a reduction in amplitude of sEMG signal and a different MUs recruitments strategy in terms of numbers and firing rates due to a reduction of muscle fatigue [2].

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Interpersonal coordination during walking with hand contact

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Introduction

Handholding can naturally occur between two walkers. When people walk side-by-side, either with or without hand contact, they often synchronize their steps [1]. However, despite the importance of haptic interaction in general and the natural use of hand contact between humans during walking, few studies have investigated forces arising from physical interactions. There are only few studies that analysed human-human or human-robot interaction during locomotion [2,3,4]. Here, we investigated how interpersonal coordination acts through interaction forces during side-by-side walking in adult-adult, adult-child and child-child dyads.

Methods

Eleven couples participated in this study (7 adults and 9 children total): 2 couples adult-adult, 5 couples adult-child and 4 couples child-child. Each couple was asked to walk reaching 3 different targets (located at a distance of ~6 m straight, left, right) in 4 different conditions. In the two conditions ("no role"), they walked with eyes open either without hand contact or with contact. In the others two conditions ("guidance"), the first partner was a leader (with eyes open) and the second partner (blindfolded) needed to follow the leader through the hand contact and vice versa. The command to start walking was provided by an acoustic signal in the headphones. We analyzed the kinematics of both subjects, the interaction forces and the EMG activity of ten muscles of the upper limbs (7 on the side of contact and 3 on the contralateral side).

Results

All subjects completed the tasks successfully. The contact forces were generally small (<10 N through the whole trial). Interestingly, in the "no role" conditions, proximal arm muscle activity could be conserved despite reduction in arm swing. In the "guidance" conditions, we found that the upper limb of adults was significantly less compliant when guiding a child partner, while children were more compliant in all roles when their partner was an adult. Augmented arm stiffness in adults guiding children was associated with increased DELTp activity.

Discussion

In this study, we described a novel approach to evaluate human-human interaction forces during side-by-side walking with hand contact. The conservation of the proximal muscle activity of the contact (not oscillating) arm is consistent with neural coupling between cervical and lumbosacral pattern generation circuitries ('quadrupedal' arm-leg coordination) during human gait. The findings suggest that individuals might integrate force interaction cues to communicate and synchronize steps during walking, modulating the mechanical properties of their arms to increase awareness and sensitivity to ongoing interaction. Future applications of interactive locomotion related to walking assistance or rehabilitation should take into account the effect of size of subjects and the compliant behavior of the upper limbs.

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Trunk muscle coactivation changes in patient with multiple myeloma undergoing vertebral consolidation surgery: a study performed by using movement analysis technologies

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Introduction

Multiple myeloma (MM) is a cancer that causes clonal proliferation of malignant plasma cells and can result in multiple spinal injuries. Patients with multiple spinal injuries often complain of pain, stiffness, and lumbar and spinal cord compression, which limit motility and daily and occupational activities. Pathological fractures of spinal bones and vertebral collapses are associated with a sudden and abrupt increase in pain and kyphosis, deformity, and permanent disability [1,2]. Biomechanical stabilization of microfractures by percutaneous vertebroplasty may help control pain and prevent further spine damage in vertebral collapses. The current scientific scenario supports vertebroplasty's beneficial effects on patients' lives. The scientific literature describes increased joint stiffness and compressive and shear forces in the L5/S1 joint as some of the main consequences of agonist-antagonist muscle coactivation, so to assess whether vertebroplasty can benefit the patient, we hypothesized that muscle coactivation and stiffness would decrease after the operation [3]. The purpose of this study is to test the above hypothesis and to determine how spinal motility and stability change after vertebroplasty surgery.

Methods

Data were collected at the Multifactorial Analysis Laboratory of the *National Cancer Institute* (CRO) in Aviano. This clinical trial's ethical aspects adhere to the Helsinki Declaration guidelines, and the study was approved by the local ethics committee Single Regional Ethics Committee under approval number CRO-2020-35. Each of the four patients with MM without vertebral collapse leading to spinal cord compression, and four healthy volunteers performed three liftings (load 2 kg) in the sagittal plane. Patients repeated the task before and 1 month after vertebroplasty surgery. The start and end of each lifting were detected using a system of five infrared cameras considering the vertical displacement and velocity of a marker placed on the load. Surface electromyography (sEMG) was recorded bilaterally over the erector spinae longissimus and rectus abdominis superior muscles. Then, after sEMG processing and amplitude-normalization respect to the maximum peak value of each trial of a subject's task, we computed the coactivation of the trunk using the formula proposed by Rudolph and colleagues [4]. We calculated the mean, maximum and full width at half maximum (FWHM) of each curve as synthetic parameters. The non-parametric Wilcoxon signed rank and Mann-Witney statistical tests were used to compare the pre- and post-treatment conditions and the patient and healthy groups, respectively. A p-value lower than 0.05 was considered statistically significant.

Results

Both the Wilcoxon signed rank test and the Mann-Whitney test showed no statistical differences between pre and post conditions, patients and healthy controls pre and post with respect to the means (p=0.75, p=0.4, p=0.06, respectively), max (p=0.5, p=0.86, p=0.23, respectively), and FWHM (p=0.75, p=0.11, p=0.11, respectively) muscle coactivation. Fig.1 shows the mean and standard deviation values.

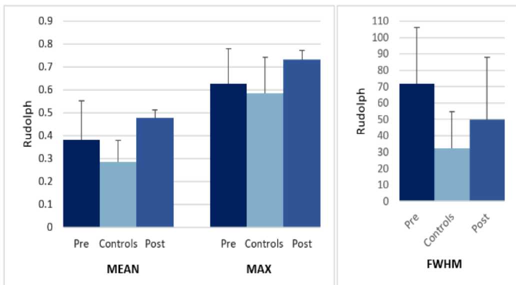

Fig.11. Histogram of coactivation in patients pre- and post-vertebroplasty and healthy subjects in the lifting task

Discussion

The results reveal an overall increase in coactivations after vertebral consolidation, due to the need of the central nervous system to further protect the spine to manage the new biomechanical condition. This explanation is strengthened by the comparison with healthy controls. In fact, before the spinal consolidation procedure, the patients' muscular behaviour was more like that of the controls. Therefore, it is of paramount importance to provide patients with appropriate rehabilitation treatment at an early stage after surgery. A limitation of this study is the small number of patients enrolled in the experimental phase up to this point. Further investigations are needed to increase the sample size and to analyse additional activities of daily living.

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