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Sessione 1A – Analisi del movimento nello sport

Validation of an inertial body sensor network for upper limb kinematic assessment in archery

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INTRODUCTION

Archery is defined as the ability to shoot an arrow at a given target by using a bow [1]. The shot is generally characterized by three specific phases: the stance, the arming and the sighting [1]. All the movements of the technical gesture involve the muscles attached to the shoulder grindle and upper extremity [2]. A biomechanical analysis of the shooting gesture could be of great interest, especially for injury prevention, but most of the studies in scientific literature focused mainly on its physiological characterization (i.e., by the analysis of the heart rate, EMG signals and body posture [3]). Aim of the proposed work is to validate an inertial body sensor network (IMU) for kinematic analysis (i.e., joint angles estimation) of the right upper limb during the execution of a typical archery task. The joint angles estimated with IMUs were compared with the one calculated using an optoelectronic motion capture system (OMC) to assess the correctness of the estimation.

METHODS

One expert archery practitioner was involved in the study. Participant, in accordance with the Helsinki protocol, signed an informed consent form. Four IMUs (Xsens, The Netherlands) were placed laterally on the right upper limb (i.e., hand, forearm and arm) and on the trunk using elastic bands. Each IMU was mounted on a 3D-printed plastic support together with three reflective markers needed to acquire reference data from the OMC (Vicon, United Kingdom). After the positioning of the IMUs, the participant performed three series of ten shots for a total of thirty repetitions. The biomechanical model used to extract the joint angles from IMUs and OMC trajectories was previously introduced by Ligorio et al. [4]. The joints involved in the study were right wrist (angles nomenclature: flexion/extension – FE, internal-external rotation – IR/ER, abduction/adduction – AB/AD), right elbow (angles nomenclature: flexion/extension – FE, pronosupination – PS, carrying angle – CA) and right shoulder (angles nomenclature: flexion/extension – FE, pronosupination – PS, abduction/adduction – AB/AD). In order to verify the accuracy of joint angles estimation, the Mean Absolute Error (MAE) and the Pearson's correlation coefficients R between IMU and OMC were calculated.

RESULTS

Table 1 reports MAEs and the Pearson's correlation coefficients for the three joint angles involved in the study.

Table 1: MAEs (mean $\pm$ std) and Pearson's correlation coefficients (R, mean $\pm$ std)

	AB/AD or CA	IR/ER or PS	FE
Wrist			
MAE [°]	3.52 ± 0.93	2.48 ± 0.55	1.98 ± 0.67
R	0.94 ± 0.07	0.99 ± 0.02	0.94 ± 0.06
Elbow			
MAE [°]	1.97 ± 0.57	2.08 ± 0.75	2.34 ± 1.09
R	0.98 ± 0.01	0.97 ± 0.04	0.98 ± 0.01
Shoulder			
MAE [°]	2.77 ± 1.52	4.52 ± 1.23	1.96 ± 0.51
R	0.99 ± 0.01	0.98 ± 0.03	0.99 ± 0.01

DISCUSSION

Results confirm the IMU body sensor network as a suitable technology for kinematic analysis (i.e., joint angles estimation) in archery. Indeed, the MAEs mean values ranged from a minimum of 1.96° to a maximum of 4.52°. Considering the complexity of the movements and the high range of motion of the right upper limb, the estimated errors could be considered acceptable for human motion analysis in archery. In addition, the high Pearson's correlation coefficients confirmed the great similarity between the joint angles estimated using OMC and the ones measured by using IMUs. The proposed solution has several advantages. Indeed, it is usable directly on the playground without altering the movement or inducing any discomfort for the user.

ACKNOWLEDGMENTS

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Biomechanical analysis of field hockey for injury prevention purposes

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INTRODUCTION

Field hockey is a very popular sport, played by men and women both at the recreational and professional level. In North America, there are over 35000 players registered in national associations, but despite the sport's popularity, there are few publications that focus on field hockey injuries prevention [1]. Field hockey is a sport in which speed is the most important aspect, for this reason the athletes are typically required to perform several sprints running during the competitions. The aim of this study is to understand whether females are more prone to lower limb injury risk than males and whether different techniques for holding the stick can play a role with this respect. Hence two cohorts of players were acquired while performing a sprint holding the hockey stick with one or two hands.

METHODS

Nine female athletes (mean (SD): age: 21.56 (4.67) years; BMI: 22.01 (0.99) kg/m^2) and seven male athletes (mean (SD): age: 22.00 (2.83) years; BMI: 23.71 (1.67) kg/m^2) of the CUS Padova hockey team signed informed consent and took part in the study. All the athletes were acquired directly on the field, while performing two consecutive 10m sprints in two different conditions: one carrying the hockey stick with one hand and one with two hands. Data were acquired by means of four GoPro Hero3 and plantar pressure insole (Pedar X, Novel). TrackOnField was used as software for automatic tracking of features (BBSoF S.r.l.) and self-developed Matlab (R2017a) codes were used to estimate lower limb joint angles and moments (hip, knee, ankle) [2]. A simplified version of the IORgait was used as a marker set [3]. Only sagittal plane kinematics was considered. Normative bands were created for each variable. Student T-test (after evidence of normality, $p<0.05$) was applied in order to compare the biomechanical variables between the female and the male cohorts.

RESULTS

Significant differences were observed between the two cohorts, especially in terms of lower limb's hip joint rotations and knee moments. Higher hip flexion angles were observed in female athletes. An opposite trend was observed in the male athletes and higher knee moments were measured; female athletes recorded very high knee varus moments differently from male athletes that recorded low valgus/varus moments. Moreover, when the athletes performed the sprint task holding the hockey stick with two hands, they showed a better control of their movement and lower risk of injury compared to the sprint task carrying the stick with only one hand.

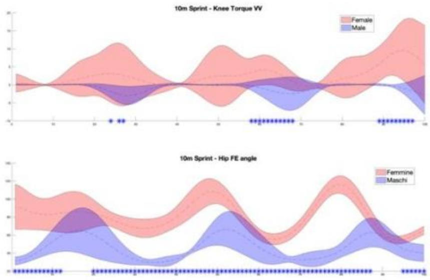

Figure 1: Figure on the top: Comparison between the knee moments of the two teams; Figure on the bottom Comparison between the hip angles of the two teams

DISCUSSION

The present study highlighted differences between male and female cohorts. The female team resulted to be at higher risk of injury than males, with the knee joint resulting in the one at higher risk.

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Influence of a maximal running incremental test on jumping performances

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INTRODUCTION

A good level in explosive strength has been proved to increase running economy and decrease the risk of overuse injuries among middle and long-distance runners. To optimize the number of training sessions, middle/long distance runners often perform endurance running and strength workouts combined in the same training session, even if the efficacy of the concurrent training of strength and endurance is a theme still debated. Jumping exercises (e.g., counter movement jump *CMJ*, single-leg jumps *SLJ*) are some of the most used methods to train and test explosive strength [1]. The efficacy of jumps exercise is higher when they are performed close to the maximal athletes' level of performance and with a correct technique. However, there is not yet scientific consensus about the influence of the fatigue caused by endurance running training on jumping ability. Some studies observe a decrease in jumps height and motor control after submaximal long runs, while other an increase in jumps height after a continuous run close to the maximal threshold [2,3]. The aim of this study is hence to analyze the effect of a maximal running incremental test on jumps exercise performance, in terms of jumps' height, kinematic jumping patterns and level of neuromuscular control.

METHODS

15 middle-distance recreational runners of both sexes (age 22±3, BMI 23.2±2.4) performed two jumping trials (i.e., five CMJ and five consecutive SLJ on place on the dominant lower-limb) before and after a treadmill running maximal incremental test. Participants were requested to reach the maximal height in each trial. Four inertial measurement units (Pivot, TuringSense, USA) were placed unilaterally on the foot, shank, thigh and center of mass and they were used in association with a photosensor system (Optogait, Microgate, Italy) to analyze the effect of the running test on the kinematic of CMJ and 5SLJ. The biomechanics of both jump types was described trough the jumps' height. For CMJ we also evaluated the vertical center of mass (CoM) displacement during the eccentric/concentric phases (EP/CP), the CoM velocity and the mean relative force expressed during EP/CP. The 5SLJ test was described trough the foot contact area across jumps, the maximal force and the Relative Strength Index (RSI, a proxy for stiffness). CMJ was used to evaluated the subject's level of explosive strength, while the 5SLJ the capacity to maintain a good level of neuromuscular control while performing a complex explosive strength exercise. Wilcoxon signed rank test was used to identify differences in jumping's parameters before and after the incremental test (pre-run/post-run). Cliff's Delta effect size was used to quantify the effects on the aforementioned parameters.

RESULTS AND DISCUSSION

The fatigue caused by a maximal running incremental test did not affect the level of explosive strength of CMJ and 5SLJ (i.e., jumps' height did not decrease after run), but influenced their kinematic patterns and, as expected, decreased the level of movement control in the most technically complex exercise (i.e., contact area of 5SLJ was larger in post-run conditions), table 1. In fact, in post-run CMJs the CoM descended less and slowly during the eccentric phase and the force expressed in the concentric phase was higher. Even in the post-run 5SLJ, the force expressed was higher, as the RSI. These results suggest that the maximal running test might enhance a higher neuromuscular recruitment, increasing stiffness, thus keeping jumps height despite fatigue conditions. Consequently, when looking at jump height, CMJ can be exercised with no difference before and after a maximal endurance running effort. On the contrary, when moving the attention to different aspects as it is in 5SLJ-based parameters, it is important to consider the fatigue-related effects on neuromuscular control, affecting the gesture quality.

Table 1. Jump parameters showing a statistically significant pre-run vs post-run difference.

	Parameters	Pre-run mean(SD)	Post-run mean(SD)	*p*	Effect-size
CMJ	Vertical CoM displacement of EP (cm)	15.0(1.0)	13.0(1.0)	<0.01	0.43
	CoM velocity of EP (m/s)	0.61 (0.07)	0.56(0.09)	<0.01	0.24
	Mean force of CP (N/kg)	7.35(1.26)	8.69(1.31)	<0.01	0.31
5SLJ	ContactArea (m^2)	345.9(68.4)	359.9(64.6)	<0.05	0.33
	Maximal Force (N/kg)	35.95(12.50)	38.22(11.43)	<0.01	0.26
	Relative Strength Index	0.493(0.332)	0.540(0.158)	<0.05	0.29

ACKNOWLEDGMENTS

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Joint kinematics and EMG characterization of para-archery shooting technique: an explorative study

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INTRODUCTION

Archery requires fine control of neuromuscular and biomechanical variables to improve shooting precision, thus optimizing performance [1]. Biomechanical analyses of the shooting technique showed that a 90° arm elevation is the best position to reduce tremor [2], with the trapezius muscle of the draw side (i.e. side from which the arrow is drawn) being the most involved in scapular fixation during shooting [3]. This shooting characterization is currently lacking when considering archers with disability, for whose postural adjustments related to disability can highly influence the performance. Therefore, the aim of this study is to provide a characterization of the archery technical gesture in terms of upper limb joint angles and muscular activity of two elite para-athletes suffering from different motor disabilities.

METHODS

One W1 archer (male, 34 years, spastic tetraplegic) and one OPEN archer (male, 57 years, paraplegic) shot 3 ends of 4 arrows at a target positioned at 10 meters from the shooting line. An optoelectronic system (Vicon, UK, 200 Hz) was used to track the 3D trajectories of 7 markers attached on C7, sternum, acromion process, medial and lateral epicondyles, and on radius and ulna styloid processes. Shoulder and elbow joint kinematics was obtained following the ISB recommendations [4]. EMG activity of the biceps (BI), upper trapezius (UT) and posterior deltoid (PD) muscles was registered (Cometa, IT, 1000 Hz). EMG signals were band-pass filtered (30-400 Hz), full wave rectified and low-pass filtered at 6 Hz with a zero-lag 4th order Butterworth filter to obtain EMG linear envelopes [5]. Only the draw side was considered for the present analysis.

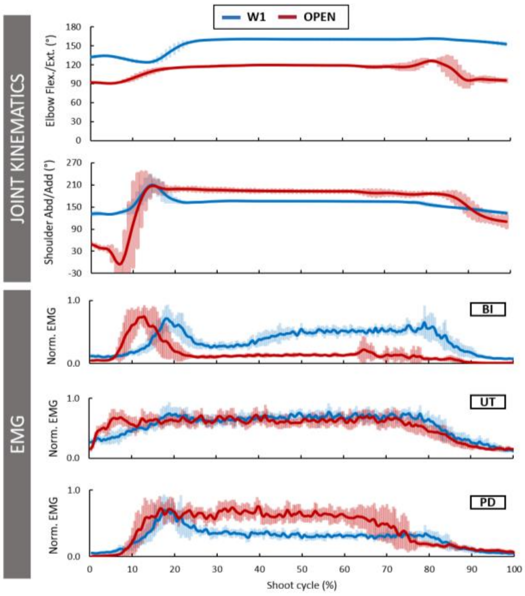

Fig.1 Shoulder and elbow kinematics as well as EMG signals of the considered muscles.

RESULTS

Elbow flexion/extension and shoulder ab/adduction are reported in Figure 1, together with ensemble averages of the amplitude-normalized EMG linear envelopes of BI, UT, and PD muscles. Subject-specific motor strategies were displayed by W1 and OPEN archers, showing differences specifically at elbow joint level and in BI and PD muscles activities (Figure 1).

DISCUSSION

As expected the two athletes adopted different strategies according to their functional limitations. Specifically, the OPEN archer, paraplegic, showed shoulder abduction and elbow flexion angles similar to those previously reported in able-bodied athletes [2]. Conversely, W1 archer's showed a greater activation of the biceps muscle during the pulling of the bowstring and different joint range of motions throughout the movement. Besides providing interesting elements to coaches and athletes for correcting possible technique errors, the present characterization could be of great interest for the advancement of an objective classification of the athletes' with disability in para-archery, which is indeed a critical issue due to the heterogeneity of motor impairments.

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The effects of different midsole bending stiffness of sport shoes on lower limb biomechanics

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INTRODUCTION

The assumed relationship between repeated heel impacts in running and the developments of overuse injuries has led to heel cushioning being a key design feature in running shoes [1]. Indeed, running mechanics can be influenced by shoes' midsole stiffness/geometry as demonstrated in [2]. The midsole is the primary component of the cushioning system, it comprises the midsole along with the outer sole and innersole or sock liner. The design and construction of these components are crucial to the effective functioning of the shoes [3]. The goal of this study is to define a pipeline (i.e. tasks and biomechanical variables) to assess the impact of different shoe characteristics such as stiffness and geometry on lower limb biomechanics. For this purpose two shoes with different comfort and cushioning characteristics were compared during different tasks (i.e. running, landing, gait).

METHODS

After signing informed consent, 10 healthy (mean ± SD; age 26.4 ± 4.35 years; BMI 24.71 ± 3.25 kg/m^2) male subjects were acquired. All the subjects performed several gait cycles, 6 single leg (right/left) drop landing tasks from a 32 cm height and a running session. Lower limb kinetics and kinematics were acquired by means of a stereophotogrammetric system (6 cameras, BTS, 60-120 Hz), a force plate (Bertec, 960Hz), a pressure insoles system (Pedar X, Novel, 100Hz) and an sEMG system (FreeEmg, BTS, 1000Hz) that collected the activity of Tibialis Anterior (TA), Gastrocnemius Lateralis (GL), Gastrocnemius Medialis (GM) and Peroneus Longus (PL). Reflective markers were applied according to a simplified version of [5] and joint angles and moments were determined [5]. The biomechanical variables of interest were: peak and mean pressure, ground reaction forces, contact surface, center of pressure (COP), ankle joint angles, moments, work and power, sEMG activity (i.e. signal envelope normalized on the maximum value within the tasks). For the running sessions only the pressure insoles system was used. Two shoes, one with enhanced cushioning and comfort characteristics and a regular running shoe were tested and compared across the different tasks (Wilcoxon rank sum test, α=0.05).

RESULTS

The results show that the proposed pipeline is able to identify the impact of the different cushioning characteristics through a set of tasks and biomechanical variables. The shoe characterized by enhanced cushioning revealed during walking (1), drop landing (2) and (3) running respectively: (1) higher peak pressure at pushoff, larger contact surface, larger COP excursion, lower ankle range of motion in flexion-extension and inversion-eversion rotations, larger adduction angle, reduced medial-lateral and anterior-posterior ground reaction forces, but higher vertical forces at pushoff, higher ankle eversion moment, lower work produced at the ankle, higher sEMG activity on PL and GM; (2) lower peak pressure and higher ankle range of motion in flexion-extension and inversion-eversion rotations, higher anterior-posterior and vertical ground reaction forces, higher work produced at the ankle joint and power exerted, reduced GM and TA activity coupled with higher GL and PL activity at contact; (3) lower peak pressure, higher forces and contact surface.

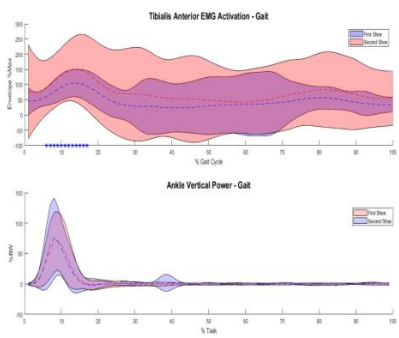

Figure 1. Up, the Tibialis Anterior Activation in the gait cycle; Down, the Ankle Vertical Power in the Drop Landing. In Blue and in Red the two different shoes.

DISCUSSION

Results of this study showed that, in order to define the impact of sport shoes on athletes performance, both the shoe inner sole and the sock liner characteristics should be assessed on different tasks through kinematics, kinetics and sEMG foot and ankle related variables.

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3D lower limb joint kinematics of Snowboard Giant Slalom: preliminary analysis using wearable inertial sensors

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INTRODUCTION

The use of wearable inertial and magnetic measurement units (IMMUs) has got increasing interest in winter outdoor sports applications like snowboard as it allows in field acquisition during training sessions(1). IMMUs technology can monitored the action continuously without specified spatial limitation and does not require long-time post-processing and complex experimental setup (1). To improve the knowledge of performance factors and to provide suggestions to athletes and coaches, the kinematic analysis of a whole snowboard slope is fundamental. The aim of the present study was to compare 3D lower limb joint kinematics of elite and experienced recreational snowboarders during giant slalom using IMMUs.

METHODS

Four males belonging to the Italian Snowboard National Team (age 27±3.2y, height 1.80±0.10 m, mass 83.4±4.3 kg) and 4 males experienced recreational athletes (age 41.5±5.5 y, height 1.76±0.03 m, mass 89.0±12.2 kg) were acquired. Two trials on a snowboard slope (14 gates spaced at 21 m, 200m total descent) were acquired for each athlete. Eight IMMUs (APDM Opals, 128 Hz) were attached on sternum, sacrum, thighs, shanks, toe of ski boots (right and left). Outwalk protocol was implemented for the 3D kinematic analysis of trunk-pelvis, hip, knee and ankles joints (2). Backside and frontside turns (BT, FT) were identified using the change of ski edge for the identification of the beginning/end of a turn. To validate the algorithm for the automatic identification of the change of the ski edge using IMMU, snowboarders were filmed for the first 4 gates using a video camera (JVC full HD, 250hz). Joint kinematics on sagittal and frontal planes were expressed in percentage of the duration of the BT and FT, mean and standard deviation curves were estimated for the two groups and compared using statistical parametric mapping (3).

RESULTS

The elite athletes showed an almost fixed value of flexion for the trunk-pelvis joint during both FT and BT, the recreational athletes exhibited a similar pattern for the BT while a more flexed trunk during the FT. Only during the BT, more flexed hip joint was found for the elite (105±9 deg) with respect to the recreational (81±7deg) athletes. On the frontal plane, no differences were found.

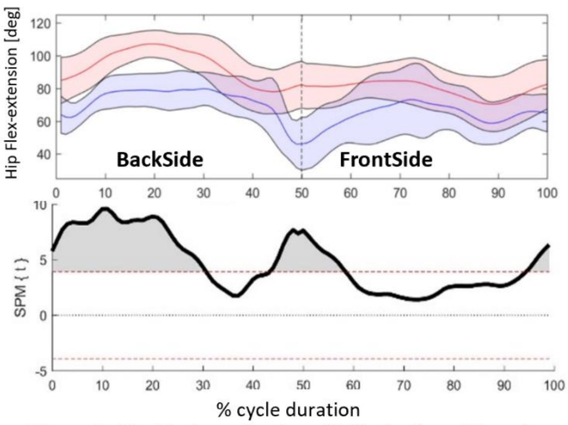

Figure 1. Hip Flexion extension of Elite (red) and Experienced recreational athletes

DISCUSSION

The differences found for the trunk-pelvis and hip joints were consistent with the higher technical skills of the elite snowboarders. Furthermore, the recreational snowboarders showed higher variability of the kinematics patterns particularly during FT and for the knee identifying this phase and this joint as the most critical factors. Results indicated the IMMU technology as a viable option to analyse the joint kinematics of snowboard giant slalom in real field. Further studies will be developed to investigate the kinematics variability of the turns execution during the whole slope.

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Sessione 1B – Analisi del movimento in chirurgia ortopedica

Typical Risk Pattern for Anterior Cruciate Ligament Injury is Largely Present in Competitive Athletes: Biomechanical Screening through Wearable Sensors

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INTRODUCTION

The incidence of Anterior Cruciate Ligament (ACL) injury is growing with particular regards to young and female athletes' populations. Recently, specific biomechanical patterns involving multiple joints have been described in ACL injured players [1]. The rehabilitation programs after ACL injury are increasingly relying upon the avoidance of such biomechanical risk factors. It is not clear whether and to what extent such patterns are present in the healthy athletes' population. The aim of the present study was to investigate the presence of biomechanical risk patterns for ACL injury in a healthy population during the execution of high-dynamics movements.

METHODS

Thirty-four competitive young, healthy athletes (22.8±4.1 years, 18 males and 16 females, Tegner Level 9) were enrolled. Every athlete performed a test battery of five motor tasks: drop jump (DJ), lateral landing (LL), frontal deceleration (DEC), single-leg hop (SLH), change of direction at 90° (COD). Three valid repetitions per leg of every task were collected. Kinematical data of ankle, knee, hip, and trunk joints were collected through a set of 15 wearable inertial sensors (Awinda, Xsens Technologies). According to the current literature on ACL injury pattern [1], 9 risk factors were identified: limited knee and hip flexion, ankle plantarflexion, high knee valgus and internal hip rotation, high internal/external hip and ankle rotation, high trunk contralateral rotation and ipsilateral tilt. A movement was considered "at-risk" in the presence of at least 5 simultaneous risk factors. The central strike of each task was isolated, and risk factors were assessed at initial contact and at the maximum knee flexion angle. The number of athletes with at-risk movements was assessed with specific regard to gender, movement complexity, and limb dominance. The incidence of the injury pattern was statistically compared through the Fishers' Chi-Square test with $p<0.05$.

RESULTS

The presence of the injury risk pattern in at least one movement was identified in 32 athletes (94%). The 74% exhibited the risk pattern in at least three movements, and 41% in at least 5 movements. Five athletes (15%) exhibited the risk pattern in more than 7 movements (up to 11 movements). More than half of the at-risk patterns were identified in the COD and DEC tasks. A significantly higher incidence of injury pattern was found in the initial contact compared to the maximum knee flexion angle and in the players performing the task with their non-dominant limb (Table 1). No differences were found between the incidence of male and female athletes.

Table 1. Rate of risk pattern according to athletes' and movements' characteristics. IC=Initial Contact; MKF=maximum knee flexion angle; Dominant limb= kicking limb; n.s.= non-significant differences.

	Rate (%) of risk pattern (minimum 5 risk factors)	**P-value**
Gender (male, female)	47 / 53	n.s.
Frame (IC, MKF)	58 / 42	0.007
Limb (dominant, non-dominant)	39 / 61	<0.001

DISCUSSION

The present study underlined a large presence of biomechanical patterns typical of ACL injury in young and healthy athletes during the execution of complex dynamic movements. Such movements should be investigated in sport-specific environments for a wider comprehension of the actual risk level. The early identification of at-risk athletes might promote preventative training strategies focused on the increasing of movement quality and the reduction of dangerous biomechanical patterns.

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Superimposition of ground reaction force on tibial-plateau morphology supporting diagnostics and post-operative evaluations in high-tibial osteotomy. An novel methodology.

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INTRODUCTION

Abnormal varus knee may result in medial knee osteoarthritis, medial condyle hyper-compression, and unnatural locomotion. Medial knee decompression is considered to prevent end-stage medial knee osteoarthritis, generally via High Tibial Osteotomy (HTO). This is expected to restore normal lower-limb mechanical alignment and locomotion, and proper condylar load distribution [1]. Although good clinical results are reported for this treatment, the literature lacks relevant careful biomechanical evaluations. To this end, a fully personalized combination of gait analysis (GA), including Ground Reaction Force (GRF) data, and patient-specific knee morphology, as reconstructed from Computed-Tomography (CT), could provide valuable insight. The aim of this study was to employ the above novel methodology to provide a holistic patient-specific analysis of the mechanics of the knee under load before and after HTO. We hypothesized that the position of GRF with respect to the tibial plateau during locomotion reflects the mechanical advantages of the treatment.

METHODS

Twenty-five patients selected for HTO received pre-operative clinical, radiological and instrumental examinations; to date, these were repeated post-operatively on 16 of these patients at 6-month follow-up. GA was performed during level walking, stair-climbing/descending, chair-rising/sitting and squatting. A 9-camera motion capture system, combined with wireless EMG and two force platforms, was used together with an established protocol [2]. The latter was enlarged with 4 additional skin markers around the tibial-plateau rim. All analyzed patients received full lower-limb upright X-ray and weight-bearing CT scan of the knee while still wearing the additional markers. Morphological models of the proximal tibia and of the additional markers were reconstructed from relevant DICOM files and a tibial anatomical reference frame was defined. The markers from CT reconstruction were then registered to the corresponding trajectories as tracked by GA during motion. Resulting registration matrices were then used to report GRF data on the reconstructed tibial model. Kinematics/kinetics and intersection paths of GRF vectors with respect to the tibial-plateau plane were calculated.

RESULTS

Pre-operative clinical/radiological examinations confirmed original knee impairments and misalignments. The registration of GRF was successfully achieved pre- and post- HTO, barring an acceptable level of error. As expected, pre-operative GRF patterns and peaks of the intersection curve, including those associated to knee joint moments, were observed located medially to the knee. In post-HTO, these were observed lateralized and much closer to the tibial plateau, as desired. When post- is compared to pre-op, the difference of the centroids of GRF intersections were 54.4±18.0 mm (min÷max: 36.5÷73.0 mm) more lateral during walking and 52.5±28.5 mm (24.6÷87.5 mm) during stair climbing. When reported in % of the entire medial-to-lateral tibial plateau width, these values became 69.2±20.1 (46.1÷81.4) and 78.1±30.0 (43.4÷98.0), respectively. Post-op clinical outcomes and GA revealed considerable overall functional improvements.

DISCUSSION

The present novel approach allows a personalized combination of motion data, GFR, and tibial-plateau morphology. Its exploitation in HTO pre- and post-operative analyses offers a novel quantification of the original misalignment and of the surgical correction which could enhance diagnostics and surgical planning of HTO as well other knee treatments.

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Effect of functional surgery on the recovery of foot rockers in patients with Charcot-Marie-Tooth disease. Observational study.

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INTRODUCTION
Charcot-Marie-Tooth (CMT) disease is the most frequent hereditary neuromuscular disorder, with a prevalence of 40 cases per 100,000 individuals [1]. It is a peripheral progressive motor and sensory neuropathy that determines, among other consequences, a severe cavo-varus foot deformity. Functional surgery (FS) is being increasingly used in the management of foot deformities in CMT patients to restore the physiological tibiotarsal and foot joint biomechanics [2]. The effect of FS on the recovery of foot rockers during the stance phase of gait has not been described in the literature yet.

METHODS
We retrospectively analyzed data from CMT patients referred to our laboratory, over the period 2018-20, for clinical and instrumental assessment (GA with dynamic EMG) preliminary to FS. Inclusion criteria: genetical diagnosis of CMT; ability to walk for at least 10 meters without footwear; available instrumental data (≥3 trials) both before and 1 month after surgery; available signed informed consent. Surgical procedures to be performed on each patient were chosen by a multi-disciplinary team (orthopedic surgeon, physiatrist and physiotherapist) and could include osteotomies, arthrotomies, tendon transfers and muscles lengthening [2]. The surgery was performed by the same surgeon.
The outcome variable used to assess the effect of FS on the recovery of foot rockers during gait was the progression of the center of pressure (COP) in the walking direction, normalized to the foot length (FL) [3]. COP was obtained by four force plates embedded in the floor (BTS Bioengineering, Infini-T, sampling frequency 400 Hz). The median value among trials was used for further analysis.

RESULTS
Data from 16 feet of 12 patients were included, 5F/7M, age range 11-64 years. COP progression values are shown in Figure 1 for all subjects. COP progression significantly improved in the sample (p=0.002, Wilcoxon test) from a median value of 50% FL (range 19-70%) to a median value of 65% FL (range 49-91%).

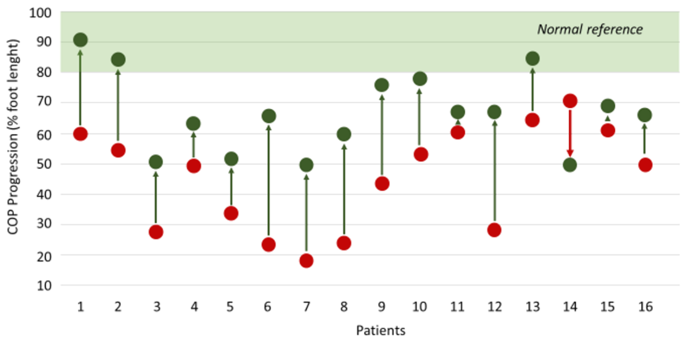

Figure 1. Variation of the center of pressure progression in the walking direction, normalized to the foot length, before (red dots) and one month after foot functional surgery (green dots).

DISCUSSION
Foot FS was effective in improving or restoring the foot rollover in the sample, as measured by COP progression. Better foot alignment and biomechanics determine better balance and gait in CMT patients [4].

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TUG test may be an outcome indicator before and after hip and knee arthroplasty

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INTRODUCTION
Total hip arthroplasty (THA) and total knee arthroplasty (TKA) are the most performed orthopedic surgeries in Italy. Time up and go (TUG) test has been widely used for these patients in order to compare patients to control subjects [1] and it has been demonstrated that it is a good indicator for both THA and TKA: according to Kristensen et al. TUG is a sensitive measure for identifying people with hip fracture at risk for new falls [2] while Yuksel et al. showed that it has an excellent test-retest reliability in patients with TKA [3]. The aim of this research is to show that parameters extracted from a TUG test through a G-Walk device are sensitive to gait improvements in patients who underwent THA and TKA.

METHODS
Overall, 30 patients were included in the study; they had a mean age 67,10 ± 7,26 and 19 of them were females. They performed a TUG test while wearing a G-Walk on their back; it is a wireless inertial sensor which allows users to extract spatial, temporal (and other) parameters characterizing gait of patients. A t test for paired data was employed to compare 12 parameters extracted during the TUG test immediately after surgery and two weeks later.

RESULTS
Table 1 contains the results of the statistical analysis and shows that the duration of the test and the rotation phase decreased, the accelerations increased and the rotation speed increase significantly two weeks after surgery.

Table 1. Descriptive statistics before and after surgery for each TUG feature and relative p-value. *=significant at 0.05; **=significant at 0.01; ***=significant at 0.001

Features	Pre (Mean ± Dev. Std)	Post (Mean ± Dev. Std)	p-value
Test duration	22,56 ± 6,54	18,77 ± 4,38	0,004 **
Lift phase duration	1,51 ± 0,36	1,49 ± 0,29	0,799
Sitting phase duration	2,08 ± 0,71	2,01 ± 0,69	0,710
Anteroposterior acceleration lift	2,64 ± 0,90	3,01 ± 0,96	0,029 *
Anteroposterior acceleration sitting	2,37 ± 1,12	2,92 ± 1,34	0,025 *
Lateral acceleration lift	1,66 ± 0,68	1,90 ± 0,95	0,264
Lateral acceleration sitting	3,00 ± 1,30	3,31 ± 1,43	0,228
Vertical acceleration lift	3,57 ± 1,10	4,09 ± 1,27	0,047 *
Vertical acceleration sitting	3,75 ± 2,56	3,45 ± 1,40	0,304
Intermediate rotation phase duration	5,15 ± 1,32	5,26 ± 7,62	0,937
Final rotation phase duration	3,64 ± 1,06	2,99 ± 1,25	0,042 *
Maximum intermediate rotation speed	70,47 ± 13,78	87,37 ± 20,57	<0,001 ***

DISCUSSION
This preliminary statistical analysis proved that the TUG test is a good screening to evaluate the improvements in patients before and after THA and TKA. A greater dataset would allow to use features extracted from TUG as predictors of the outcome of this type of patients through a machine learning approach.

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Kinematical patterns through Dynamic RSA reflected clinical outcomes improvement during at two-years follow up.

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INTRODUCTION

A new concept of total knee arthroplasty (TKA), the medial-stabilized (MS) knee prosthesis, has been developed trying to mimic distal femur and tibial plateau geometry, thus reproducing the natural knee motion. However, the relationship between knee motion and patients' satisfaction is still unclear [1]. The use dynamic radiostereometric analysis (RSA) could be useful in predicting the clinical outcomes through kinematical patterns [2].

The aim of the study was to evaluate the clinical outcomes and the kinematical pattern of the MS TKA during a two-follow-up period. We hypothesized that (1) an improvement in clinical outcomes and (2) coherent changes in kinematical patterns.

METHODS

10 patients were evaluated through clinical and functional scores evaluation (Knee Society Score -KSS, Womac, Oxford), and kinematically through dynamic RSA at minimum 9 months (FU1) and at 2 years (FU2) after MS-TKA, during the execution of a sit to stand. The clinical and kinematical differences were evaluated through Student's t test ($p < 0.05$) and a correlation analysis between score improvement and kinematics was performed through the Pearson's correlation coefficient r.

RESULTS

A significantly greater ($p < 0.001$) anterior translation of the lateral compartment with respect to the medial one was found in both FU1 and FU2 (Table 1), thus resulting in a medial pivot pattern. Significant improvement of KSS clinical was found (delta 20.3, p=0.018), while the other scores remained stable. Significant correlations were found between KSS clinical improvement and laxity reduction, particularly with peak external rotation (r=0.47), peak anterior translation (r=0.62), varus-valgus rotation (r=0.75).

Table 1. Anterior-posterior translation of the medial and lateral condyles of the femoral compartment at two follow up.

	FU1	FU2
Medial condyle	2.6 mm ± 0.8 mm	1.4 mm ± 0.5 mm
Lateral condyle	8.3 mm ± 2.8 mm	7.3 mm ± 3.0 mm

DISCUSSION

Clinical outcomes either improved or remained stable between FU1 and FU2 and a medial pivot pattern was confirmed. Laxity reduction evaluated through Dynamic RSA concretely reflected the patients' clinical improvement.

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Sessione 2 – Analisi del movimento: strumenti e metodi

Accuracy of a multi-sensor system in stride parameters estimation: comparison of straight and curvilinear portions

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INTRODUCTION

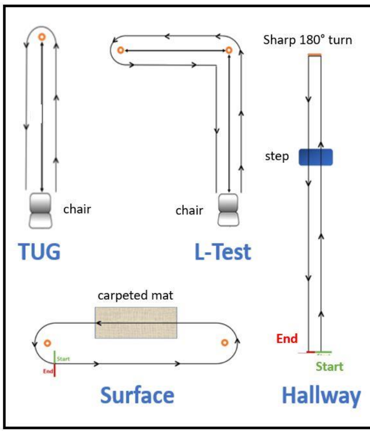
The evaluation of gait performances in free-living conditions requires the adoption of wearable devices to step out of the laboratory. With this aim, researchers are focusing their attention on the development of technologies and algorithms to estimate the relevant digital mobility outcomes with the same level of accuracy and robustness reached in standardized environments. When analyzing real world walking, it is fundamental to discriminate between straight and curvilinear portions. This because specific analysis of curvilinear walking can be informative of turning impairments in pathological populations [1]. This work deals with the evaluation of performances of a wearable multi-sensor system (INDIP) against the stereophotogrammetric (SP) system in the estimation of stride-related variables for both straight and curvilinear portions.

METHODS

The INDIP system includes three inertial measurement units (IMUs, fs=100 Hz, lower back and feet), two plantar pressure insoles (PI, 16 sensing elements, fs=100 Hz) and two time-of-flight distance sensors (fs=50 Hz) [2]. Experiments were carried out on 20 healthy participants (12 males, age 29.4±9.4 years) while performing four motor tests (Fig. 1). Data were processed according to the following steps: (i) static/dynamic activity periods recognition; (ii) PI-based gait events detection; (iii) spatial variables computation from feet-IMUs; (iv) stride identification and selection; (v) walking bouts identification; (vi) turning portions recognition from lower back IMU [2] and distinction between straight and curvilinear strides; (vii) parameters estimation including stride duration, stride length. For each parameter, accuracy was evaluated for each test in terms of Bias and standard deviation (STD) and mean absolute percentage error (MAE%).

RESULTS

Results averaged over subjects are presented in Fig.1.



DMO	Tests	MAE %		Bias (STD)	
		Straight	Curves	Straight	Curves
Stride duration (ms)	TUG	3.2	2.6	-17 (30)	1 (31)
	L-Test	1.3	1.3	-8 (16)	1 (21)
	Surface	1.3	1.2	-10 (18)	0 (19)
	Hallway	1.8	3.1	-5 (30)	4 (35)
Stride length (mm)	TUG	3.6	9.4	-6 (60)	5 (114)
	L-Test	3.4	5.3	4 (52)	17 (73)
	Surface	3.7	4.3	11 (60)	24 (60)
	Hallway	4.3	15.8	10 (71)	12 (154)
Stride speed (mm/s)	TUG	5.7	8.8	17 (50)	7 (114)
	L-Test	3.7	5.2	12 (49)	15 (61)
	Surface	3.9	4.3	20 (50)	20 (51)
	Hallway	4.5	16.8	11 (61)	-2 (135)

Figure 1. Overview of the tests and results obtained from the INDIP system.

DISCUSSION

Results showed that, for stride duration, the errors are very limited and similar for both straight and curvilinear strides (MAE%: 1.3%-3.2%). For both stride length and speed, errors are always higher in case of curvilinear strides. Smaller errors were observed for those tests such as L-Test and Surface test show which include more progressive and smooth turns. Larger errors observed for the TUG and the Hallway tests can be ascribed to the limited length of the walking portions and the presence of 180° sharp turn. Future developments include the extension of this analysis to free-living conditions, including both healthy participants and patients affected by different mobility impairments.

ACKNOWLEDGMENTS

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A wireless and miniaturized EEG-EMG acquisition system for the assessment of sensorimotor integration during overground gait

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INTRODUCTION

The study of sensorimotor integration during locomotion requires integrated acquisitions of multiple bio-signals (EEG, EMG) and kinematic. Current biomedical instrumentation allowing the simultaneous acquisition of such signals is often wired, non-wearable and prone to movement artifacts. As a paradigmatic case, treadmill walking is often used to overcome these technological physical constraints. However, the differences in muscle activation patterns between treadmill and overground walking [1] make the latter preferable as it represents a more naturalistic condition. The aim of this work is to design and validate a new fully wireless Body Sensor Network (wBSN) for the sensorimotor investigation during overground gait.

METHODS

The developed wBSN is based on a hybrid wireless network capable to simultaneously manage Bluetooth, Bluetooth Low Energy and Wi-Fi links. It integrates: (i) a 32-channel EEG acquisition unit, (ii) a set of bipolar sEMG acquisition units (DuePro, OT Bioelettronica, Italy), and (iii) a general-purpose acquisition unit collecting magneto-inertial signals and an additional analogue signal. After the system bench characterization (bandwidth, gain, latencies etc.), we collected EEG, EMG (left TA GM muscles), basographic and inertial signals from 10 subjects during 10 s overground walking at self-selected speed and 10 s of rest. The signal quality was evaluated in terms of slow and fast movement artifacts during the gait cycle. After gait segmentation, EEG-EMG coupling was assessed through coherence analyses [2].

RESULTS

Raw signals and topographic CMC distributions across the EEG electrodes of a representative subject are shown in the Figure. No relevant gait-related artifacts were detected in the wireless EEG recordings (Figure b). EEG and EMG showed significant CMC (β band, 14–30 Hz) in the right hemisphere over the sensorimotor area for both TA and GM, as previously shown [3]. As expected, no significant CMC was observed in the β band during rest (Figure d).

DISCUSSION

The proposed wBSN allowed the integrated acquisition of high-quality signals during overground walking thus enabling to obtain new insights in neurophysiological characterization of gait.

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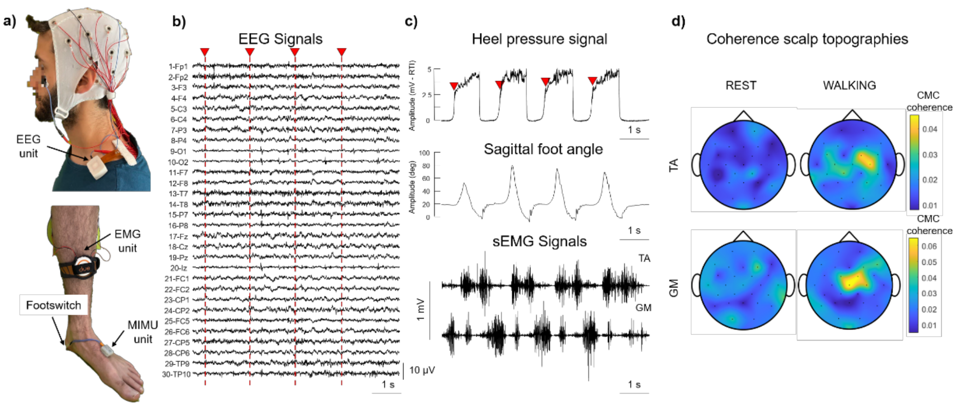

Figure 1. a) Experimental Setup. b) Recorded EEG signals. Vertical dashed lines indicate heel strikes. c) From top to bottom: signals collected from a footswitch positioned below the heel, sagittal foot angle and sEMG signals from TA and GM. d) Topographic CMC distributions over the scalp.

A biomechanical index of trunk displacement during gait: application to Parkinson's disease

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INTRODUCTION

The development of the upright posture and its consequences on gait are matter of debate in the framework of evolutionary theories [1]. Since humans developed bipedal locomotion, the trunk changed its position and so it did the centre of mass (COM). As a consequence, a reorganisation of the neural substrates underlying motor control was needed. Based on the theory of a suprasegmental control exerted on the body as a whole (i.e., the COM) [2], we developed a synthetic trunk displacement index (TDI) for the evaluation of the dynamic stability during gait. We tested this novel index in Parkinson's disease (PD), a pathology known for its motor impairment tied to axial rigidity [3]. Specifically, we compared the TDI in healthy controls (HC) and PD patients before (off condition - PDoff) and after (on condition - PDon) levodopa treatment in order to test the sensitivity of the novel index.

METHODS

Twenty-three PD patients and HC were recruited in this study. Both groups underwent gait analysis through a stereophotogrammetric system, recording the movement of the participants through fifty-five reflective passive markers. TDI was calculated for each participant as follows:

$$TDI = \frac{\sum \|Td\|}{\sum \|COMd\|}$$

where Td is the 3D vector of the distances between trunk trajectory and the average position of the COM, and COMd is the 3D vector of the distances between COM trajectory and the average position of the COM, during gait. The statistical analysis was performed in MATLAB. The three groups (HC, PDoff, PDon) were compared through a permutational multivariate analysis of variance (PERMANOVA). Post-hoc analysis was carried out through permutations. In both cases, each subject label was permuted 10,000 times. After False Discovery Rate correction, a p-value < 0.05 was considered as significant.

RESULTS

The comparison showed that the PD patients in off condition exhibited higher TDI values during gait compared to both PDon and HC groups. Furthermore, in the PD group, the TDI correlated positively with the Unified Parkinson's Disease Rating Scale (UPDRS).

DISCUSSION

The TDI was able to distinguish patients from HC. Moreover, it showed to be a sensitive biomechanical index able to distinguish between off and on condition within PD patients. Furthermore, it correlated positively with the UPDRS score, highlighting its clinical significance.

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Point-based inertial sensors anatomical calibration for talo-crural joint modelling

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INTRODUCTION

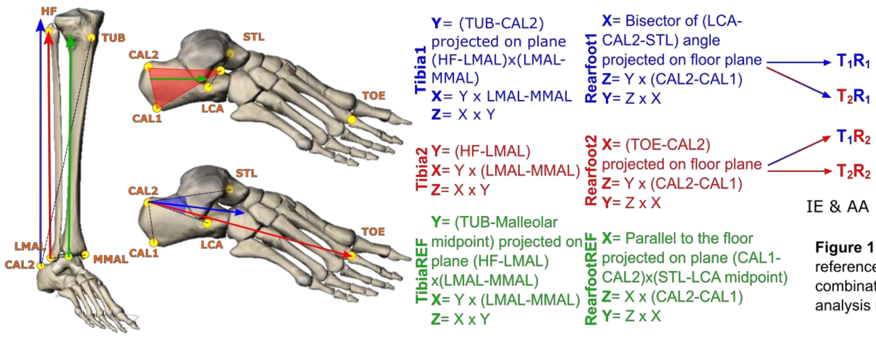
For clinical ankle kinematics analysis, the choice of the appropriate multi-segment foot model is crucial [1]. Joint kinematics assessment with inertial measurement units (IMUs) is mature for clinical use [2], but only limited attention has been devoted to implementing multi-segment models to describe the talo-crural joint [3]. To address the issue, this study focused on the point-based approach to IMU anatomical calibration [4], the definition of several anatomical calibration coordinate systems (ACSs) for rearfoot and shank segments, and the comparison of their resulting planta-dorsiflexion kinematics with respect to the current, most appropriate corresponding ACS [5].

METHODS

To analyse the impact of the anatomical description without the burden of IMU drawbacks, a 7-cameras photogrammetric system (MTx, Vicon, UK; at 100 sample/s) was used to track 9 anatomical landmarks (ALs) (Fig. 1) placed on the foot of 10 participants (age: 20±8 years, mass: 70±9 kg, stature: 1.8±0.1 m). These ALs were selected to identify 2 ACSs for the rearfoot and 2 for the shank, to be easily subjected to a point-based approach for IMU anatomical calibration (Fig. 1). Each participant performed 5 gait trials at self-selected speed and the third was analysed. Talo-crural planta-dorsiflexion curves were obtained from all tibia and rearfoot ACSs combinations (T_nR_n) and compared with the reference kinematics ([5] option 4 and 5, Fig. 1). The linear fit method [6], which provides information about the linear relationship (R^2) the offset (a_0) and the amplitude scaling factor (a_1) among curves, and the root mean squared difference (RMSD) were used to perform the comparison.

RESULTS

All talo-crural planta-dorsiflexion obtained from the 4 ACSs combinations had a small RMSD (<0.3 deg), and almost perfect kinematic coherence (R^2 and a_1, Fig. 1) and a negligible offset (a_0, Fig. 1). Inversion-eversion and ab-adduction, grouped for all ACS combinations, showed higher RMSD (3.3 - 4.0 deg) and offsets (2.9 - 2.9 deg), but had similar shape (R^2 = 0.93 - 0.94) and ranges (a_1 = 0.98 - 0.93).



	RMSD (deg)	R^2	a_0 (deg)	a_1
T_1R_1	0.30	0.99	0.21	0.99
T_2R_1	0.30	0.99	0.21	0.99
T_1R_2	0.24	0.99	0.13	0.99
T_2R_2	0.23	0.99	0.13	0.99
IE & AA	3.63	0.93	2.90	0.98

Figure 1 describes all the ACSs, the reference ACS[6], their point-based combination, and the coherence analysis results

DISCUSSION

Results support this approach as a viable alternative to photogrammetry for multi-segment foot tracking. A sensitivity study of the impact of the anatomical calibration repeatability for the selected ALs could inform the best selection of the suggested ACSs.

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Responsiveness to rehabilitation of a set of gait stability indexes in persons with Parkinson's disease.

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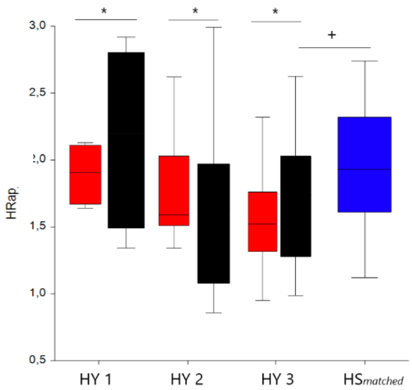
INTRODUCTION. Greater trunk mobility improvements during gait predict gait improvements to normative values after rehabilitation [1-2]. Recently, the discriminative ability of a set of trunk-acceleration derived gait stability indexes have been described in a sample of persons with Parkinson' disease (pwPD) [3]. This study aimed to observe their responsiveness to rehabilitation and the correlations between the improvements (Δ) in gait stability indexes and spatial and kinematic gait parameters.

METHODS. The trunk acceleration patterns were acquired during the gait of 31 pwPD using an inertial measurement unit placed at the lower back at baseline (T0) and after a 10-week rehabilitation period (T1). Harmonic ratios (HRs), percent recurrence, percent determinism, coefficient of variation, short-term Lyapunov exponent, and normalized jerk score in each spatial direction for each participant were calculated. 31 age-and-speed matched healthy subjects (HS) were included as a control group. Repeated measures ANOVA, using time and the Hoehn and Yahr disease staging classification (HY) as factors, was performed to identify significant improvements in the gait stability indexes. Multiple linear regression analysis and partial correlation analysis excluding the effects of gait speed and HY were performed to identify correlations between the Δ of the improved stability indexes and the baseline and Δ values of the spatio-temporal and kinematic parameters. The indexes that improved and overcame the cutoff values characterizing pwPD were considered as "normalized". Area under the ROC curve (AUC), minimal clinically important difference (MCID), likelihood ratios, and post-test probabilities were calculated to assess the responsiveness to normalization of the improved indexes and the correlated Δ gait parameters.

RESULTS. A significant improvement in HR of the antero-posterior (HR_{AP}) and medio-lateral (HR_{ML}) directions was found at T1, regardless of the HY stage. No significant difference in HR_{AP} between pwPD and HS was found at T1. ΔHR_{AP} was correlated with Δ pelvic obliquity (PO) ($r = 0.716$, $p = 0.001$), and ΔHR_{ML} ($r = 0.601$, $p = 0.001$) regardless of the HY stage and Δgait speed. Lower PO values at baseline and higher ΔPO predicted ΔHRAP values ($R^2_{adj} = 0.636$, $F_{(2, 17)} = 17.601$, $p = 0.000$). Seven pwPD improved and normalized their HR_{AP} values (Fig. 1). ΔHR_{AP} and ΔPO showed optimal ability to characterize pwPD who normalized the HR_{AP} values (AUC = 0.89 and 0.84, respectively). ΔHR_{AP} values >14.97% and ΔPO values >6.11% identified the improved and normalized pwPD with 91% and 90% probability, respectively.

Figure 1. ***HR_{AP} values at baseline (red) and after rehabilitation (black), compared with HS_{mached} (blue). *, significant improvements at T1, + normalization after rehabilitation***



DISCUSSION. HR_{AP} showed to be responsive to rehabilitation treatment and correlated with pelvic mobility, as an expression of the improvements in axial rigidity of pwPD. Subjects who improve their pelvic obliquity after rehabilitation by more than 6.11% are likely to improve their harmonic content of trunk accelerations during gait to normative values.

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Characterization of ankle musculotendon dynamics and muscle forces in Parkinson's disease patients: data-driven approach and statistical parametric mapping analysis

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INTRODUCTION

Reduced stride length, stride velocity and lower limb joint range of motion are hallmarks of parkinsonian gait [1]. Recently, the authors identified an impaired magnitude on leg muscle forces in Parkinson's Disease (PD) during gait when compared with healthy control subjects (CS) [2]. The aim of the proposed study was to enhance subject-specificity of the previous model, including a scaling technique for the optimization of musculotendon units (MTU) parameters [3].

METHODS

Thirteen CS (age=57.8±5.6 years, BMI=27.3±3.9 kg/m2) and ten PD subjects (age=62.8±11.4 years, BMI=27.1±2.9 kg/m2) were acquired with a 6-cameras motion capture system (60Hz, BTS), synchronized with 2 force plates (960Hz, Bertec) and an 8-channels EMG system (1000Hz, BTS) that recorded bilaterally the activities of 2 muscles: Gastrocnemius Lateralis and Tibialis Anterior. Inverse kinematics, inverse dynamics, and muscle analysis were performed in OpenSim using both a linearly and a muscle-optimized scaled model [3], including 24 lower limb muscles. Muscle-tendon parameters were calibrated to the individual using CEINMS [2]. EMG-assisted neuromusculoskeletal modelling was used to extract normalized MTU lengths and muscle forces of the ankle joint. Results obtained with the two scaling approaches were compared. Models' validity has been assessed comparing experimental excitations and simulated activations over the gait cycle using a within-participant analysis of variance with statistical parametric mapping (SPM) methods [4] ($p<0.05$, Bonferroni post-hoc). Differences between the MTU length and muscle forces obtained with the muscle-optimizer were compared using two-sample nonparametric t-test with SPM methods ($p<0.05$).

RESULTS

Statistically significant reduction of MTU lengths range of motion either for the ankle flexors and extensors in the PD group, accompanied by a statistically significant reduction of gastrocnemius lateralis and tibialis anterior magnitude were displayed in Figure1.

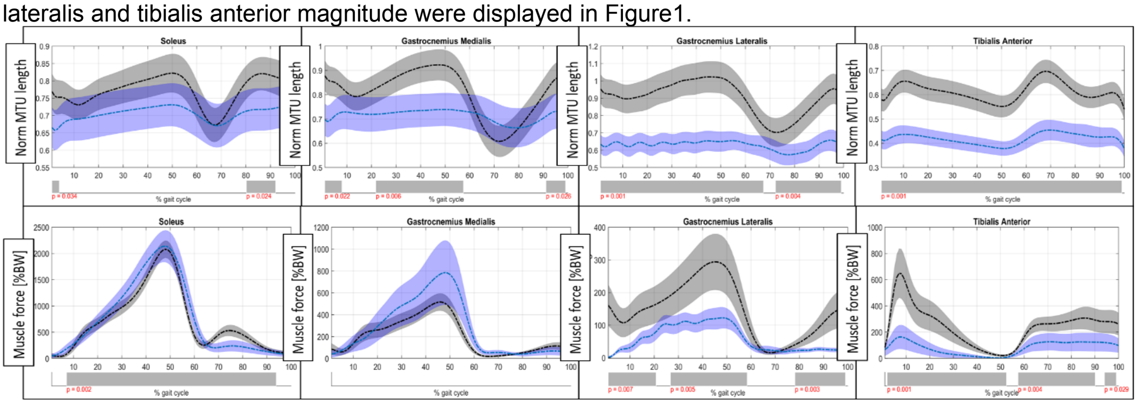

Figure 1: Normalized MTU lengths (upper row) and forces (bottom row) during walking in CS (black) vs PD subjects (blue). Cross-subject mean trajectories with standard error clouds. Lower black bars are the significant areas indicated by the SPM{t} statistic.

DISCUSSION

The evidence retrieved with the current analysis could provide a deeper understanding on the biomechanical reason for the impaired muscle forces and joint torques generation in PD.

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The inter-session reliability of instrumented insoles to compute gait parameters in Parkinson's disease

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INTRODUCTION

Gait impairment and walking limitations are common among patients with Parkinson's Disease (PD) and typically exacerbate throughout the disease progression [1]. In clinical settings, rating scales, as the Unified Parkinson's Disease Rating Scale (UPDRS), are typically used to examine gait disturbances in PD patients. In the effort to move towards a quantitative home-based assessment, different technological solutions have been proposed [2]. Instrumented insoles could be promising easy-to-use tools for an unobtrusive and continuous monitoring of PD patients during daily-life walking [2]. To detect real changes in walking conditions and distinguish them from measurement errors, it is essential to adopt tools that provide reliable findings [3]. The purpose of this work is to test the inter-session reliability of spatial and temporal parameters of gait captured via instrumented insoles (FeetMe insoles®, Paris, France) in patients with Parkinson's disease.

METHODS

Twelve PD patients (age mean±SD: 71±6 years, 10 males, UPDRS motor examination mean±SD: 16.3±3.2) were enrolled. The protocol included two testing sessions within one week. During each session, participants were asked to walk at their preferred speed along a straight-line path, wearing a pair of instrumented insoles inside their usual footwear. A customized Android-based mobile app [4] was used to collect gait parameters (gait speed (cm/s), cadence (step/min), stride length (cm), stride time (s), and double support time (s)) for each stride.

A paired t-test was conducted to examine whether systematic errors existed. The level of significance was set at p-value<0.05. The inter-session reliability was investigated through Intraclass Correlation Coefficient (2-way mixed effect model, absolute agreement, ICC(2,1)) with 95% Confident Intervals (CI). ICC(2,1) values higher than 0.750 indicate acceptable reliability. For clinical use, Minimal Detectable Change at 95% CI (MDC_{95}) was additionally computed to determine the minimal magnitude of change beyond which the change is likely to be real, rather than a random measurement error.

RESULTS

Instrumented insoles showed excellent inter-session reliability in measuring the examined gait parameters (Table 1). MDC95 values were below 11% of the mean. Furthermore, paired t-test analysis did not show any significant difference, demonstrating no systematic bias.

Table 1. Inter-session reliability results on 12 patients with Parkinson's disease.

	Session 1 Mean±SD	Session 2 Mean±SD	Systematic error (p-value)	ICC(2,1) [95% CI]	MDC_{95}
Gait Speed (cm/s)	90.4±24.3	87.5±21.3	0.133	0.978 [0.923-0.994]	9.38
Cadence (step/min)	102.4±12.4	101.7±11.2	0.722	0.918 [0.714-0.976]	9.41
Stride length (cm)	105.0±20.7	103.1±20.5	0.132	0.989 [0.961-0.997]	5.99
Stride time (s)	1.19±0.17	1.19±0.13	0.960	0.906 [0.668-0.973]	0.13
Double support time (s)	0.38±0.06	0.39±0.06	0.207	0.944 [0.812-0.984]	0.04

DISCUSSION

These preliminary findings support the adequate reliability of gait parameters captured by instrumented insoles to examine gait in patients with Parkinson's disease. These results encourage the application of FeetMe insoles® to assess patients with Parkinson's disease. Further investigations are needed to validate the use of instrumented insoles against gold-standard tools in patients with Parkinson's disease, with the final aim of providing accurate systems able to obstructively and continuously monitor patients in free-living environments.

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Is it possible to discriminate risk classes according to the revised NIOSH lifting equation using machine learning algorithms fed with features extracted from acceleration signals?

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INTRODUCTION

Lifting activities can cause a biomechanical overload leading to a potential risk of work-related musculoskeletal disorders. To improve risk prevention, the National Institute for Occupational Safety and Health (NIOSH) established a methodology for assessing lifting action through a quantitative method based on intensity, duration, frequency and other geometrical characteristics of lifting [1]. This methodology allows to compute the Recommended Weight Limit (RWL) for the specific lifting task and the risk index named Lifting Index (LI). The question remains whether it is possible to discriminate no-risk/risk classes according to the Revised NIOSH lifting equation (RNLE) using machine learning (ML) algorithms fed with time-domain features extracted from acceleration signals.

METHODS

A single Opal sensor (APDM, Inc.) placed on the lumbar region was used to acquire acceleration signals along the three axes during lifting tasks designed to correspond to no-risk/risk classes according to the RNLE. Five healthy subjects were recruited in the study. Each subject performed a task session based on two trials. Each trial consisted of 30 consecutive lifting tasks. The first trial consisted of repeated liftings in a condition of LI < 1 (LI = 0.5) namely the no-risk class, the second trial consisted of repeated liftings in a condition of LI > 1 (LI = 1.3) namely the risk-class. The subjects performed the task lifting a plastic container (56 x 35 x 31 cm^3) from 50 cm to 125 cm (optimal geometric condition). The acceleration signal acquired during the trial underwent a segmentation process to extract the region of interest (ROI) corresponding to the window time in which the subject performed the lifting. For each ROI and for each axis we extracted four time-domain features: Root Mean Square, Standard Deviation, Minimum and Maximum considering that during the lifting activity the subject moved in two different directions (bottom to top and vice versa). Tree-based ML learning algorithms: Decision Tree, Random Forest, Gradient Boosted Tree and AdaBoost of Decision Tree fed with the time-domain features were employed to assess their feasibility to discriminate no-risk/risk classes according to the RNLE. Ten-fold cross validation and Accuracy, Sensitivity, Specificity and ROC area were used to validate the four predictive models. Knime Analytics platform was employed to perform the ML analysis.

RESULTS

We performed the ML analysis considering the whole study population, the resulting dataset is composed of 300 instances (60 x 5) balanced between the two risk classes, two classes (no-risk/risk) and 12 features (4 x 3). The results of the ML analysis on the dataset are shown in Table 1, where the no-risk class was considered as the reference class for Sensitivity and Specificity.

Table 1. Evaluation metrics scores of ML Algorithms fed with features extracted from acceleration signals

ML Algorithms	Accuracy	Sensitivity	Specificity	AucRoc
Decision Tree	0.89	0.89	0.89	0.95
Random Forest	0.94	0.93	0.95	0.98
Gradient Boosted Tree	0.94	0.93	0.95	0.98
AdaBoost of Decision Tree	0.91	0.87	0.96	0.95

DISCUSSION

The high scores in evaluation metrics showed that the proposed combinations of features and tree-based ML algorithms represents a valid approach to automatically classify the biomechanical risk to which subjects may be exposed during lifting activities. The presented methodology could represent a valid integration to the established protocols to evaluate the biomechanical risk more quickly and easily. Moreover, it could represent a valid tool when the conditions required for the application of standardised evaluation methods do not exist. These results are of direct practical relevance for occupational ergonomics, as they present the opportunity for automatic, economic and non-invasive detection of data able to assess the musculoskeletal and biomechanical risk associated with lifting.

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Tonic Stretch-Reflex Threshold (TSRT) estimation through a novel mechatronic system for the evaluation of movement dysfunctions at the elbow level

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INTRODUCTION

The clinical assessment of muscle spasticity is crucial for an effective rehabilitation of subjects with lesions of the Central Nervous System (CNS), e.g. post-stroke. Clinical evaluation protocols are usually strongly operator dependent and do not distinguish between neural and non-neural components in the resistance, neither measure the velocity-dependent reflex response which, in Lance's definition, is an essential feature of spasticity [1]. To overcome this limitation, we propose a mechatronic device for estimating the Tonic Stretch Reflex Threshold (TSRT), as proposed by Levin and Feldman in the context of the Equilibrium-Point Hypothesis (EPH), which allows for a reliable and operator-independent assessment of spasticity [2].

The reduction of the maximum voluntary force in the limb muscles (paresis) is another typical symptom of patients after a stroke. The torque/angle profile of the individual muscle groups evaluates the muscle force produced over the entire range of joint excursion, measuring the weakness of the paretic muscles at different muscle length value, in agreement with EPH.

METHODS

In this work, we present a new mechatronic device that was described in [3] which can estimate the tonic stretch reflex threshold at the level of the elbow muscles and can, at the same time, potentially act as a rehabilitation system. The device we propose consists of a support for forearm and arm, coaxially actuated with respect to the elbow joint. The motor allows to control the torque applied to the joint, or to assign an arbitrary angle, in a given range of values. In particular, the device can provide a controllable torque/speed stimulation and record the most relevant functional parameters of the musculoskeletal system at the elbow (joint position, torque and multichannel electromyography), with the ultimate goal of: i) gathering significant information for the instrumental and objective assessment of muscle spasticity and ii) allowing future therapeutic usage.

RESULTS

We developed two control strategies for two experimental procedures: (mode A) a position control for the estimation of the TSRT; (mode B) a torque regulation for the estimation of the torque/angle plot [4]. To test the performance of our device under both control modes, we performed preliminary experiments with a healthy participant. More specifically, mode A control was used for the estimation of the TSRT: a naïve subject was asked to hold the device handle, while maintaining the muscles relaxed. When a bell-shaped velocity profile (peak velocity ranging between 10°/s and 110°/s) was provided as input to the motor, the subject was required to contract the muscles in the middle of the trajectory, to simulate a stretch reflex (Fig.1). Tests in mode B were conducted by evaluating the step response, considering as input reference torques between 1 and 10 Nm. The subject was asked to slowly move the arm in flexion (average velocity 10°/s) multiple times. The first repetition was performed in free motion, then at each iteration the opposite torque was increased of 1 Nm, up to the threshold of 10 Nm. Results show that our device allows the correct implementation of the envisioned experimental procedures (mode A and B) with good performance in terms of tracking errors.

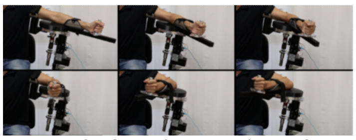

Fig. 1: Snapshot of a test for the estimation of TSRT (mode A), performed using the device

DISCUSSION

In this paper we presented a mechatronic device for the analysis of muscular spasticity and other movement disfunctions at the elbow level. This device is portable and enables different control possibilities. Future work aims to further develop the control techniques currently used, arriving at simulating the presence of a virtual object of arbitrary mass that the patient will be required to actively move. An evaluation of the repeatability and accuracy of the measurements will also be performed by enrolling a cohort of healthy subjects. Finally, the application for rehabilitative purposes is also envisioned.

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Sessione 3A – Neurofisiologia del movimento

The analysis of gait initiation using a wearable sensor detects specific-disease feature in subjects with Parkinson's Disease

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INTRODUCTION

A new approach for quantifying gait initiation using a wearable sensor has been recently developed and validated in a cohort of young and adult healthy subjects [1]. Anticipatory postural adjustments (APAs) are a specific type of weight shift that occurs prior to performing a postural task. In persons with Parkinson's Disease (PD) APAs prior to voluntary stepping are altered [2] and this compromises the subsequent motor performance. The recovery of the effectiveness of these steps is important for fall prevention.

The development of a simple gait initiation testing system, made up of a single sensor placed on the lower back and therefore usable outside the lab, would allow home-based monitoring and could contribute to measuring the effectiveness of rehabilitation treatments. For this reason, the aim of this work was to investigate if the acceleration-based algorithm described in [1] is able to discriminate between healthy subjects and persons with Parkinson's Disease.

METHODS

Fourteen subjects with PD (71.1 ± 5.7 yrs, Hoehn&Yahr 2-3) were enrolled in this study. The experiment took place during the "on" state (1 hour after taking their antiparkinsonian medications). Disease severity was assessed with the Unified Parkinson's Disease Rating Scale (UPDRS) Part III. The subjects stood with their feet in parallel at hip width and were asked to initiate gait in response to auditory stimuli and to stop as soon as possible with both feet on the ground. The protocol included five trials and the stimulus was a neutral voice saying 'Start'. An inertial measurements unit was placed on the lower back at L4-L5 using an elastic strap. Eight age-matched healthy elders provided the normative data.

The following parameters were calculated from the acceleration data, according to the algorithm published in [1]: 1) APA duration, the time from the beginning to the end of the APA waveform, and 2) Swing time duration, the time from the toe-off to the heel-strike of the first step. The differences between groups (PD and ELD) were tested using unpaired t test.

Correlation analysis was performed between the APA parameters and UPDRS Part III using the Pearson correlation test.

RESULTS

Persons with PD showed longer temporal parameters compared to those of healthy subjects for both phases (Mean ± SD, APA duration [s]: PD 0.83 ± 0.19, ELD 0.64 ± 0.16, $p = 0.03$; Swing time duration [s]: PD 0.53 ± 0.14, ELD 0.42 ± 0.06, $p = 0.06$).

A positive correlation was found between UPDRS item 3.14 related to bradykinesia and i) APA duration ($\rho = 0.61$, $p = 0.01$) and ii) Swing time duration ($\rho = 0.66$, $p < 0.01$).

DISCUSSION

Persons with PD showed prolonged phases compared to those of elders during gait initiation. In addition, both parameters, the APA duration and the Swing time duration, were moderately associated with bradykinesia. These results support the hypothesis that APA alteration likely contributes to hypokinetic steps often observed in this population [3,4]. Our results suggest that the analysis of the postural adjustments from a wearable sensor is able to detect one disease-specific deficit (i.e. bradykinesia) particularly disabling in persons with PD. The current work sets the stage for future developments of rehabilitation exercises in tele-rehabilitation programs using a single wearable sensor.

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Title: FIT-SAT neuro-rehabilitation treatment for acquired peripheral facial paralysis after smile reanimation: a pilot study

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INTRODUCTION
FIT-SAT is a new rehabilitation treatment[1], based on mirror mechanisms and hand/mouth synergies, for patients treated with neuromuscular transplantation (free gracilis muscle graft, FGMG) re-innervated by the massetteric nerve. Combining the most recent discoveries from the world of neuroscience with the needs of clinical practice, FIT-SAT includes the observation and execution of corner-of-the-mouth smile (facial "smile" imitation treatment, FIT)[2] accompanied by the closing of the hand (synergistic-activity treatment, SAT)[3]. Previous studies demonstrated the efficacy of FIT-SAT in recruiting the transplanted muscle in comparison to spontaneous recruitment through teeth clenching in congenital peripheral facial palsy (PFP). Here we tested the efficacy of the FIT-SAT treatment also in patients with acquired unilateral PFP who have undergone FGMG. The 3D kinematic data of participants' unilateral mouth movements were compared between acquired and congenital paralysis group.

METHODS
Eight patients who have undergone FGMG took part in the study. Four of them had a congenital PFP (C-PFP group) while the other four had acquired PFP (A-PFP group). As soon as an initial activation of the transplanted muscle was observed participants began FIT-SAT at home and took part in an experimental session in which the three-dimensional (3D) kinematics of mouth was registered (SMART-DX-100 system, BTS Bioengineering, Milan, Italy). The experimental conditions required participants to: imitate the unilateral smile observed on video-clips by closing the ipsilateral hand (SO-HC); imitate the movement observed on video-clips without closing the hand (SO); perform a unilateral smile without observing it on video-clips and close the ipsilateral hand (HC); perform a unilateral smile without observing it and without closing the ipsilateral (BC) hand. Two markers were applied at the corners of the mouth and a further additional marker was placed on the nose (reference point). Unilateral smile amplitude was calculated as the maximal intercommissural distance (MID), that is, the Euclidian distance in millimiters between the two lip corner markers.

RESULTS
We used linear mixed-effects models fit by maximum likelihood (LMM) to test the efficacy of the FIT-SAT conditions on the excursion of the patients' unilateral smile. Results suggest that the observation of a smile and its subsequent reproduction associated with hand closure (SO-HC) increased patients' unilateral smile excursion with respect to the baseline condition. No other differences were found.

DISCUSSION
As already demonstrated in previous studies[1], the combined use of smile observation and hand closure (SO-HC condition) determined a greater recruitment of the transplanted muscle with respect to baseline condition. Moreover, no group effect was found. This is particularly interesting for the purposes of this study because It demonstrates an improvement in smile excursion in the SO-HC condition independently of group. This supports the use of the treatment also for acquired paralysis.

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INFLUENCE OF AGE, SEX, AND ANTHROPOMETRY IN THE I-MOVE STUDY: A SENSOR-BASED AMBULATORY ASSESSMENT OF GROSS-MOTOR DEVELOPMENT IN SCHOOL-CHILDREN

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INTRODUCTION

Timely motor development in childhood is the foundation of healthy adult life and aging, affecting not only physical, but also mental health, and social participation. Nevertheless, how intrinsic and extrinsic factors influence this development is still not clear. Several approaches have been proposed for the monitoring of motor development, but recently, wearable inertial sensors allowed to develop a quantitative longitudinal assessment approach, exploitable in ambulatory conditions [1]. The present study is comprised in the I-MOVE study [2], a school-based intervention trial, with a quasi-experimental design, performed in a primary school, and aims to analyze gross motor development in school children with respect to age, sex, and anthropometric characteristics.

METHODS

One hundred and fifty children from an Italian primary school participated in the study, 72 first- (38M, 34F; age 75±5 months) and 78 third grade (48M, 34F; age 108±6 months). Anthropometric characteristics (height, weight, triceps and subscapular skinfold thicknesses) were collected according to standardized procedures. Children walked at self-selected speed (NW) and in tandem (TW) wearing three inertial sensors on the lower back and on the shanks. Temporal parameters, short- and long- term variability, and nonlinear metrics of trunk kinematics (i.e. recurrence quantification analysis, multiscale entropy) were calculated [2] and statistically analyzed (Kruskal-Wallis test 5%).

RESULTS

Stance and double support duration increased during NW and decreased during TW with age independently from sex, while their variability decreased.

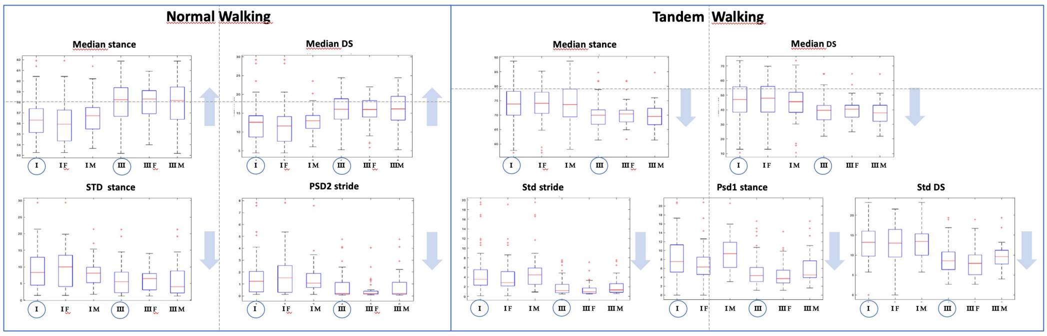

Figure: Temporal parameters (stance and double support) and variability (standard deviation, Std, short- and long-term variability, PSD1 and PSD2) as related to age (first grade, I, third grade, III) and sex (F, M)

Automaticity (i.e. recurrence indexes) increased with age during NW more in female than in males, while it decreased during TW independently from sex. Complexity (i.e. entropy) increased with age during TW. No dependency on height or weight alone was identified independently from age, while overweight (i.e. BMI and skinfold thicknesses) was associated to a reduction in the development of automaticity during TW independently from sex.

DISCUSSION

Both sex and anthropometry resulted to influence motor development in the target population, in particular overweight appears to delay the maturation of automaticity.

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Global lower limb muscle coactivation from slow walking to running

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INTRODUCTION

Muscle coactivation is one of the strategies that the central nervous system (CNS) exploits to simplify the controlling the movements of the effectors [1,2]. The muscle co-activation has been poorly explored during running. In the present study, we investigated the simultaneous activation of many muscles of the lower limb (global coactivation) from slow walking to running to understand how the CNS changes the control of the whole-lower limb stiffness in the transition from walking to running. At this aim, we focused on: i) the impact of the gait speed; ii) the differences in the flexor and extensor muscles coactivation; iii) the changes in the muscles coactivation according to the rostro-caudal (from L2 to S2) anatomical organization.

METHODS

19 healthy runners were recruited (9 M, 10 W; age, 41±8 y; weight, 66±15 Kg). Each runner on a tapis-roulant were asked to perform thirteen walks from 0.8 km/h to 6.8 km/h and five runs from 7.8 km/h to 9.3 km/h with steps of 0.5 km/h. We recorded sEMG signals at 2 KHz using a 16-channel wireless system (Mini Wave System, Cometa, Italy). Surface electrodes were placed over the following right-side lower limb muscles: gluteus medius, rectus femoris, vastus lateralis, vastus medialis, tensor fascia latae, semitendinosus, biceps femoris, tibialis anterior, gastrocnemius medialis, gastrocnemius lateralis, soleus, and peroneus longus. The raw signals were processed and then it was calculated the time-varying multi-muscle coactivation function (TMCf) [3]. The following parameters were measured: i) co-activation index (CI); ii) full width at half maximum (FWHM) and iii) center of activity (CoA).

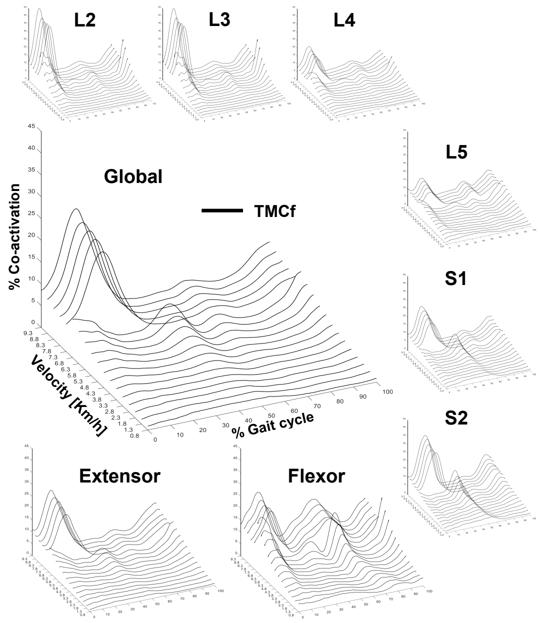

Figure 1: *The global, flexor-extensor and rostro-caudal lower limb muscle co-activation curves for each speed*

RESULTS

The repeated measures ANOVA test revealed a significant effect of the speed on CI (df =17, F =303.47, p <0.001), FWHM (df=17, F 18.27 p<0.001) and CoA (df=1, F=7.24, p<0.01). The global co-activation of the entire lower limb from slow walking to running show a different shape of activation (Fig. 1): the curves show a single peak at slow walking, 4 peaks at fast walking and 3 peaks at running. The coactivation of the extensor muscles showed a curve function similar to that of the global coactivation, whereas the coactivation of the flexor muscles significantly differed from it. Moreover, the coactivation of the flexor muscles abruptly increased just before the running speed threshold, in the late fast walking. A clear propagation delay in the global coactivation, according to muscle recruitment from L2 to S2, was found.

DISCUSSION

In the present study we have shown how the lower limb muscle coactivation changes from slow walking to running (Fig. 1), from flexor to extensor muscles and from rostral to caudal muscle recruitment: Overall our findings suggest that CNS simplifies the motor control of running by increasing/decreasing the whole-limb stiffness within a clear flexor/extensor and rostral/caudal coactivation pattern, which starts since the fast walking.

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A deep-learning approach to decode executed and imagined upper limb movements from EEG and interpretation of the learned features

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INTRODUCTION

Electroencephalographic (EEG) signals contain information about motor events, both in case of executed and imagined movements. In particular, neural activity generated prior to the motor event reflects motor preparation and gives rise to characteristic slow waves (motor-related cortical potentials) immersed in the noisy EEG, traditionally extracted via averaging techniques over multiple trials. Decoding preparation of movements from raw EEG signals on a single-trial basis, is a very challenging task, which may have important implications in the context of neurorehabilitation (e.g. to monitor rehabilitation progress) or Brain-Computer Interfaces (to promote more natural control of external devices). Deep learning-based decoders such as convolutional neural networks (CNNs), automatically learning relevant EEG features, are showing promising results in EEG decoding and may also contribute to enhance the comprehension of motor correlates by interpreting the features used for classification. The aim of this study is twofold: i) Evaluate the feasibility of a CNN-based model for decoding the preparation of different upper limb movements (both performed and imagined movements); ii) Investigate the motor-related spectral and spatial EEG features exploited by the CNN.

METHODS

We used a publicly available dataset [2] consisting of signals of 13 healthy participants recorded while performing or imagining the following movements with their right arm: elbow flexion/extension, forearm supination/pronation and hand open/close. During the task, 61 EEG channels (512 Hz) were recorded together with kinematics signals. EEG signals were filtered between 0.3-30 Hz and downsampled to 128 Hz. Then, to consider movement preparation, epochs were extracted between -1:0 s respect to movement onset. Therefore, the CNN input was represented by a single 1s-epoch and the CNN outputs were probabilities to classify the 3 joint movements. Here, we trained EEGNet [3], a previously validated CNN also for sensory motor rhythm decoding, using a 5-fold cross-validation scheme. Once trained, the learned temporal filters devoted to filter each EEG channel were analyzed in the frequency domain and the contribution of each EEG band was computed (counting how many filters contributed more within each band). In addition, the electrodes more relevant for each band were visualized.

RESULTS

The CNN F-score was 61.9±7.1, 57.7±9.1, 68.0±13.0% (mean ± std) when decoding performed movements preparation, for elbow flex./ext., forearm sup./pron. and hand open/close, respectively, and 46.2±8.2, 51.7±11.9, 46.7±9.8% when decoding imagined movements preparation. In Figure 1 the spectral and spatial features that allowed the separation between different movements preparation are reported, showing a larger contribution for δ band and for central electrodes.

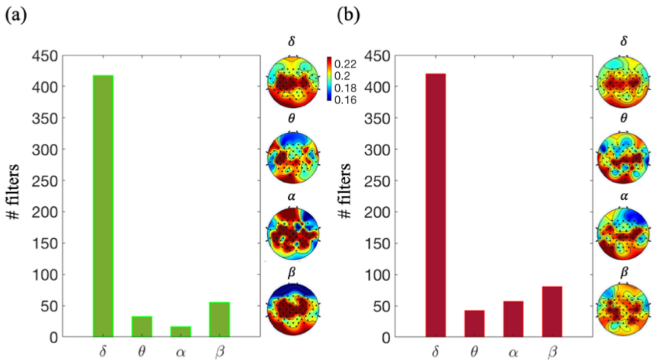

Figure 1. Spectral and spatial features within each EEG band when decoding performed (a) and imagined (b) movements. Bands were: δ (<4 Hz), θ (4-8 Hz), α (8-13 Hz), β (13-30 Hz).

DISCUSSION

The results suggest that a CNN-based workflow could be able to decode EEG activity preceding movement onset related to different joint movements (both imagined and performed), with higher performance when decoding performed movements. The δ band was the most used to discriminate the movement classes with electrode contributions more focused on central sites, suggesting that electrophysiological signatures of different upper limb movements mainly rely on slow frequency range.

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Higuchi's fractal dimension of lumbar acceleration during static tasks in Parkinson's Disease

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INTRODUCTION

Parkinson's Disease (PD) is characterized by impaired gait and postural control, leading to an increased risk of falls. Balance performances can be described analyzing signals from waist-mounted accelerometers [1]. Those signals are often used as proxy of body Center of Mass (CoM) motion, which is a non-stationary process with fractal properties [1]. Being clearly defined and having a low computational cost, the Higuchi's fractal dimension (FD) is frequently adopted in the analysis of electroencephalogram [2] and has been recently used to study postural control in younger and older adults [3]: the higher the fractal dimension (FD), the higher the signal complexity. This study aims to evaluate the complexity of balance control in people with PD using a fractal analysis of lower back acceleration before and after a rehabilitation program and before and after the COVID-19 lockdown.

METHODS

Thirteen participants with PD were recruited (age: 68-75 yo; H&Y: 2-3; MMSE>24; stable pharmacological treatment in the 3 months prior participating in the study). Participants motor status was assessed using an accelerometer (142 Hz - WaveTrack, Cometa Srl) mounted on their fifth lumbar vertebra (L5) pre and post a program of physical exercise (12 sessions of 45 min). They were asked to stand as still as possible for 30 s keeping their gaze at a point in front of them on a 3 m front wall. Tasks were differentiated asking participants to keep their eyes open (EO) and closed (EC), performing a cognitive task (EODT), standing on a foam (EOFoam; ECFoam) and on a hard inclined plane (ECinc). Data collection was performed during the COVID-19 pandemic and same data were recorded also pre and post the full lockdown in Italy (March-May 2020). The Higuchi's FD (H_{lk}) was calculated after having low-pass filtered (2nd-order Butterworth, 15 Hz) and corrected the L5-acceleration for misalignment of the sensor axes with the anterior-posterior (AP) and medial-lateral (ML) directions of the body [3]. Participants were divided between those with (T) and without tremor (NT).

RESULTS

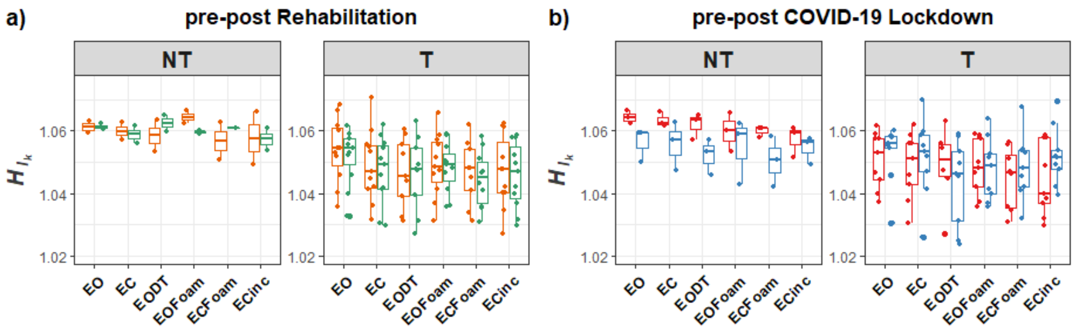

Fig 1. Higuchi's fractal dimension *(H_{lk})* calculated in different conditions for individuals without (NT) and with tremor (T): **a)** pre (orange) and post (green) the rehabilitative program; and **b)** pre (red) and post (blue) the COVID-19 lockdown.

DISCUSSION

In our previous work [3], the H_{lk} was equal to 1.10 in younger adults, with slightly lower values in older adults. The H_{lk} values reached values of 1.05 only when challenging postural tasks with cognitive load. This was ascribed to a more complex ability of younger adults to continuously adjust their balance with respect to the external stimuli [3]. No qualitative differences can be found looking at the H_{lk} values pre-post rehabilitation in both individuals with and without tremor, most likely indicating that the intervention helped them preserving their motor complexity. The prolonged isolation and the consequent limited mobility seem to lead to similar results for those individuals with tremor pre-post lockdown. Conversely, individuals without tremor depleted their motor complexity and lost their ability to respond to external stimuli, reaching the same impairment of those with tremor, with a potential higher risk of falls.

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Sessione 3B – Teleriabilitazione e Telemonitoraggio

Virtual coaching platform for stroke rehabilitation: preliminary usability results from vCare project experience

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INTRODUCTION

Stroke causes different impairments such as loss of muscle strength, sensation and coordination deficits, gait and balance disorders, motor disabilities of the upper limbs and hands. Impairments and the related disabilities may have a significant impact on an individual's independence, safety, and QoL. Although rehabilitation centres are fundamental in the management of debilitating diseases, scarcity of medical personnel, limited resources of inpatient rehabilitation and missing continuity of care call for an innovative approach integrating the home rehabilitation seamlessly into the clinical care chain. The interruption of care's continuity in stroke patient's transition from hospital to home has been further accentuated by the recent COVID-19 pandemic.

In the last few years, several projects have been focused on virtual coaches development in order to improve patients' rehabilitation through an intelligent environment, integrating machine learning technologies together with well-elaborated coaching and clinical pathway services [1]. vCare project, funded under the EC's Horizon 2020 call "Personalised coaching for well-being and care of people as they age" (SC1-PM15-2017), fits into this context by proposing a new ICT-based concept. The proposed platform encapsulates a set of coaching services for empowering and motivating people, helping them to proceed with a personalized rehabilitation that complies with age-related physical, cognitive, mental, and social conditions by a virtual coach [2].

The aim of this preliminary study was to analyse the usability and satisfaction of the vCare platform prototype from both patient's and therapist's point of view.

METHODS

Stroke survivors of different impairment levels were enrolled in the study among patients hospitalized at the Casa di Cura del Policlinico (Milan, IT). According to patient's clinical status and clinicians' indications, the vCare system proposes personalized rehabilitation treatments providing a suite of motor and cognitive serious games in a virtual reality environment (VR). Subjects experienced two weeks long rehabilitation treatments autonomously under clinician supervision. A 3D depth camera recognizes the user's movement without controller. The user's movement in the VR were displayed through a monitor (40-inch wide screen) in real time. For cognitive rehabilitation activities, patient uses a tablet (10-inch). Both activities (i.e., motor and cognitive) were characterized by specific goals, generally with specific rules to reach them, in some cases distractor were presented to increase the difficulty level. The usability of the platform as well as the subjects' satisfaction with the services were assessed by patients, at the end of the intervention by System Usability Scale (SUS) [3]. Motor and cognitive services were assessed separately. Additionally, SUS questionnaire was filled out by therapists (physiotherapists and neuropsychologists), who evaluate also the process of patient's characterization and rehabilitation plan's definition inside the vCare clinician platform.

RESULTS

Eight stroke patients (7 ischemic / 1 haemorrhagic strokes; 74.50±15.67 years old; 4 females / 4 males) were recruited. All participants completed the study protocol and no adverse events were reported. Patients' SUS average scores were 80.00±19.36 and 77.19±16.61 points for motor and cognitive services, respectively. Furthermore, four therapists (2 physiotherapists and 2 neuropsychologists), involved in patient's supervision, evaluated vCare solution with SUS scores of 79.38±8.98.

DISCUSSION

Results showed that for both patients and therapists vCare platform's usability is good. SUS values are widely above the limit of acceptability (i.e., 68 points). These preliminary results prove the system's intuitiveness and ease of use even without a significant training phase and they are fundamental in order to enhance patient's adherence to the care plan. The clinicians' SUS reflects a high usability of the system, demonstrating a promising future use of this technology also by the therapists. Considering these positive results, it would now be possible to proceed with the deeply evaluation of the overall system, also within the home context. In this way, the effective realization of the vCare project's outcomes could be proved.

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Real-time kinematics estimation with a scalable IMU body-sensor network in tele-rehabilitation

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INTRODUCTION

After a stroke event, survivals must follow a long rehabilitation program which is only partially sustained by the public health service. The DoMoMEA project aims to provide a tele-rehabilitation system based on a body-sensor network of inertial measurement units (IMUs) to assist the patients during the execution of exergames [1]. Real-time joint angular kinematics estimation is used to guide patients in the exercise execution and to provide visual feedback. Motion data are also essential to quantitatively evaluate the patients' progress during longitudinal monitoring. In this work, we presented the IMU-based method for the joint angles estimation and validated the results against a marker-based clinical protocol.

METHODS

Validation experiments focused on six planar exercises involving the shoulder abdo-adduction and elbow, wrist, hip, knee, and ankle flexion-extension executed by a healthy subject. For each movement two trials consisting of ten repetitions at small, medium and large amplitude were acquired. A total of seven IMUs (MIST, mfr. 221e s.r.l.) were attached using elastic straps and aligned along the relevant segment longitudinal axis thereby avoiding the need for functional movements [2]. Marker-set included 46 skin markers (according to the Davis's protocol) whose trajectories were recorded using a 12-camera Vicon Vero stereo-photogrammetric system. Preliminarily, a static acquisition with the subject in the neutral posture was recorded to mathematically realign the stern and the lower limb IMUs along the gravity direction to compensate for manual misalignments. Then, inertial data were fused on board to estimate in real-time the orientation of each IMU using the Madgwick's filter [3] which was transmitted via Bluetooth to a PC at 50 Hz. The standardized IMU positioning provided the missing information of the IMU relative orientation on the horizontal plane, since the magnetometer data were not used to prevent any corruptions due to ferromagnetic objects, very likely in a domestic environment. For each joint, the relative orientation between the proximal and distal IMUs was computed and then decomposed into the triplet of Euler angles following the ISB recommendation. The root mean square (rms) difference between IMU and marker-based angular kinematics were computed after removal of eventual offset [2].

RESULTS

Average rms difference values (deg) over trials (small, medium, and large) were: shoulder (1.3, 1.8, 2.5), elbow (4, 4.1, 5), wrist (2.8, 2.8, 3.0), hip (0.7, 0.9, 0.7), knee (1.5, 1.3, 1.2), and ankle (1, 1.3, 1.3).

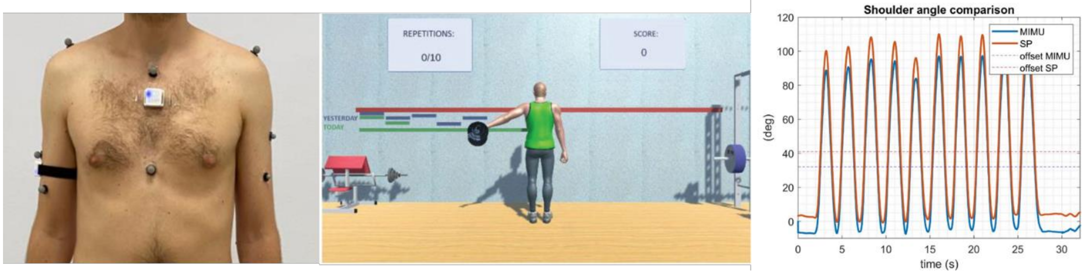

Figure 1. Example of experimental setup (static), feedback and comparison for the shoulder (large).

DISCUSSION

Based on this preliminary analysis, the proposed method seems suitable for providing a realistic feedback and assessing rehabilitation outcomes as errors varied between 0.7 and 5 deg [4] and were almost insensitive to the different motion amplitudes. The larger errors obtained for the elbow are due to the different definition of the upper-arm axis between the IMU and marker-based systems. This study is funded by Sardegna Ricerche with POR FESR 2014/2020 funds.

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Post-COVID19 telerehabilitation with AI-based platform enabling tailored motor and respiratory home rehabilitation (ARC-Intellicare): preliminary results.

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INTRODUCTION

According to a systematic review on rehabilitation needs, i) early rehabilitation should be granted to patients with COVID19; ii) people with restricted mobility due to COVID19 quarantine or lockdown should receive exercise programs to reduce the risk of frailty, sarcopenia, cognitive decline and depression; iii) telerehabilitation may represent the first option for people at home [1].
ARC-Intellicare (ARC) is an Artificial Intelligence (AI)-powered and Inertial Motion Unit (IMU)-based mobile platform enabling personalized rehabilitation for functional and respiratory recovery, for patients requiring continuous and safe home rehabilitation. It has been conceived and developed to target post-stroke patients (MAGIC, grant agreement n. 687228), and then optimized to address the above mentioned emerging needs coming from COVID19 pandemic (POR FESR 2014-2020-Asse I COVID19), following recommendations for people recovery after COVID19 [2].

METHODS

'Ricominciare' is a pilot single-center, not controlled, prospective, pre-post intervention study aimed at verifying the feasibility and safety of a medical device platform intended for home rehabilitation of people suffering from mild to moderate disabilities due to respiratory or neurological conditions, also related to COVID19. At the enrollment, each subject received from the site investigator a 30-minute training session on the use of both software (SW) and hardware (HW) components of ARC. Once completed, each subject carried out a usability test, in which he/she was asked to perform 15 tasks (6 related to HW and 9 to SW components). For each task the patient was asked to indicate if he/she needed support from the investigator and the degree of difficulty encountered in carrying it out on a scale from 0 to 10 (0 = no difficulty and 10 impossible to perform). Each subject then completed the System Usability Scale (SUS) [3]. Finally, the subject was asked to indicate their satisfaction in using ARC on a scale from 0 to 10. After enrollment, each subject received an ARC unit to perform 45-minute exercise sessions at home, 5 days/week for 4 weeks and at least 30-minute/week video-call with the investigator using the ARC Application. The use of ARC during the unsupervised sessions allows exercise monitoring thanks to data from 5 IMU sensors, processed by an AI proprietary library to provide i) patients with real-time feedback, ii) therapist with information on patient adherence to the prescribed therapy. Besides, ARC collects feedback from the patient on his health status during and at the end of each session. Baseline assessment was performed at enrollment (T0) and at the end of the 30-day intervention period (T1), when monitoring of primary and secondary outcome measures on adherence, acceptability and safety is completed.

RESULTS

None of the 5 subjects recruited so far (2 women and 3 men, mean age 51) required support for carrying out the 15 assigned tasks. The maximum difficulty level reported was 2 (mild). The mean total SUS score is equal to 89.5 (standard deviation 10.6) on a scale from 0 to 100. Regarding the satisfaction visual analogue scale (VAS 0-10), the 5 subjects indicated an average score of 9 (standard deviation 1.41). After 30 days, SUS and VAS scores remained unchanged compared to baseline ($p>0.05$). On average, patients' adherence to exercises prescriptions resulted above 70% (median 73.5; range 0-100).

DISCUSSION

Usability test results were consistent among usability questionnaires, SUS and satisfaction scores. Considering the reference threshold for the SUS score (80.3), a mean total value of 89.5 indicates high users' satisfaction and consequent high likelihood that they would recommend ARC. The mean adherence over the threshold of 70% is clinically relevant and above the 30% adherence reported in the literature [4].

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The DoMoMEA telerehabilitation system for post-stroke patients: first usability assessment

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INTRODUCTION

The COVID-19 pandemic pinpointed the urgent need for effective tools to provide remote assistance to those non-COVID patients that are unable to access healthcare centers for multiple reasons. In this context, telemedicine represents a powerful solution [1]. The DoMoMEA telerehanilitation system overcomes the limits of conventional rehabilitation approaches by proposing a semi-automatized tele-monitoring tool able to administer a complete neuromotor-rehabilitation therapy for post-stroke patients straight at their home [2].

METHODS

The DoMoMEA system exploits a set of inertial and force-sensing resistor wearable sensors, applied on the body through custom fixing aids and connected via Bluetooth Classic to an Android Tv-box. The system can quantify the movements performed by the patient during the exercise execution, by measuring parameters necessary to the clinician to remotely assess the rehabilitation progresses, by exploiting a scalable store-and-forward approach. By using the exergaming approach, providing scores along with motivational and corrective biofeedback, DoMoMEA aims to prevent compensatory movements and to reduce drop-outs by increasing the patient's engagement.
DoMoMEA usability was preliminarily assessed on 11 healthy elderly volunteers (69 ± 10 years old) with low levels of education and computer literacy; none of them experienced similar technologies before. The subjects were asked to perform a series of three exercises (shoulder abduction-adduction, trunk flexion-extension and lateral rotation) selected from a complete clinical protocol, following the specific instructions provided step by step by the system, with the only help of a peer. They experienced both exercises implemented according to the gamification approach (first and third exercises) and serious interfaces (second exercise), i.e. interfaces where only a quantitative indication of the trained parameter (like a joint angle) is presented, without a gamification. At the end of the test, the participants answered a System Usability Scale (SUS) questionnaire [3], widely used for usability assessment.

Figure 1. The DoMoMEA system: a subject wearing the sensors (a) and playing an exergame (b).

RESULTS

The SUS results (82 ± 6 points) were far above the average (68 points) indicating an excellent degree of usability of the system. Semi-structured interviews showed high level of satisfaction among the participants and highlighted how easy the system is to use, despite the lack of preliminary training. All the volunteers appreciated the provisions of scores and feedbacks on the obtained performances. Everyone got enthusiastic about using the system and none experienced negative effects, neither psychologically nor physically.

DISCUSSION

Starting from the positive results shown by the prior testing phase carried out on healthy subjects, revealing good usability, engagement, and safety, DoMoMEA is now approaching the tests on the target population of stroke patients with mild movement impairment. This research was funded by Sardegna Ricerche with POR FESR 2014/2020 funds in the framework of the DoMoMEA project.

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7-days actigraphy in persons with Parkinson disease: variations detected at 4-year follow-up

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INTRODUCTION

The quantitative assessment of the motor functions and activities of persons with Parkinson Disease (PD) has a major role in the their clinical management [1]. The authors are following once -a-year a cohort of 12 persons with PD by means of standard clinical evaluations and by 7-days actigraphic monitoring [2]. The present study reports the analysis of the variations either in their clinical scores and in their actigraphic indexes as quantified at the 4th year follow-up.

METHODS

Twelve participants with Parkinson disease under pharmacological treatment and with preserved motor functions were recruited at Centro Medico Riabilita – Mano Amica Onlus (Schio, VI). Details of the study features are available in [2]. Patients participated to group activities including motor and logopedic rehabilitation as well as cognitive stimulation exercises. Ten participants were still included in the study at 4-year follow-up Standard clinical examination and actigraphic assessment (*Geneactiv,* Activinsights Ltd, Kimbolton, UK) let to quantify the 4-year variations of UPDRS and Hoen&Yahr clinical scales, and of AD (duration of active behaviour) and AP (peak of motor activity).

RESULTS

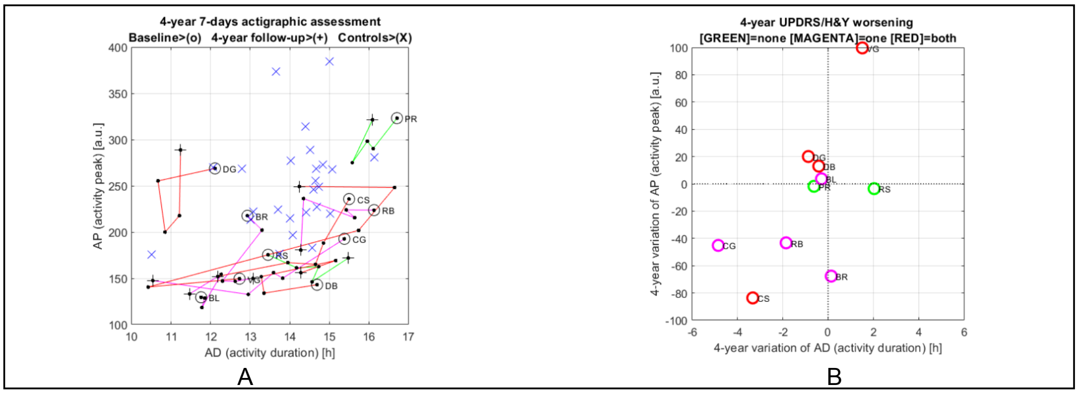

Figure 1

The plot in Figure 1A reports individual trajectories of the actigraphic indexes, along the four years follow-ups. The plot in Figure 1B reports the variations of the same actigraphic indexes. Colors classify as follows: green marks no worsening at fourth year either in UPDRS and H&Y scores, magenta marks worsening in one of the two scores, red marks a worsening in both clinical scores.

DISCUSSION

The data reported in figure 1 has been considered in the clinical management of the patients along their care programs particularly the actigraphic indexes supported the design/modification of therapies, and contributed to motivate the patients in their commitment to the physical and cognitive rehabilitation programmes.

The differential analysis of those data lets to evaluate the changes occurred in a 4-year span. An overall comment is that there is no perfect agreement between clinical evolution and the variations in the quantity and quality of daily activities. A perusal of individual features lets to interpret any combination of evidences and lets to drive future decisions about therapies, including multidisciplinary rehabilitation programs.

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Sessione 4 Analisi del movimento: applicazioni cliniche

A MULTIPLE BIOMARKERS APPROACH FOR THE EARLY MONITORING OF GAIT DEVELOPMENT IN PRETERM CHILDREN

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INTRODUCTION

Preterm children have an increased risk of motor delay [1]. Gait analysis and wearable technology allows the assessment of motor performance in toddlers, identifying early deviations from typical development. Using a sensor-based approach, gait performance of preterm and full-term toddlers at different risk of motor delay was analyzed. The aim was to measure quantitative differences among groups and provide a tool for early monitoring gait development.

METHODS

Three groups of 2 year old toddlers, matched for age and walking experience, participated in the study: preterm at high risk of motor delay (Hrisk-PT, n=8, born at <28 gestational weeks or with <1000g of body weight), at moderate risk (Mrisk-PT, n=21, born at 28-36 gestational weeks), and at low risk (FT, n=17, born full-term). Children walked at self-selected speed wearing three inertial sensors on the lower back and on the shanks. Temporal parameters, short- and long- term variability, and nonlinear metrics of trunk kinematics (i.e. recurrence quantification analysis, multiscale entropy) were calculated [2] and statistically analyzed with respect to risk of motor delay (Kruskal-Wallis test, significance level 5%).

RESULTS

For increasing risk of motor delay (from FT to Hrisk-PT), children showed significantly longer stride-, stance- and double-support-time, higher short-term variability and lower multiscale entropy values on the frontal plane (Fig.1). No difference was found for the other parameters.

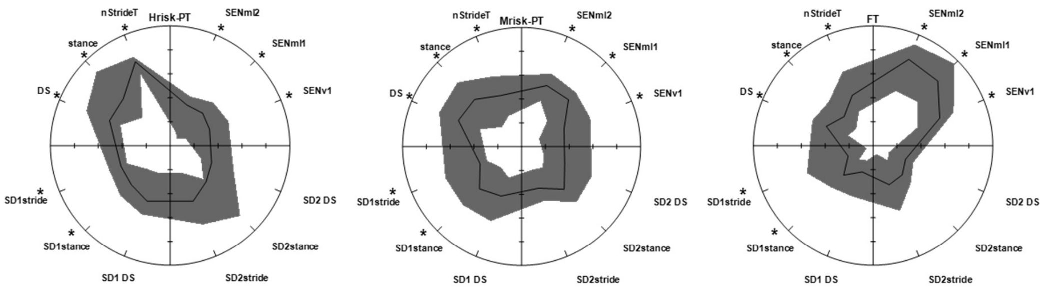

Figure 1. Polar bands (median, 25th and 75th percentiles) for Hrisk-PT, Mrisk-PT and FT children. Asterisks indicate significant effect of risk of motor delay ($p<0.05$). Represented parameters are:
1) 'Motor complexity': Sample entropy on the vertical (SENv ($\tau=1$)) and mediolateral axis (SENml ($\tau=1,2$)).
2) 'Temporal parameters': normalized stride (nStrideT), stance time (stance) and double support (DS).
3) 'Short term varibility' (SD1) for strideT, stance and DS.
4) 'Long term variability' (SD2) for strideT, stance and DS.

DISCUSSION

Sensor-based gait analysis allowed differentiating gait performance of toddlers at different risk of motor delay. When analyzing the present results with respect to the expected trajectory of locomotor development, children born preterm, in particular those at higher risk of motor delay, exhibited a less mature motor control performance during gait: lower stability (i.e. longer support phases), and higher variability (i.e. higher short-term variability), although not structured towards the exploration of more complex movements (i.e. higher recurrence- and lower multiscale entropy values). The proposed set of parameters can serve as biomarkers for the early detection of the risk to develop persistent motor impairments.

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The Distal Shank method in clinical practice: ankle power evaluation in patients with diabetes and peripheral neuropathy.

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INTRODUCTION

Biomechanical dysfunctions in the distal lower limbs are evident in patients with diabetes and peripheral neuropathy. Diabetes associated with neuropathic complications can result in several functional deficits, including loss of sensation, reduced strength and thickening of soft tissues [1]. The quantification of the ankle power during walking can provide interesting features of the pathological gait related to alterations of the foot biomechanics. In most gait analysis protocols, the ankle power computation is based on the assumption that the foot is a rigid structure, hiding important mechanisms of power absorption and generation. Instead, the Distal Shank method (DS), takes into account the effect of pronation/supination, foot arch deformation and other intrinsic movements, without requiring to increase the complexity of the acquisition protocol thus resulting promising for clinical applications [2]. In order to verify its applicability in clinical practice the method was applied to three cohorts of subjects: diabetic subjects with and without peripheral neuropathy and healthy controls.

METHODS

Gait analysis was performed on 38 subjects: 12 diabetics without peripheral neuropathy (D group, mean (SD) age: 65(5) years), 17 with peripheral neuropathy (N group, mean (SD) age: 64(6) years) and 9 healthy controls (C group, mean (SD) age: 58(5) years). Kinematic data were recorded with a stereophotogrammetric system BTS (six cameras, 60–120 Hz) using a full body marker set (a modified version of [3], [4]) and two Bertec force plates (FP4060–10, 960 Hz) were used for kinetics data. Subjects were asked to walk at self selected speed along a 10 meters walkway. At least two gait cycles were averaged for each subject considering both right and left foot contact. Smart Analyzer was used for data elaboration. Statistical analysis was conducted with Spm1d (Matlab, R2019b) [5] by applying non-parametric anova1d and post-hoc non-parametric T-test ($p<0.05$), after evidence of non-normality of data (Lilliefors test, $p<0.05$).

RESULTS

At the beginning of the stance phase, the N group revealed a more reduced ($p<0.05$) power absorption than both C and D groups (Figure 1). The positive peak of the power, instead, appeared greater in the N group, highlighting an increased ankle power production ($p<0.05$).

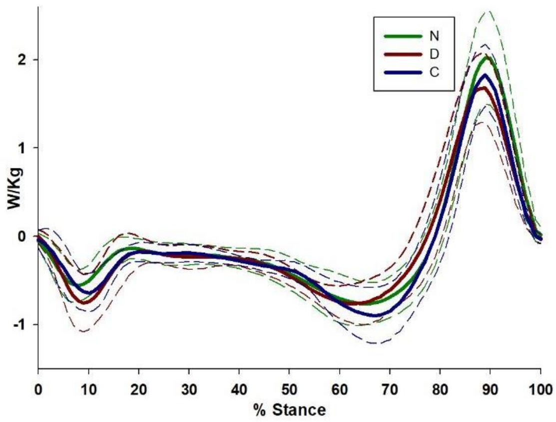

Figure 1. Average curves (+/-1 SD) of power for N, D and C groups in percentage of the stance phase.

DISCUSSION

Late stance power alterations in D subjects may be related to the joint stiffness due to the increasing of collagen cross-linking. On the contrary, the lack of somatosensory information at the lower limb and the poor balance control could be responsible for the increment in generated power observed in N.

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Kinematic analysis of healthcare workers during patient-handling

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INTRODUCTION

About 50 per cent of the reported injuries and illnesses among healthcare workers are musculoskeletal disorders (MSDs), affecting mostly the lower back [1]. They are mainly due to the repetitive and heavy tasks, such as handling the patients for lifting, and cause a number of drawbacks in terms of quality of life [2]. Most of the literature studies performed qualitative or video-based analyses to evaluate caregiver biomechanics during different manual handling techniques. The former does not provide quantitative data and the latter may suffer of occlusions (due to the difficulty of the analyzed action) that significantly affect the quality of the retrieved information [3]. This paper intends to advance the literature by adding an objective evaluation of patient handling actions performed by healthcare workers both manually and through a small aid (i.e. patient shifter). Head, trunk and shoulder angles of the healthcare worker were measured by using magneto-inertial sensors (M-IMUs) positioned on the worker body. The preliminary results showed that risk of muscular overload is high and allowed identifying the most stressed joints. They also provided interesting insights for improving current techniques to transfer patients.

METHODS

Wearable M-IMU sensors (Xsens MTw, 40 Hz sampling frequency) were adopted to reconstruct worker kinematics. Two healthcare workers were asked to move, for 3 times, from a bed to a litter a patient who underwent a knee replacement (i.e. temporarily non-cooperative) in two different modalities: manually and by means of a patient shifter (Fig. 1). Four M-IMU sensors were positioned on the subject's body, to reconstruct the flexion/extension (F/E) of trunk, head and shoulders' angles. The Rapid Upper Limb Assessment (RULA) scale was applied to evaluate incorrect postures that can lead to MSDs. The percentage of time where an incorrect posture is assumed by the worker with respect to the total duration of the trial was computed for each body district. The upper and lower thresholds (i.e. the thresholds determining a score increase for the districts in the RULA test) for head and trunk F/E angles were set to 0.17 and 0 rad, respectively and for the shoulder F/E was set to 0.34 and 0 rad.

Figure 1: A) Manual handling and B) handling with a patient shifter. Protocol adopted to position M-IMUs on the worker.

RESULTS

The mean durations of the manual handling and of the aided handling modalities were 143.7 ± 22.4 s and 288.9 ± 46.3 s, respectively. The normalized percentage of time where an incorrect posture is assumed during manual handling are: 0.67 ± 0.06 for the head, 0.76 ± 0.12 for the trunk, 0.85 ± 0.04 for the right shoulder and 0.58 ± 0.05 for the left shoulder. The results obtained for the aided modality are: 0.58 ± 0.11 for the head, 0.77 ± 0.02 for the trunk, 0.27 ± 0.14 for the right shoulder and 0.10 ± 0.15 for the left shoulder. From the angle behaviour it is evident that the thresholds are frequently exceeded, showing the healthcare workers exposure to ergonomic risk factors. It is particularly evident for the manual handling modality which is the riskiest for the worker. The introduction of a patient shifter allows reducing the exposure to MSDs. The trunk angle frequently overcomes the RULA thresholds for both modalities because the worker has to move the patient toward the litter by leaning over the bed.

DISCUSSION

A preliminary analysis of the upper body kinematics of healthcare workers during patient handling in two different modalities (manually and through a patient shifter) was performed. The comparison was carried out by computing the normalized time percentage of an incorrect posture (retrieved by 4 M-IMU sensors). The obtained results demonstrated that i) the trunk is the most stressed part of the body during both handling modalities and ii) the use of the shifter reduces the exposure time to ergonomic risk factors. Future works will be devoted to increase the number of analyzed subjects and handling modalities and to contribute to define new guidelines for patient handling with reduced MSD risks.

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Energy content in slow and fast twitch muscle fibers in diabetics with and without neuropathy.

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INTRODUCTION

Diabetic peripheral neuropathy (DPN) and peripheral arterial disease are common complications of diabetes that are responsible for diabetic foot pathology [1]. In DPN subjects (DPNS) loss of motor units and reduction of muscle volume have been documented together with significant alterations in the morphology of surface electromyography (sEMG) signal at the lower limb muscles [1]. However, the state of the art focused its attention on the analysis of temporal and intensity related sEMG parameters (i.e. time of activation/deactivation, peak of the envelope) in DPN subjects during gait. This study aimed to perform the analysis of sEMG signal in time-frequency domain, using discrete wavelet transform (DWT) [2], in order to assess the amount of energy produced by slow twitch and fast twitch fibers in diabetics with and without DPN. To this purpose, sEMG was acquired during gait and its spectral attributes were extracted.

METHODS

After signing appropriate informed consent, 15 diabetic subjects ((DS) mean (±SD) age and BMI respectively of 63.9 (±9.2) years and 26.5 (±2.5) Kg/m^2), 15 DPNS mean (±SD) age and BMI respectively of 65.0 (±5.2) years and 26.6 (±3.6) Kg/m^2) and 10 controls ((CS) mean (±SD) age of 59.8 (±6.3) years and BMI of 26.1 (±7.7) Kg/m^2), were evaluated at the BiomovLab (Department of Information Engineering, University of Padova). Kinematics and sEMG data were synchronously acquired through a BTS motion capture system (6 cameras, 60–120 Hz), 2 Bertec force plates (FP4060-10), and a 16 channels sEMG system (POCKETEMG, 16 channels, BTS) which collected the activity of Tibialis Anterior (TA), Peroneus Longus (PL), Rectus Femoris (RF) and Gluteus Medius (GM). Each subject performed several gait trials and at least three left and right trials per subject were processed. DWT provides an estimate of the local time-frequency energy localization of sEMG signal. Then, the percentage distribution of signal energy in frequency bands of fast and slow muscle fibers (450-125 Hz and 125-75 Hz) was extracted [3].

RESULTS

Results consistently showed the presence of an altered energy content of muscle activity (Fig. 1): DNS and DS displayed an increased percentage (p < 0.05) of total energy in the frequency band between 125-450 Hz in all the analyzed muscles, and a decreased percentage (p < 0.05) of the energy in the band between 75-125 Hz in TA and PL.

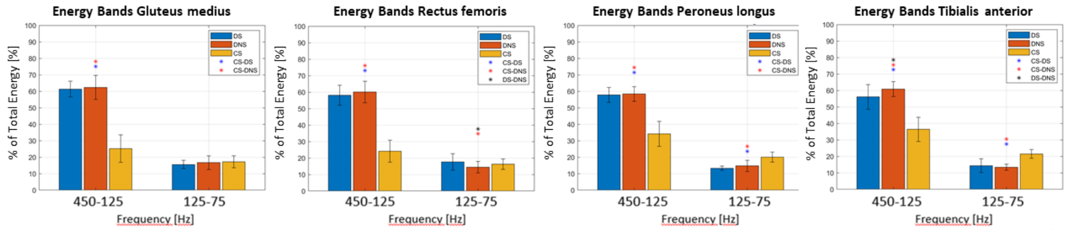

Figure 1. The percentage distribution of energy in the frequency bands during gait cycle (450-125 Hz and 125-75Hz; blue CS, orange DNS and yellow CS; mean±SD) (* - significant difference)

DISCUSSION

Results suggest that both DPNS and DS recruit higher percentage of the fast fibers during gait than CS, and recruit lower percentage of slow fibers in TA and PL. This information can help in better understanding the motor control alterations associated with diabetes and DPN.

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Use of the Gait Profile Score to evaluate long-term gait modification in Parkinson's disease.

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INTRODUCTION

Gait disorders are one of the most common and disabling symptoms of Parkinson's disease (PD), negatively affecting quality of life and increasing disability. To improve PD management and move towards a quantitative assessment, 3D gait analysis (3D-GA) allows evaluating specific gait abnormalities, both at spatiotemporal and kinematic levels. Recently, the Gait Profile Score (GPS) has been introduced for the assessment of gait quality (Baker et al, 2009 [1]). The present study aims to establish if the GPS can detect long-term gait changes in low disabled PD patients, correlating with some clinical assessment scales (UPDRS-III, Timed Up and Go (TUG)) and spatiotemporal gait data.

METHODS

A group of 17 patients, affected by idiopathic PD with a Hoehn and Yahr (H&Y) scale stages 1-3 (mean age 71,72±4,92; 9 man, 8 woman; mean UPDRS-IIIi 13,88±5,80), followed an extensive multidisciplinary program over a 12-month period. At baseline (T0) they were all assessed by an expert clinician, using H&Y scale, UPDRS-iii, TUG, Berg Balance Scale (BBS) and Mini Best Test (MBT). At the same time, patients underwent a 3D-GA, with a six-camera SMART DX 6 BTS system (Milan, Italy) at 100 Hz, obtaining GPS values by Smart Analyzer BTS software platform. After a 12 months period (T1), all patients repeat the evaluation procedures. Since 2 patients withdrew from the study and did not undergo the T1 clinical assessment, inferential and descriptive statistics were performed on 15 patients. Non-parametric statistical tests were used (Stata, Ver. 15.0). Pre-post comparison was carried out using Wilkoxon signed rank test for paired data. The statistical significance level was set at $p=0.05$. Spearman's correlation was used to assess associations between GPS scores and clinical and other 3D-GA outcomes.

RESULTS

Descriptive analysis on 15 patients (median [IQ1-IQ3] age = 72 [69-74] years old, Male/Female=8/7) showed mild to moderate disability assessed with H&Y and UPDRS-III scales, and limited impairment in balance according to the MBT and BBS scores. Clinical and 3D-GA are listed in Table 1. The patients' gait speed was in line with normative data on age-matched subjects (Bohannon et al 2008). However, GPS scores at T0 showed pathological values (above 7.0) both in the right and left lower limb in most of the patients (11/15). Interestingly, the correlation analysis at T0 between the GPS scores and other outcomes pointed out no significant association, except for GPS-L and H&Y ($\rho=-0.59$; $p=0.02$). The T0-T1 analysis showed a moderate but significant worsening in H&Y and TUG in accordance with the diseases' progression. In contrast, little but significant improvement was measured in gait speed measured during the gait analysis.

Clinical outcomes	**UPDRS III**	**H&Y**	**MBT**	**BBS**	**TUG (s)**
T0	14 (9-19)	1.5 (1.5-2)	25 (21-26)	55 (54-56)	10.3 (8.3-11.3)
T1	15 (12-24)	2 (1.5-3)	25 (21-26)	55 (54-56)	10.4 (9.3-11.9)
T0-T1 comparison	p=0.07	p=0.01*	p=0.38	p=0.33	p=0.04*
Gait analysis outcomes	**GPS – R (°)**	**GPS – L (°)**	**Stride length - R (m)**	**Stride length - L (m)**	**Gait speed (m/s)**
T0	8.1 (6.7-9.1)	8 (6.8-9.5)	1.12 (1.03-1.18)	1.11 (1.03-1.2)	1.0 (0.9-1.1)
T1	7.5 (6.6-9.8)	7.1 (6.2-9.4)	1.21 (1.09-1.29)	1.17(1.06-1.28)	1.1 (1-1.2)
T0-T1 comparison	p=0.69	p=0.82	p=0.36	p=0.33	p=0.03*

Table 1: Clinical and Gait Analysis outcomes. GPS-R: Gait Profile Score - Right Limb; GPS-L: Gait Profile Score - Left Limb. Data are reported as median (IQ1-IQ3). *: statistically significant ($p<0.05$).

DISCUSSION

The present study suggested that in a cohort of PD patients with mild to moderate disability, the GPS showed limited association with other clinical and spatiotemporal gait parameters. Based on the present data, in this kind of patients, the GPS score should be interpreted with caution and may not represent a reliable synthetic index of gait function.

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Wearables and machine learning for the modified Dynamic Gait Index score estimation in Multiple Sclerosis patients from 6-minutes walk test data

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INTRODUCTION

Multiple Sclerosis (MS) often cause gait instability and difficulty in dynamically interacting with the environment. The Dynamic Gait Index and its extended modified version (mDGI) [1] are two of the most common clinical scales to assess dynamic balance skills in persons with neurological diseases. Reliability of the mDGI as a functional assessment tool on MS patients has been demonstrated with a moderate interrater variability [2,3] and strong correlations were found with instrumentally derived indexes [4]. We targeted the estimation of the mDGI from data collected with inertial measurement units (IMUs) during 6-minute walk test (6MWT) using machine learning. This opened the possibility to get insights about dynamic balance from 6MWT.

METHODS

Fifty-one people with MS (F:28, median age 54 years, IQR =20.5) were enrolled into the study after signing a written consent. Three IMUs (MTw, XSens, NL) placed at pelvis and both ankles were sampled at 75 Hz while patients performed the 6MWT. Stride, step and swing time were extracted, as well as stride and step frequency and the variation coefficient of both step and stride time. Furthermore, step and stride regularity were calculated for each direction (antero-posterior, medio-lateral and vertical) [5]. Log-normalized jerk, multiscale (5-levels) entropy and its integral were calculated for each direction. Improved harmonic ratios [6], absolute and relative root mean square value of the active range of motion and short-term Lyapunov exponents, were computed. Lastly, the 6MWT distance and the walking support (absent/bilateral/monolateral) completed the dataset. To automatically estimate mDGI, a LASSO regression model was optimized with the *Optuna* and *Scikit-Learn* libraries. To assess the robustness of the model, a double cross-validation approach was adopted. For the outer level (testing), a leave-one-subject-out procedure was used, whilst for the inner level (tuning), a 5-fold cross-validation was conducted. A feature selection pipeline was conducted independently for each model before the regression training. Three pipelines were compared: a feature screening step only (retaining features with a significant correlation with the mDGI, $p < 0.05$), the screening followed by a principal component analysis (PCA, retaining 95% of explained variance) or followed by a recursive feature selection.

RESULTS

The cohort (median disease duration 19 years, IQR = 15.8) resulted in a median mDGI of 40 [IQR = 20.8]. The initial screening discarded on average the 38% of features (s.d. = 2.41%). Lyapunov exponents, ROM relative root mean square values and medio-lateral multiscale entropy were systematically discarded. PCA and recursive selection did not improve results: the simpler solution yielded to a mean absolute error on the test set of 3.9 points (IQR = 13.0) on the mDGI scale (Fig. 1). Train and validation median absolute errors reached 3.4 [8.8] and 3.8 [12.2] points respectively.

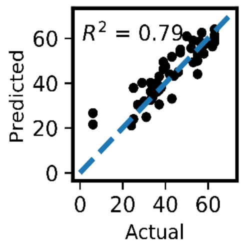

Fig 1. Actual vs. predicted mDGI

DISCUSSION

In this study, we trained, optimized and cross-validated a LASSO regression model capable of predicting the mDGI score of 51 patients from a 3-IMUs set-up. Results confirms its usability in the clinical practice being 6 points the minimum clinically relevant variation in mDGI [7]. Translationally, the solution could enable the self-assessment of the mDGI scale via two IMUs at the feet and one in the pocket (smartphone). Future studies will validate the algorithm to a multi-pathology group of patients tested longitudinally, to track the evolution of the gait alteration during a rehabilitation treatment.

ACKNOWLEDGMENTS

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Angular velocity of turning is a better fall predictor than the traditional Timed Up and Go test in stroke patients.

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INTRODUCTION

Falls are a major public health problem. The Timed Up and Go test (TUG) is widely used to evaluate motor impairment and for fall risk assessment. The instrumental TUG (ITUG) test, i.e. the TUG recorded with inertial sensors, allows measuring different motor tasks, such as curvilinear walking and postural transfers [1].

In previous works, we have studied how ITUG measures can be good measures of balance in the neurological population and which of these are responsive to conventional rehabilitation treatments [2,3]. Here we aimed to assess whether the ITUG test can also be used to identify fallers in the stroke population.

METHODS

We recruited sixty-four stroke patients (age: 72.5 ± 14.4 years, 29 females, MMSE 25.7 ± 3.1; FIM 103.6 ± 14.1; miniBESTest 15.7 ± 6.5). They completed the ITUG test before and after rehabilitation, and they were contacted monthly for nine months after discharge with a telephone interview.

During the ITUG, subjects wore a commercial inertial measurement unit (mHT) secured to their trunk. Several movement parameters were calculated: such as the total TUG duration [s], sit-to-walk duration [s], 180° turn duration [s], turn duration in the turn-to-sit Phase [s], mean angular velocity of the 180° turn [°/s], mean angular velocity of the turn-to-sit Phase [°/s], peak angular velocity of the 180° turn [°/s], peak angular velocity of the turn-to-sit phase [°/s], normalized jerk score of the 180° turn, normalized jerk score of the turn-to-sit Phase, straight walk duration [s] in TUG test. Differences between fallers (i.e. those patients who fell at least once in the follow-up period) and non-fallers were assessed with the Mann-Whitney U test. The significant level was established if <0.05.

RESULTS

21 (out of 64 patients) have fallen at least one in the follow-up period. The total TUG duration was not significantly different in the two patient groups ($p = 0.08$). On the contrary, the peak and mean angular Velocity of the 180° Turn [°/s] of the TUG test assessed at the end of the rehabilitation period was significantly lower in fallers than non-fallers ($p = 0.03$ and $p=0.04$ respectively). No significant difference was found for the other movement parameters.

DISCUSSION

The angular velocities of the 180° Turn [°/s] during TUG test could be a better falls risk indicator in stroke patients than the traditional TUG test. This preliminary finding could shed some light on clinically useful of instrumental wearable motor assessment, and valid outcome measure means.

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Validation of a 2D RGB-depth method for gait analysis in children with cerebral palsy.

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INTRODUCTION

Instrumented clinical gait analysis is an important tool for the quantification of gait alterations in children with cerebral palsy (CP). 2D markerless gait analysis (ML) has been shown to be a valid tool for follow-up and screening programs, since it combines good performance, ease-of-use and cost effectiveness [1]. The aim of this study is to present and validate a ML clinical gait analysis protocol based on the use of a single low-cost RGB-Depth camera. Kinematic parameters, including spatio-temporal parameters and sagittal lower limb joint angles were validated against a standard marker-based gait analysis protocol (MB).

METHODS

Eighteen children with bilateral CP (GMFSCS level I–III) were acquired in a gait analysis laboratory equipped with an RGB-D camera (Kinect v.2, fs = 30 fps) placed laterally to the walkway and a MB system (Qualisys, fs = 100 Hz) as gold standard. Children wore ankle socks of different colors and underwear. For validation purposes, the Davis marker set was used. A static upright posture and three gait trials at self-selected speed for both right and left side were acquired. The gait cycle was automatically identified by first isolating each foot using a color filter and then by computing initial and final contacts as the first (and last) instant with stationary antero-posterior coordinates of a given foot portion. Step length and gait speed were then determined by applying a depth-dependent conversion factor (pixel to meter). A subject segmentation algorithm was then applied for each frame and joint kinematics was estimated by fitting a multi-segmental model [2]. The difference between the manual and the automatic identification of gait events, the absolute errors (AE) of the spatio-temporal parameters and the RMS difference (RMSD) between the MB and ML joint kinematics (after offset removal) were estimated.

RESULTS

Errors in gait events detection: 1 frame (33 ms). Mean and standard deviation of AE (%): step length (2.0±1.1), gait speed (3.1±1.7). Average RMSD values: hip (3.5°), knee (3.2°), and ankle (4.5°).

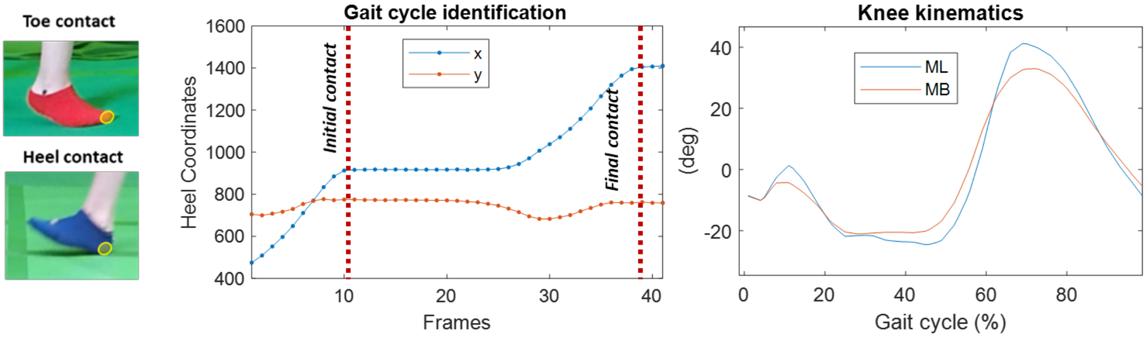

Figure 1. Example of heel and toe contacts, gait cycle identification and knee kinematics without offsets.

DISCUSSION

Gait events detection procedure was effective for tracking both children with drop foot and equinus gait [1]. Residuals errors in spatio-temporal parameters computation can be ascribed mostly to ML system limitations (lower frame rate, fixed exposure time resulting in blurred images and unavoidable inaccuracies of the conversion factor). Errors in joint kinematics estimation were mainly due to differences in the anatomical axes definition and were comparable to those obtained in healthy subjects [3]. Despite these differences, ML could be used to detect changes over time in children with CP.

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Does muscle activity change with personalized plantar orthoses?

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INTRODUCTION

Foot ulceration is amongst the most serious complications of diabetes mellitus, from 19 to 34% of people with diabetes will develop a foot ulcer [1]. Reducing high plantar loads or foot pressures is one of the main targets of treatments aiming at preventing plantar ulcers [1]. Guidelines recommend that people with diabetes wear appropriate ‘diabetic footwear’ or plantar orthoses (PO) designed to reduce repetitive stresses at all times [1]. When considering that important muscular alterations were also detected in diabetic subjects with and without neuropathy during gait [2], it is worth mentioning that the adoption of specific muscle strengthening through physiotherapy strategies appears to be a promising approach to plantar ulcers prevention[3]. The aim of this contribution was to verify the impact of personalized plantar orthosis on diabetic patients muscle activity during gait.

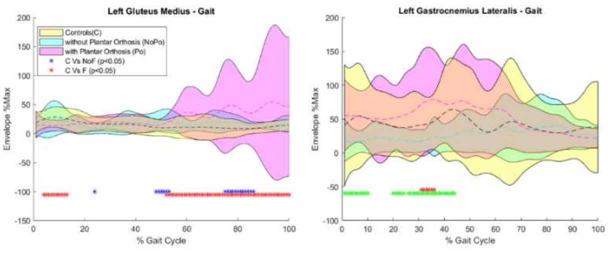
METHODS

Five subjects participated in the study (BMI 27.4±6.5 kg/m2, age 61.4±18 years). Subjects walked with and without a personalized plantar orthosis (PO) at their preferred walking speed at the orthotics manufacturers site; a minimum of three walking trials per subject were collected through 7 GoProHero 7®, Novel PedarX system, a surface electromyography (SEMG) system (FREEEMG1000, 1000 Hz, BTS). The electrical activity of 4 muscles was acquired bilaterally: Rectus Femoris (RF), Tibialis Anterior (TA), Medius Gluteus (MG), Gastrocnemius Lateralis (GL). SEMG signal envelopes were computed and normalized on the maximum value detected in the gait cycle [3]. Comparisons were made through Wilcoxon Signed Rank Test ($p<0.05$) with and without PO, through Wilcoxson Rank Sum Test with a population of healthy controls from a previously published study [3].

RESULTS

The most significant results were reported as mean and standard deviation of the SEMG envelope in Figure 1. More in general the following changes were observed while walking with PO: RT showed an increased activity between 35 and 45% of the gait cycle, LT showed and increased activity at initial contact, LG showed an increased activity from 20 to 60% of the gait cycle, right RF showed an increased activity both at initial contact and from 40 to 60% of gait cycle. In the comparison with the healthy subjects an improvement was detected at the right and left MG activity during swing between 60 and 100% of the gait cycle.

Figure 1. Mean and SD of normalized envelope of Left Gluteus and Left Gastrocnemius Lateralis: healthy subjects (yellow), diabetic subjects with PO (pink) and without PO (light blue). Asterisks identify statistically significant differences.



DISCUSSION

The use of personalized PO showed to improve MG muscle activity. In agreement with recent findings [3], a strengthening and mobility exercises programme could be performed in association with PO to restore a more functional gait in diabetic subjects.

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Sessione Poster
Analisi del movimento: applicazioni cliniche

Dual task balance performance in patients with severe COVID-19. A retrospective cohort study with healthy subjects.

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INTRODUCTION

The most frequent clinical presentation of the COVID-19 is the development of an acute respiratory distress syndrome, associated with subsequent cognitive decline, executive dysfunction, and reduced quality of life [1]. Not only critically ill patients with COVID-19 (PwCOVID), but also patients with severe COVID-19 were highly likely to experience an impaired mental status [2]. Moreover, the relationship between cognitive, and balance and gait impairments is considered to be an important issue for rehabilitative world since it play a fundamental role in predicting falls. It is known that adding a concurrent cognitive task can provide important information about balance control impairments that may not be identified with a single-task testing, in particular in the sub-acute disease period [3]. To date, no study has explored the effect of cognitive dual task on gait and balance performance in PwCOVID.

METHODS

We recruited 30 inpatients with a diagnosis of severe COVID-19 in the acute phase (age 68.6 years ± 10.1), not having other neurological or respiratory disease and able to walk independently. They were assessed ~1 day before discharge from rehabilitation ward. In order to compare their performance, we extracted the pre-existing data of 30 age-matched healthy subjects (HS) (68.9 years ± 6.5) from our database of the Posture and Movement Laboratory. All subjects completed the Mini-Mental State Examination (MMSE) and performed both the Timed Up and Go (TUG) test and the stabilometric evaluations (with eyes open (EO) and closed (EC)) under single task (ST) and dual task (DT) conditions (ie. counting backwards in threes). We calculated the Correct Cognitive Response (CCR) [4], higher scores associated to better cognitive performance, and the dual task cost (DTC), higher scores correspond to higher cost due to the adding of a second task [5].

RESULTS

Groups were not different in age, body mass index and MMSE. In ST, PwCOVID employed more time than HS to complete TUG test ($p<0.0005$) and had a larger sway path, both in EO and EC ($p<0.0005$). Adding the cognitive task, PwCOVID increased time in TUG test more than HS ($p<0.05$), with a similar DTC ($p=0.12$) but a lower CCR ($p<0.005$). In DT, sway path increased similar in both groups ($p=0.49$ and $p=0.87$, respectively for EO and EC), with a similar DTC ($p=0.11$ for EO and $p=0.76$ for EC) but lower CCR of PwCOVID ($p<0.0005$ for both visual conditions).

Table 1. Single and dual task performance in TUG test and stabilometric assessment.

	PwCOVID	HS	P value
ST TUG test (s)	10.28	7.98	<0.0005
ST sway path EO (mm)	571.67	331.37	<0.0005
ST sway path EC (mm)	975.11	575.71	<0.0005
DT TUG test (s)	12.09	8.80	<0.0005
DT sway path EO (mm)	834.99	551.38	<0.0005
DT sway path EC (mm)	1093.61	685.25	<0.0005

DISCUSSION

PwCOVID showed worst performance in both static and dynamic (TUG test) balance when compared to HS. Both groups worsted when a second cognitive task was added; the DTC was similar in patients and HS, indicating a similar requirement of attentional resources for that cognitive task. However, even if PwCOVID had not an overt cognitive impairment, the CCR, used as a measure of good cognitive performance, was lower than HS in each trial. In conclusion, PwCOVID showed balance impairments and had difficulties in cognitive DT; this suggest that a program of home falls prevention might be useful in PwCOVID discharged from hospital, since most activities of daily living involve the simultaneous performance of cognitive and motor tasks [6].

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Balance deficits before walking impairments: a cross-sectional study on people with early Multiple Sclerosis

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INTRODUCTION

Since the very early stages of the disease, people with Multiple Sclerosis (PwMS) show subtle balance deficits [1] often difficult to be detected with classical clinical assessments [2]. Nonetheless, their prompt quantification would be important to provide hints for early preventive rehabilitation that can potentially slow the MS-related functional decline, as recently suggested [3]. In this context, wearable inertial sensors (IMUs) seem good candidate to provide objective and sensitive balance measures directly in clinical settings. This study aims at assessing the discriminant ability of a quick instrumented balance test in early-stage, normally walking PwMS. The study was supported by FISM (grant N16/17/F14).

METHODS

59 PwMS (age: 38.1±9.1years, EDSS<=2.5, disease duration<=5 years) and 40 healthy subjects (HS, 38.9±10.9years) were recruited. Walking was assessed using the Timed 25-foot Walk (T25FW), and instrumented features describing a 15-meter fast walking trial executed wearing 3 IMUs (MTw, XSens, NL) on trunk and ankles (temporal parameters, gait symmetry, regularity and instability). Standing balance was tested during Item4 of Fullerton Advanced Balance short (FABs) scale. Participants stood upright with eyes closed on a foam pad for 30 seconds wearing an IMU at sternum level. The task was scored on a 5-point scale (0-4, 4: normal performance), and with instrumented metrics: trunk sway amplitude (SwayA), velocity (SwayV), and sample entropy considered a regularity measure (SwaySE).

RESULTS

T25FW (3.9±0.6 s) was normal (≤5.2s) in all subjects, meaning normal gait speed. All instrumented gait features were comparable between PwMS and normative subjects (p>=0.17), indicating the absence of significant gait alterations in the recruited sample. FABs-Item4 clinical score was 4 for all participants (Figure 1). Instrumented features showed in PwMS vs. HS larger medio-lateral SwayA (PwMS: 174±166 mm/s^2; HS: 92±44 mm/s^2; p=0.001), higher SwayV (PwMS: 96±113 mm/s; HS: 47±39 mm/s; p=0.007), and lower SwaySE (PwMS: 1.4±0.5; HS: 1.7±0.3; p=0.024), the latter result meaning higher regularity. 41% PwMS showed at least one abnormal metric. 14% showed abnormal values of all metrics. (Fig. 1)

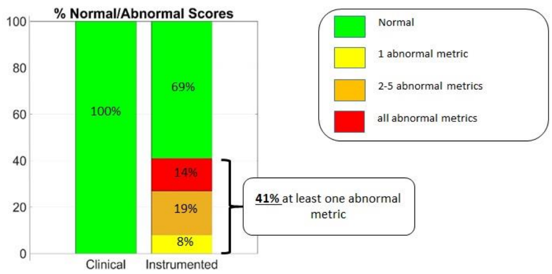

Figure 1. Percentages of PwMS showing normal/abnormal clinical score (left bar) and instrumented metrics' values (right bar) of balance performance during item 4 of FABs scale.
Abnormal clinical score: <4; Abnormal instrumented metrics: values outside 5th-95th percentile range from HS.

DISCUSSION

While FABs-Item4 score showed normal balance all subjects, IMU-based features discriminated PwMS from HS. Although the tested PwMS still walked normally, they maintained balance with larger, faster, and more regular trunk sway, the latter suggesting reduced adaptability of balance control system. The results indicate that balance impairments begin early in the MS course, and that the considered metrics, computed from a single IMU during a simple balance test, could be sensitive biomarkers to detect subtle deficits and follow their progression over time. Future reliability studies should test this hypothesis.

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Evaluation of postural control and proprioception in women with osteoporosis, before and after an exercise training

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INTRODUCTION

Osteoporosis (OP) is a skeleton systemic disease characterized by a reduced bone mass and deterioration of micro-architecture. OP is often accompanied by an increased risk of fall and consequently a high risk of fracture. Since postural control and proprioception are two of the most significant factors in falls and injury prevention, exercise training, including specific balance and proprioceptive exercises, could be the keys to reducing the risk of fall and fractures. This study was aimed at assessing proprioception and postural control, using Delos Postural Proprioceptive System (DPPS; Delos, Turin, Italy)[1], in persons with osteoporosis, before and after an exercise training.

METHODS

A cohort of 29 women with osteoporosis aged 66.20±5.80 were involved in the study. The participants will perform training, structured in 2-days per week, to improve joint mobility, muscle force and balance. Moreover, an additional activity between walking, cycling, or swimming was requested to improve endurance and reach the weekly exercise recommended by World Health Organization[2]. Finally, every six weeks, the trainer upgraded the exercise program following the principle of frequency, intensity, time and type. DPPS was used to assess postural control and proprioception in single-limb stance, respectively, with open and closed eyes. The parameter considered is the stability index (SI; percentage score where 100% is a theoretical task performed with maximum stability).

RESULTS

No significant differences were found in terms of dominant and non-dominant limbs. Thus, the analysis was performed on the average results of two limbs. The SI improved both with opened eyes ($p < 0.05$) and closed eyes ($p < 0.05$) [Table 1].

Table 1. Results before and after training

	Before Training	After Training	p.value
Open Eyes	84.14%±10.10	86.96%±5.60	0.0361
Closed Eyes	52.22%±13.87	56.25%±17.60	0.043

DISCUSSION

In people with osteoporosis, fall prevention is essential to decrease the risk of fall, build confidence for performing daily-life activities and improve the quality of life. Moreover, preventing falls decrease the costs for the health care systems. Physical activi+ty should be integrated with pharmacotherapy in osteoporosis treatment since it benefits bone tissue and improves global fitness. In particular, including balance exercises in a training program is effective in improving postural control and proprioception. The latter seems to have greater benefit and is very important in poorly lighting places or conditions of sudden instability.

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Ability of a set of trunk inertial indexes of gait to identify gait unbalance and fallers in subjects with cerebellar ataxia.

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INTRODUCTION. Persons with cerebellar ataxia (pwCA) exhibit unstable trunk behavior during gait that acts as a generator of dynamic imbalance [1] and further affects gait performance, balance, and risk of falls [2-4]. In this study, we aimed to assess the ability of 25 trunk acceleration derived gait stability indexes to characterize the gait of pwCA, compared with age-and-speed-matched healthy subjects (HS), their ability to characterize the gait of fallers, and their correlations with the clinical and spatio-temporal gait parameters, regardless of gait speed [5].

METHODS. The trunk acceleration patterns were acquired during the gait of 34 pwCA and 34 HS using an inertial measurement unit placed at the lower back. We calculated the harmonic ratios (HRs), percent recurrence, percent determinism, step length coefficient of variation (CV), short-time largest Lyapunov exponents (sLLEs), normalized jerk score, log-dimensionless jerk (LDLJ-A), root mean square (RMS), and root mean square ratio of accelerations (RMSR), in each spatial direction for each participant. T-test or U-Mann Whitney tests, the area under the receiver operating characteristics curve and post-test probabilities were calculated to assess the ability to discriminate between pwCA and HS and to identify fallers. Partial correlation analysis excluding the effects of gait speed was performed to assess the correlations between the gait stability indexes and the clinical and spatio-temporal gait parameters.

RESULTS. The HRs, CV, and sLLEs, showed the highest probability to discriminate pwCA and HS (Figure 1). The HRs also showed to identify fallers and were correlated with the disease severity, history of falls, stance, swing, and double support duration, regardless of gait speed. The sLLEs showed to identify fallers with high probability but were not correlated with the disease severity and the history of falls, regardless of gait speed. CV was correlated with the disease severity, stance, and swing duration, but was not able to identify fallers, regardless of gait speed. The RMSs and RMSRs and LDLJ-A were slightly able to characterize the gait of pwCA yet failing to characterize fallers.

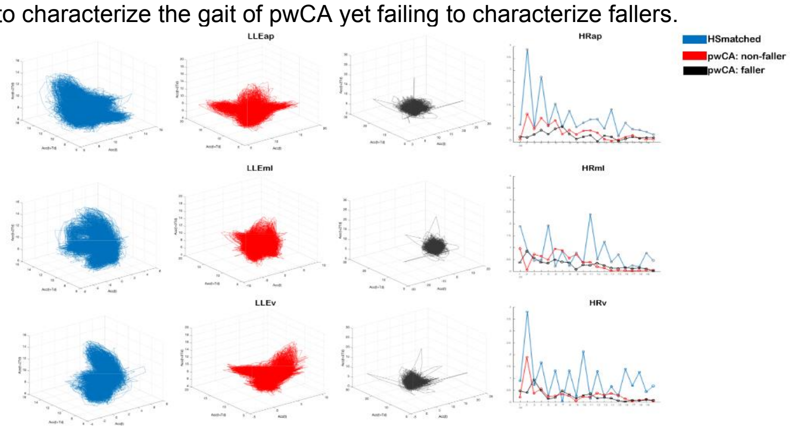

Figure 1. *3D-reconstructed state-space of the acceleration and its time-delayed copies (time delay of 10 data sample) and Harmonic Ratio values for each of the 20 considered stride in a representative HS (blue), pwCA non-faller (red), pwCA faller (black).*

DISCUSSION. The HRs, CV, and sLLEs showed to characterize the gait of pwCA, regardless of gait speed, thus reflecting the loss of smoothness and the inability of the trunk to recover from small self-generated perturbations during walking. Lower HRs values also characterized the gait of fallers and were correlated with the disease severity, regardless of gait speed. The ability of the sLLEs to characterize the gait of fallers was dependent on the gait speed compensation experienced by pwCA and cannot be considered as a marker of falls risk, regardless of gait speed.

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Reliability and validity of balance variables evaluated by a robotic platform in patients with subacute stroke

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INTRODUCTION

Patients with stroke have trunk balance problems that increase the risk of falls and impairs their independence during daily living (Aprile, I., et al. 2008). Assessment of trunk balance can be implemented by analyzing center of pressure (COP) parameters. Recently a new stabilometric platform capable to provide different mechanical interaction was developed (De Luca et al. 2020); however, the psychometric properties of the provided balance parameters were never investigated. The purpose of this study was to test the reliability and validity of COP-based variables, recorded by the robotic platform in patients with stroke with severe condition.

METHODS

Twenty-two patients with stroke were evaluated using a robotic platform (HUNOVA, Movendo Technology) in a sitting position. Stabilometry were evaluated under dynamic and static conditions with eyes open and closed (EO and EC respectively). Several COP parameters were analyzed (COP area; COP mean velocity, COP sway; COP swing). Furthermore, during each session the Tinetti Balance Scale (TIN-B) was evaluated. The instrumental evaluation was performed twice, one day apart, to assess the reliability of the COP parameters using the Intraclass Correlation Coefficient (ICC). Furthermore, the validity of the COP parameters was assessed through their correlations with the clinical scale (Spearman's rank correlation coefficients).

RESULTS

ICCs and 95% confidence intervals and the results of the correlation analysis between the robotic indices and the clinical sale are reported in Table 1.

Table 1. Reliability and validity results.

BALANCE VARIABLES	Reliability		Validity	
	ICC (static)	ICC (dynamic)	r_s (static)	r_s (dynamic)
Area EO [cm^2]	**0.814 (0.618-0.909)**	0.443 (-0.145-0.728)	-0.14	-0.071
Area EC [cm^2]	0.542 (0.087-0.774)	0.479 (-0.022-0.740)	-0.131	-0.203
Romberg Index	0.367 (-0.318-0.697)	-0.012 (-1.114-0.514)	-0.267	-0.252
COP sway EO [cm]	**0.908 (0.789-0.957)**	**0.729 (0.449-0.867)**	**-0.406***	-0.047
COP sway EC [cm]	**0.657 (0.302-0.833)**	**0.617 (0.222-0.813)**	-0.284	-0.069
COP Swing AP EO [cm]	**0.845 (0.671-0.926)**	**0.628 (0.232-0.819)**	-0.294	-0.192
COP Swing AP EC [cm]	**0.552 (0.106-0.780)**	0.416 (-0.220-0.718)	-0.195	-0.195
COP Swing ML EO [cm]	**0.789 (0.556-0.898)**	**0.644 (0.277-0.825)**	**-0.385***	-0.107
COP Swing ML EC [cm]	**0.660 (0.325-0.830)**	**0.542 (0.069-0.776)**	**-0.323***	-0.111
Ellipse axes ratio EO [%]	0.352 (-0.318-0.681)	0.417 (-0.234-0.722)	-0.298	0.141
Ellipse axes ratio EC [%]	0.383 (-0.268-0.698)	0.012 (-1.005-0.518)	-0.167	-0.15
COP (AP) Mean velocity EO [cm/s]	**0.908 (0.794-0.957)**	**0.722 (0.429-0.866)**	**-0.464****	-0.09
COP (AP) Mean velocity EC [cm/s]	**0.590 (0.194-0.794)**	**0.620 (0.211-0.817)**	**-0.327***	-0.082
COP (ML) Mean velocity EO[cm/s]	**0.865 (0.722-0.934)**	**0.595 (0.157-0.806)**	**-0.442****	-0.018
COP (ML) Mean velocity EC [cm/s]	**0.605 (0.215-0.803)**	0.447 (-0.178-0.742)	**-0.358***	0.008

EO=eyes open; EC=eyes closed; AP=anterior-posterior; ML=medio-lateral; COP=center of pressure; r_s=spearman correlation coefficient.

DISCUSSION

Our study show that some COP variables demonstrated good or excellent test-retest reliability and, in static condition only, a fair to good validity (Table 1). We conclude that this robotic system, integrated with clinical practice, can be used as an objective tool for the evaluation of balance performances in the sitting position of patients with subacute stroke with severe condition. Furthermore, the procedure we used could be applied in studies concerning trunk balance variables in the field of rehabilitation for monitoring patients recovery.

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Actigraphic Measurement of the Upper Limbs for the Prediction of Ischemic Stroke Prognosis: An Observational Study

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INTRODUCTION

It is often challenging to formulate a reliable prognosis for patients with acute ischemic stroke. The most accepted prognostic factors may not be sufficient to predict the recovery process [1]. In this view, describing the evolution of motor deficits over time via sensors might be useful for strengthening the prognostic model [2]. Our aim was to assess whether an actigraphic-based parameter (Asymmetry Rate Index for the 24 h period (AR2_24 h)) obtained in the acute stroke phase could be a predictor of a 90 days prognosis.

METHODS

In this observational study, we recorded and analyzed the 24 h upper limb movement asymmetry of 20 consecutive patients with acute ischemic stroke during their stay in a stroke unit. We recorded the motor activity of both arms using two programmable actigraphic systems positioned on patients' wrists. We clinically evaluated the stroke patients by NIHSS in the acute phase and then assessed them across 90 days using the modified Rankin Scale (mRS).

RESULTS

We found that the AR2_24 h parameter positively correlates with the 90 d mRS ($r = 0.69$, $p < 0.001$). Moreover, we found that an AR2_24 h > 32% predicts a poorer outcome (90 d mRS > 2), with sensitivity = 100% and specificity = 89%.

DISCUSSION

Sensor-based parameters might provide useful information for predicting ischemic stroke prognosis in the acute phase.

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Effect of lycra garments, ankle-foot-orthoses and shoes on the gait of three children with ataxia

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INTRODUCTION

Children with ataxia show an unstable gait characterized by high variability of pattern, which often increases the risk of fall [1]. Different treatment tools are available to improve their gait, including ankle-foot-orthosis (AFO) and elastic orthosis (i.e., lycra garment - LYC) [2]. In our knowledge, no studies have been carried out to evaluate the effect of the orthotic approach on the ataxic gait of children. We expect that orthosis application decreases pattern variability by simplifying the task.

METHODS

The retrospective study was conducted on 3 children: S1 (7y, SARA Score - SS 25/40), S2 (4y, SS 27/40), S3 (7y, SS 15/40). All of them used LYC. S1 and S2 also used walkers with pelvic belt. S1 wore AFO. S3 was able to walk without assistive devices. All the available conditions, barefoot (BAR), with shoes (SHO), with AFO, with and without LYC, were analyzed by means of 3D gait analysis. Global performance was evaluated with self-selected normalized walking speed (SPEED) and normalized stride length (STRIDE). Gait stability was analyzed with normalized step width (STEP W) and trunk ROM in the sagittal and frontal planes. Gait variability was identified by means of Coefficient of Variation (CV) [1] for spatio-temporal parameters (step length, step width and cadence), and of Root Mean Square Error (RMSE) [3] for limb kinematics (hip flexion, knee flexion, ankle dorsiflexion, foot progression angle).

RESULTS

Results are reported in Table 1.

			GLOBAL PERFORMANCE		STABILITY			VARIABILITY						
								Coefficient of Variation			Root Mean Square Error [deg]			
	Walker	Condition tested	SPEED [%h/s]	STRIDE [%h]	STEP W [%h]	Trunk ROM [deg] Sagittal	Trunk ROM [deg] Frontal	Step Length	Step Width	Cadence	Hip Flex	Knee Flex	Ankle Dors	Foot Progr
S1	Yes	**BAR**	19 ±1	42	6.0	7.1	4.2	0.20	0.81	0.10	4.4	7.4	5.9	20.6
		AFO	22 ±3	53	5.1	9.3	3.1	0.21	0.81	0.13	6.4	7.2	1.5	15.2
		LYC AFO	26 ±5	50	5.6	7.8	4.3	0.22	0.53	0.14	4.2	6.1	1.5	16.2
S2	Yes	**BAR**	26 ±3	54	8.4	6.5	2.5	0.35	0.64	0.11	6.4	8.4	4.9	9.1
		SHO	46 ±2	91	7.6	13.4	3.8	0.26	0.71	0.10	7.9	10.0	10.2	11.9
		LYC SHO	53 ±14	96	7.9	9.8	3.2	0.27	0.76	0.09	8.1	9.0	12.5	10.6
S3	No	**BAR**	66 ±4	54	11	6.2	4.4	0.09	0.30	0.06	4.0	5.0	4.2	6.6
		LYC	64 ±3	51	12	4.4	2.7	0.10	0.24	0.06	3.0	5.6	3.2	5.8
		LYC SHO	80 ±4	63	12	5.4	2.8	0.10	0.32	0.03	3.8	5.1	4.2	4.5

Table.1: Global performance. stability. and variability of the gait in S1. S2 and S3. For parameters that were computed for right and left limb, mean value is presented.

DISCUSSION

The use of AFO produced an increase in SPEED and STRIDE for S1. As expected, AFO reduced RMSE for ankle dorsiflexion since this movement is constrained. However, no other parameter markedly varied. Gait with shoes was considerably faster for S2 and S3. S2 almost doubled walking velocity (from 26 to 46 %h/s), with an associated increase in sagittal trunk ROM and in RMSE for limb kinematics. The addition of lycra garment further improved SPEED for both S1 and S2. but not for S3 (that was the fastest). Sagittal trunk ROM was slightly reduced for all of them, and frontal ROM diminished for S3. Differently than expected, no other relevant modifications were detected both for stability and variability. These results suggest that facilitating tools, especially the simple use of shoes, permit an improvement in gait performance, more than reducing variability. A larger sample is needed in order to generalize our findings.

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Gillespie rare Ataxic syndrome comparison of three different modalities of walking in a single case.

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INTRODUCTION

The Gillespie is a rare syndrome characterized by weak muscle tone in neonatal age, balance and coordination difficulties correlated to the non-progressive cerebellar ataxia, intellectual disability, eyes aniridia and other symptoms like nystagmus. This syndrome caused by a genetic mutation in the ITPR1 gene [1]. In literature ataxia walking is characterized by spatio-temporal parameters deviations from normality values [2]. The aim of this study is to evaluate the best support for this child walking.

METHODS

We analyzed three different walking conditions shoeless(S), shoes(B) and orthopedics shoes with orthosis(O), in a five-year-old patient affected by Gillespie syndrome. The gait analysis implemented with an optical motion capture system (SMART-DX 1000, BTS, Italy) combined with 16 channels FREEEMG 1000 wireless EMG device.

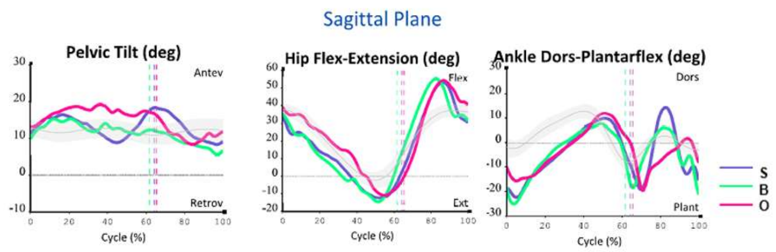
In each condition, we acquired five trials and elaborate and processing three good of these. We implemented the analyses with clinical evaluations.

RESULTS

The clinical evaluations test included GMFCS classification (Level III), Gross Motor Functional Measure-88 (Amount 57,8%; A=88,2%, B=91,7%, C=83,3%, D= 23,1%, E=18,1%). The autonomy feature evaluated with Wee FIM scale and adequate for age (Amount 70,4%).

As we expected from the literature there are spatio-temporal parameters variations from the normality. We found reduced walking speed (m/s) (S=0,56±0,06; B= 0,7±0,14; O=0,57±0,05) and cadence(steps/min) (S=85,8±4,2; B=92,2±7,55; O=79±5,1), reduced stride length (m) (S=0,51±0,23; B=0,45±0,02; O=0,46±0,04), and swing phase(%) (S=34,42±3,55; B=37,69±3.5; O=36,49±5,13), increased walking base width (m)(S=0,13±0,02;B= 0,09±0,01;O=0,11±0,01), stride time (s) (S=1,40±0,06;B=1,31±0,13;O=1,52±0,1), step time (s) (S=0,91±0,06;B=0,78±0,09;O=1±0,11), stance phase (%) (S=34,46±3,8; B=37,61±2,44; O=36,49±4,98) and double limb support phase (%)(S=15,40±2,8;B=11,06±2,62;O=13,68±2,46) in all the analysed conditions [2].

Figure 1. Three trials comparison kinematic analysis, pelvic and ankle sagittal plane



DISCUSSION

As expected, the patient preferred to use only shoes, giving him more velocity, and increasing him independence. Indeed, in the first condition (S), he became more insecure; with orthosis, he was unstable because he controlled the ankle better, but he excessively increased the pelvic anteversion.

However, the short period of training produced an increasing balance and coordination capacities not clinically evaluated but he shows these improvements in him daily living routine. These are the two big physical therapy targets.[3] The main limits of the present work were the single case and the only time zero evaluation performed. We program gait analysis follow-up after six months.

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Classification of children with Fragile X Syndrome and controls driven by gait analysis: a supervised clustering approach

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INTRODUCTION

Fragile X Syndrome (FXS) is the leading form of inherited intellectual disability and autism spectrum disorder, caused by a tri-nucleotide CGG repeat expansion in the FMR1 gene [1]. In these subjects, the frequent musculoskeletal manifestations are ligamentous laxity, flat foot and hypotonia [1], that justifies a referral for gait analysis. Supervised classification is used to find the relationship between input parameters and target variables [2]. The aim of the present study was to define the most appropriate biomechanical parameters to discriminate between controls and FXS subjects and within FXS between different mutational categories of FMR1 gene.

METHODS

After appropriate informed consent by the parents the following group of children were evaluated at the BiomovLab (Department of Information Engineering, University of Padua): 20 FXS children ((FXS) mean (±SD) age of 10,00 (±3,74) years and BMI of 18,57 (±3,46) Kg/m2), 16 healthy controls ((CS) mean (±SD) age of 10,22 (±3,19) years and BMI of 22,84 (±3,93) Kg/m2). Within FXS 12 children carried a full mutation of the FMR1 gene in a state of size (FXS-FM) and 5 carried a methylation mosaicism (FXS-M). Kinematics and sEMG data were simultaneously acquired through 4 synchronized cameras (GoPro Hero3, 30fps) and an sEMG system (FreeEmg, BTS, 1000Hz) that collected the activity of Tibialis Anterior, Gastrocnemius Lateralis, Rectus Femoris and Biceps Femoris. Each subject performed several gait trials and at least 3 trials per subject were processed. From sEMG the following parameters were extracted: duration of muscle contraction, onset and offset activation timing [3], peak of the envelope and its occurrence [4] and number of co-contraction and its occurrence [5]. The following kinematic parameters were assessed: minimum and maximum joint angles (hip, knee and ankle) and their range of motion (ROM). Seven different supervised classification techniques were applied: Decision Tree, Random Forest, CN2 Rule Induction, SVM, k-NN, Neural Network and Naïve Bayes. Three different sets of variables were employed: S1. only sEMG parameters; S2. only kinematic parameters; S3. sEMG and kinematic parameters together. All the subjects were (FXS and CS) involved or only FXS.

RESULTS

When considering all the subjects together in order to discriminate FXS from CS: the best classification on a training set (66% of subjects) was obtained by applying k-NN algorithm for S2 and Random Forest for S1 and S3 (Table 1). When considering only FXS in order to discriminate FXS-FM from FXS-M: the best classifications on a training set (66% of subjects) was obtained by applying a Neural Network algorithm for both S1 and S2 (Table 1).

Table 1. Performance of the most performant classification algorithms on training and test data.

	FXS vs CS			**FXS-FM vs FXS-M**	
Set of vectors	**S1**	**S2**	**S3**	**S1**	**S2**
Algorithm	Random Forest	k-NN	Random Forest	Neural Network	Neural network
Training set acc (%)	98,3	100,0	99,2	98,5	83,1
Test set acc (%)	98,3	100,0	96,7	90,9	84,8

DISCUSSION

All the analysed solutions allowed a good classification of FX and CS, yet using only kinematic data allowed a proper classification of all subjects. This suggests that the most evident differences between CS and FXS can be detected by analysing the kinematic parameters.

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Extracorporeal shockwave therapy: changes on the gait parameters of a subject with Hereditary Spastic Paraplegia

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INTRODUCTION

Extracorporeal shockwave therapy (ESWT) is a noninvasive treatment that involves delivery of shock waves to soft tissue to reduce pain and promote healing. It has become an alternative treatment for the spasticity in children with cerebral palsy (CP) [1]. Recently, a systematic review [2] showed that the spasticity of upper and lower limb muscles was decreased in a group of children with CP treated by ESWT, resulting in an improvement of limb joint Range of Motion. Despite these, the treatment of spasticity with ESWT in patients with Hereditary Spastic Paraplegia HSP, a rare genetic disease characterized by spasticity and weakness of the lower limbs seems not investigated yet. The aim of this study was to describe the modification of the gait parameters (spatiotemporal parameters and ROMs) in a young subject with HSP after a treatment with ESWT.

METHODS

A 13 years old patient (male) with HSP diagnosis (SPG11- autosomal recessive) attending the Casa di Cura del Policlinico (CCP) a rehabilitation hospital in Milan was enrolled for this study. The patient was able to walk independently, and showed spasticity (MAS 1+) and weakness of the lower limbs, typical signs of HSP. The ESWT (EMS- Swiss DolorClast machine) with three treatments (1 per week) of 2000 pulses each, 5 Hz and an energy density lower than 0.12 mJ/mm^2 was applied on right and left semitendinosus muscle. Assessments, pre and 4-months after the ESWT treatment, consisted of: passive ROM of the lower limbs (popliteal angle) and gait analysis. The instrumental gait analyses were performed at the Motion Lab of CCP using an optoelectronic system with 6 cameras (VICON, Oxford, UK) with a sampling rate of 100 Hz. Markers were positioned according to modified Davis marker set (Plug-In-Gait). Gait spatio-temporal parameters and ROM of knee in sagittal plane during walking trials, pre and 4-months after the ESWT, were compared using t Student test.

RESULTS

The subject completed the entire experimental procedure and no adverse events or side effects were reported. The passive ROM (popliteal angle) increased of about 15 degrees. Spatiotemporal parameters and knee flex-extension ROMs for both sides are reported in table 1.

Table 1. Spatiotemporal parameters *and ROMs* (mean and standard deviation) for the two analyzed periods. Statistical significance difference (pre vs. post) are reported in bold ($p<0.05$).

	Pre ESWT	Post ESWT		Pre ESWT	Post ESWT
Cadence (steps/min)	**83,77 ± 5,38**	**102,69 ± 5,85**	*Double Support (s)*	**0,59 ± 0,08**	**0,32 ± 0,04**
Walking Speed (m/s)	**0,42 ± 0,03**	**0,71 ± 0,06**	*Right ROM (°) knee flex-extension*	**40,19 ± 4,53**	**43,36 ± 2,96**
Stride Time (s)	**1,44 ± 0,10**	**1,17 ± 0,07**	*Left ROM (°) knee flex-extension*	31,60 ± 2,74	36,70 ± 3,13
Step Width (m)	**0,18 ± 0,02**	**0,14 ± 0,02**			

DISCUSSION

Our preliminary results showed consistent improvements of passive ROM of popliteal angle, spatio-temporal parameters (with statistical significance) and flex-extension ROM of knees during gait (statistical significance for left side). These results corroborates the hypothesis that ESWT could be useful also for HSP pathology.The mechanism through which ESWT could induce changes within tissue remains uncertains. Anyway, ESWT may cause a cascade on interaction between physical shockwave energy and biologic responses [3], that, also in HSP subjects could improve to unbend muscles and gain ROM both passive and during functional movements such as walking. This study has several limitations. HSP is a rare and heterogeneous neurodegenerative disease, so only one subject was studied. Further work is needed to better describe the effects of ESWT in these patients.

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Usage of Ankle-Foot Orthosis in knee hyperextension in patient affected by neurofibromatosis 1 (NF1): a gait analysis case report

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INTRODUCTION [1]

NF1 is a genetic hereditary disease that alters the physiological processes of nervous system growth. It enhances the possibility of development of brain, spinal cord and nerves tumors. Neurofibromatosis types (NF1, NF2 and schwannomatosis) differ in clinical features. Symptoms include: cutaneous, ocular and musculoskeletal impairments.

METHODS

Patient's joints motion of lower limbs and trunk was investigated. Kinematic data were acquired according to Davis Heel protocol. Ground reaction forces were acquired with two dynamometric platforms. Data were acquired in different conditions: without any orthosis, before rehabilitation and with the use of a walker (PHASE 0), with a prototype of an ankle-foot orthosis (PHASE 1), with the use of the final thermoplastic ankle-foot orthosis at the end of the rehabilitation (PHASE 2), and a year later as a follow-up (PHASE 3). The rehabilitation program was planned by physiatrists on the basis of data acquired in PHASE 0.

RESULTS

Gait analysis documented a progressive better stabilization of lumbopelvic segment and hip, with a reduction of hip hyperextension during pre-swing phase generated by the homolateral ankle stabilization in dorsiflexion position by means of the orthosis. The new orthosis' settings allowed a slight degree of ankle dorsiflexion during both pre-swing and swing phase with consequent accentuation of left knee flexion and, ultimately, a better mechanical control of knee hyperextension.

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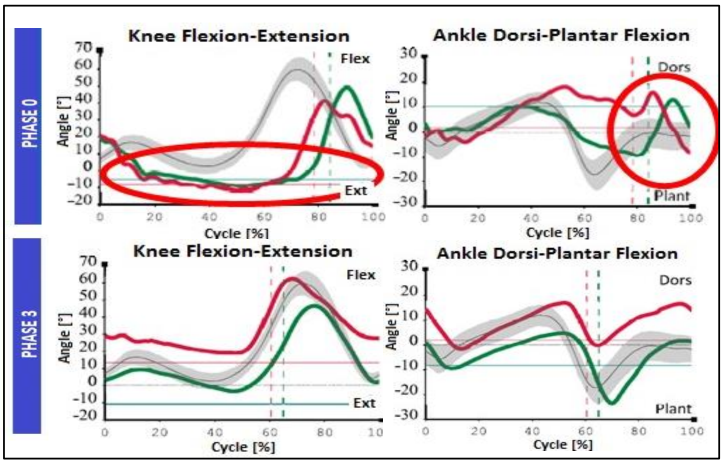
Figure 1. Knee and ankle sagittal angles of right lower limb (green line) and left lower limb (red line) with respect to normality (grey band) at different rehabilitation stages



DISCUSSION

The results allowed clinical specialists to plan the most appropriate rehabilitation program according to the patient's needs, based on functional deficits highlighted by the instrumental analysis, that also documented and monitored the efficacy of the rehabilitation process itself. Moreover, it was possible to gain the best orthosis configuration combining the requirement of a better stabilization during walking and a low invasiveness of the orthosis.

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Gait analysis as a potential indicator of the rehabilitation outcome for obese patients

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INTRODUCTION

Posture and gait anomalies investigations have demonstrated to improve to date the rehabilitation programs and patients' outcome for several types of disorders [1,2]; however, the healing pathways of some illnesses, such as the obesity, still rely on "gold standard" (clinical) methodologies. Consequently, this study aims to preliminarily assess whether gait analysis tests (performed previously and subsequently a rehabilitation program) could represent a valid rehabilitation outcome indicator.

METHODS

For this purpose, a cohort of 15 patients was enrolled. Each patient underwent an Instrumented Stand and Walking [3] test using a microelectromechanical system equipped by a series of inertial measurement units (OPAL, ADPM Inc.) to quantify seven posture and gait parameters, previously and subsequently a rehabilitation program. Prism (v. 8.4.3., GraphPad) was used to evaluate several statistical data. Specifically, descriptive statistics, data normality (D'Agostino-Pearson test), differences in parameters mean between the obese patients and a stored healthy subject matched dataset (One sample t and Wilcoxon test), respectively, and the variance (Two-way ANOVA) before and after the rehabilitation program were calculated.

RESULTS

Table 1 summarizes the descriptive statistics for the seven kinematic parameters, shows the hypothetical mean value for the healthy subject and the p-value result of the Two-way ANOVA test.

Table 1. Results of the two-way ANOVA test between several gait and posture parameters.

Feature		Obese patients PRE	Obese patients POST	Hypothetical mean value	p – value
Sway	Total sway area (m^2/s^5)	0.0049 ± 0.0024	0.0047 ± 0.0016	0.0055	ns
APA	First step latency (s)	0.3784 ± 0.1025	0.4198 ± 0.1263	0.3100	ns
	Duration (s)	0.4698 ± 0.1468	0.3898 ± 0.1930	0.4450	ns
Gait	Cadence (steps/min)	96.7616 ± 10.9463	100.9837 ± 9.2509	116.0000	<0.0001****
	Double support (%)	30.2862 ± 4.2521	28.8700 ± 3.5259	21.3500	0.2530*
	Swing (%)	34.8569 ± 2.1260	35.5650 ± 1.7630	39.3000	0.2530*
Turn	Duration (s)	4.3765 ± 2.0087	3.2226 ± 1.2212	1.8500	ns

ns = non significative; * = 0.01 < p < 0.05; ** = 0.001 < p < 0.01; *** = 0.001 < p < 0.0001.

DISCUSSION

In conclusion, this paper presents a novel view to corroborate quantitatively – through gait improvements – the rehabilitation outcome for obese subjects. Further research will involve a deeper evaluation of patients and more kinematic parameters to better corroborate the preliminary results of this study.

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Preoperative gait analysis of a transfermoral amputee patient scheduled for osseointegration surgery

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INTRODUCTION

Osseointegrated surgery is an emerging alternative to treat transfemoral amputation. It is indicated in patients that do not wear standard socket-type prosthesis (short stump, swelling, pain, and soft tissue – prosthesis mobility [1]). Given the novelty of the procedure, little functional assessment of these patients has been provided. The aim of the present study was to provide a functional assessment of a transfemoral amputee patient scheduled for osseointegrated surgery by means of wearable sensors.

METHODS

A transfemoral amputee patient (male, 47 years, time from amputation 18 years) scheduled for osseointegration surgery was enrolled in the study. The patient was able to walk without aids and performed a battery of functional tests the day before surgery with his standard socket-type prosthesis: four 10-meters walking in a hospital indoor hall (two at normal self-selected speed and two at the fastest speed possible) and two Time Up and Go (TUG) tests. A set of 15 wearable inertial sensors (Awinda, Xsens Technologies) was used to collect full body kinematics (upper limbs, trunk-pelvis, lower limbs). Complete gait cycles were isolated and spatiotemporal and kinematical parameters were extracted from each trial through a dedicated cloud platform software for gait analysis. The differences between the amputee and the sound limb and between the normal and fast gait were reported.

RESULTS

Similar speed was found in normal and fast gait (0.1 m/s difference). Shorter step length was noticed for the amputee limb regardless the gait speed (9.3% – 10.1%). A longer swing phase was noticed for the amputee limb, with greatest differences in the midstance (Table 1). In the amputee limb, no hip and knee abduction, peak ankle plantarflexion, in the swing phase, and of peak flexion in the stance phase. A greater pelvis forward tilt and obliquity on the amputee limb, trunk forward tilt, and lateral bending were noticed (greater differences in the fast gait). The TUG was completed within 11 seconds.

Table 1. Spatiotemporal parameter differences in the 10-meters walking

Gait cycle (%)	Normal	Fast	Difference
Amputee limb, stance	51.94 ± 1.09	51.00 ± 0.98	0.94 ± 0.11
Sound limb, stance	57.80 ± 0.70	58.15 ± 0.81	-0.35 ± -0.11
Difference, stance	-5.87	-7.15	1.28
Amputee limb, swing	48.06 ± 1.09	49.00 ± 0.98	-0.94 ± 0.11
Sound limb, swing	42.10 ± 1.21	41.71 ± 1.14	0.39 ± 0.07
Difference, swing	5.97	7.30	-1.33

DISCUSSION

The patient scheduled for osseointegration surgery showed no problems in fast walking and daily movements. The TUG results were also above the standards for transfemoral amputee patients [2]. The altered spatiotemporal and kinematical parameters found were in line with current literature [3]. The excessive trunk and pelvis motion might be indicative of limited gluteus and core stability and should be trained before surgery to fasten the rehabilitation period. Further functional investigation should be provided during and after rehabilitation for a more comprehensive biomechanical understanding of such an innovative surgical procedure.

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The effects of different frequencies of rhythmic acoustic stimulation on gait kinematics and trunk sway in healthy elderly population

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INTRODUCTION
Many impairments and neurological diseases cause a gait disturbance, which include loss of regularity, symmetry or synchrony in body movements, leading in turn to a loss of balance. Many studies have investigated the strategies adopted to counterbalance the increased instability, such as the sensory stimulation[1]. The increase in sensory information can help static and dynamic balance, even for individuals with sensory and motor impairment. Rhythmic Acoustic Stimulation (RAS) has been shown to improve walking in several pathological conditions, including Parkinson's disease, stroke and multiple sclerosis, as well as in healthy elderly subjects[2], although this is still an unclear topic. Our aim was to investigate, through 3D Gait Analysis, the effect of different types of RAS (either at a fixed frequency or based on the average cadence of each subject) on gait spatio-temporal parameters and stability.

METHODS
we recorded the participants' walking in six experimental conditions: 1) simple walking; 2) walking with RAS at fixed frequency, corresponding to 80 beats per minute (bpm); 3) walking with RAS at the fixed frequency of 120 bpm; 4) walking with RAS at a frequency corresponding to 90% of the participants' cadence (90%-AC); 5) walking with RAS at a frequency corresponding to the 110% of the participants' cadence (110%-AC); 6) walking with RAS at frequency corresponding (100%) to the subject-specific average cadence (AC). Spatio-temporal parameters were analysed using 3D gait analysis, while stability was estimated by an innovative measure, the trunk displacement index (TDI)[3] that we have recently implemented.

RESULTS
Our results show that the RAS at fixed frequencies is suboptimal, likely because it does not take into account the individual characteristics of the subjects. With regard to the RAS at variable frequencies, the reduction of the cadence applying a frequency of stimulation corresponding to the 90% of the subject-specific average cadence does not significantly modify the gait parameters, except velocity. Conversely, a stimulus equal to the 110% of the average cadence improves both the spatio-temporal parameters and stability. Finally, the RAS at the individual natural cadence increased stability as well.

DISCUSSION
Our study shows that the effects of RAS on gait are depending on frequency. In particular, our results show that the use of fixed frequencies could be a non-optimal strategy, not taking into account individual gait characteristics, deviating too much from the natural individual cadence.
Concerning the variable frequencies, even if the reduction of the cadence to 90% did not cause a worsening of the gait, it did not improve the stability either. Conversely, a moderate increase in cadence seems to be advantageous on gait and dynamic stability. In addition, we observed that similar effects were present when setting a stimulus that did not differ from the individuals' cadence.

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Gait and balance impairment affect exercise tolerance in patients with heart failure

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INTRODUCTION

In patients with heart failure (PwHF), the Six Minutes Walking Test (6MWT) is reduced [1], a sign of decreased exercise tolerance [2]. However, given the complex clinical picture of PwHF, involving also alterations of balance control [3] and gait [4], the 6MWT might be affected by these changes in addition to mere cardio-pulmonary deconditioning. Aims of this study were to quantify alterations in balance control and gait in PwHF and to assess if these alterations correlate with the 6MWT.

METHODS

We recruited 18 patients from the Cardiac Rehabilitation Unit, ICS Maugeri of Pavia, admitted with diagnosis of HF; patients with any other condition or disease known to affect gait or balance were excluded. We evaluated the spatiotemporal gait variables (4-m baropodometry), the 6MWT, balance control through the Mini-BESTest (MBT), and hand grip strength (dynamometry).

RESULTS

Baropodometry: gait variables were significantly ($p<0.001$) reduced in PwHF with respect to 20 age- and sex-matched healthy subjects: respectively, speed 0.91 vs 1.09 m/s, cadence 92 vs 109 steps/min, step length 52.3 vs 58.4 cm. 6MWT: travelled distance of PwHF was on average 318 m, significantly below ($p<0.01$) the predicted value of 434 m [1]. The MBT of PwHF scored on average 16/28, corresponding to moderately severe deficit of balance control [5]. Hand grip test of PwHF was on average 28 kg, similar to its predicted value [6]. In PwHF, significant correlations were found between 4-m speed and 6MWT or MBT, and between MBT and 6MWT.

DISCUSSION

As expected, the 6MWT was reduced in PwHF. However, gait speed measured over a short path was also abnormal, and correlated with the 6MWT. This finding suggests a role of altered neuromotor control in reducing exercise tolerance. Impairment in balance control seemed to accompany the reduction in gait speed. Slow gait speed might further contribute to reduced exercise tolerance, due to the high energy cost of slower than normal walking [7], in addition to mere cardio-pulmonary deconditioning.

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Frequency content of EMG signal acquired in ankle flexor muscles during Parkinson walking

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INTRODUCTION

The analysis of surface EMG (sEMG) signal has recently gained attention in Parkinson's disease (PD). In particular, significant differences were reported in both timing (i.e., on/off activation) and intensity (i.e., envelope peak) of sEMG activity during PD-subject gait with respect to controls, especially for the recruitment of gastrocnemius lateralis (GL) [1]. However, to authors knowledge, no information about sEMG activity during gait has been reported in frequency domain. Thus, the aim of the study is the assessment of the frequency content of the main sEMG activity of GL during walking in PD individuals.

METHODS

sEMG signals were acquired from GL during walking of seven PD subjects (PD-group) and seven age-matched controls (C-group) at the BiomovLab, Department of Information Engineering, University of Padova, Italy. Mean (±SD) demographic parameters were respectively for PD-group: age = 61.9 ± 14.2 years; height = 1.70 ± 0.13 m; mass = 73.9 ± 22.8 Kg; and for C-group: age = 59.9 ± 5.0 years; height = 1.71 ± 0.13 m; mass = 75.8 ± 18.7 Kg. Time-frequency characterization of sEMG signals was provided by means of Continuous Wavelet Transform (CWT), a time-scale analysis method for multiresolution decomposition of continuous time signals. CWT coefficients allow reconstructing the scalogram function, providing an estimate of the local time-frequency energy density of a signal. Onset and offset events were identified in each stride as the beginning and the end of each time interval where the scalogram was exceeding the 1% of the peak value of energy density in each sEMG signal. Corresponding values in frequency domain provided frequency content of the specific activation.

RESULTS

In the present study, only the main GL activation (≈ 20-50% of gait cycle, GC) was considered. An example of scalogram function depicting this single activation in a representative PD patient is reported in Fig. 1. No significant difference ($p > 0.05$) was detected between groups in time domain for both the mean onset (PD-group: 22.8 ± 15.1% of GC; C-group: 20.8 ± 15.6% of GC) and offset (PD-group: 55.3 ± 9.6% of GC; C-group: 47.5 ± 15.7% of GC) events. No significant differences ($p>0.05$) were observed either in the frequency range, in terms of mean minimum (PD-group: 10.0 ± 2.4 Hz; C-group: 8.0 ± 3.5 Hz) and maximum (PD-group: 422 ± 87 Hz; C-group: 368 ± 125 Hz) values.

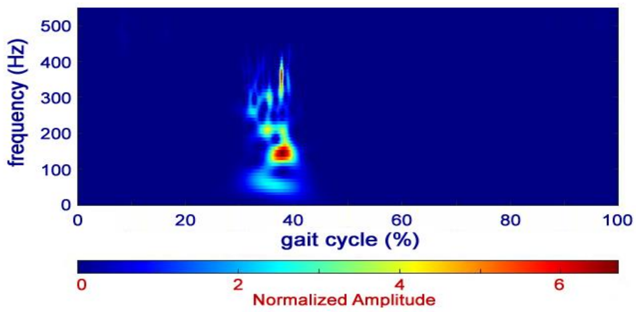

Figure 1. Example in a representative PD patient of the scalogram function where only the main GL activation is highlighted in time-frequency domain.

DISCUSSION

The main role of GL during walking is the active participation in restraining the forward progression of the tibia over the talus during the second rocker [2]. No significant modification in frequency domain of this activation during walking in PD individuals, should be considered as the main finding of the present study. Findings in time domain do not find agreement with what reported in literature. This is likely due to the fact that only the main GL activation is considered. Thus, future development could be tailored at investigating other phases of the gait cycle where GL is recruited with different functional purposes.

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ELECTROMYOGRAPHY-BASED TREATMENT WITH BOTULINUM TOXIN OF ANTEROCOLLIS IN PARKINSON'S DISEASE

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INTRODUCTION

Anterocollis is a form of cervical dystonia characterized by forward neck flexion when in a sitting or standing position [1]. Botulinum toxin injection is report to be effective. Dynamic and needle electromyography (EMG) investigates the synergies of cervical muscles and identifies affected muscles to be inoculated with botulinum toxin for specific protocol of rehabilitative treatment [2].

METHODS

86 patients (39 females and 47 males; the average age was 72 years) were studied prospectively and were performed to look for electrophysiological dystonic activity. The patients were studied using dynamic EMG (Pocket EMG, BTS, Milan, Italy) from sternocleidomastoideus, trapezius, splenius, paravertebral cervical and needle EMG signals from longus colli, scalenus anterior and medius. All patients underwent clinical investigation with Cervical Dystonia Disability Scale of Tsui, X-rays and EMG on two occasions: at inclusion and 1 month after botulinum toxin injection. The measurements were performed in "on" conditions 1 h after the regular morning antiparkinsonian drug administration.

We injected botulinum toxin (Dysport) in the dystonic muscles using 20 U per muscle. In addition the patients underwent a rehabilitation programme consisting of individual 90-minute daily sessions, 5 days a week for 4 weeks.

RESULTS

In 63 patients EMG identified at rest persistent tonic muscle activity in the anterior (sternocleidomastoideus and scalenus ant & med) and posterior (splenius and trapezius) neck muscles at sitting position, while contraction of the posterior neck muscles was reduced in the supine position. Abnormal tonic hyperactivity of longus colli was recorded in 18 patients. Botulinum toxin injections in the EMG-indicated muscles markedly improved anterocollis in these patients. After the treatment, the score of Tsui showed a mean significant improvement of 8 points. Significant decrease of X-ray degree of cervical kyphosis (34.2° ± 5.6° vs. 46.1° ± 9.7°) was observed.

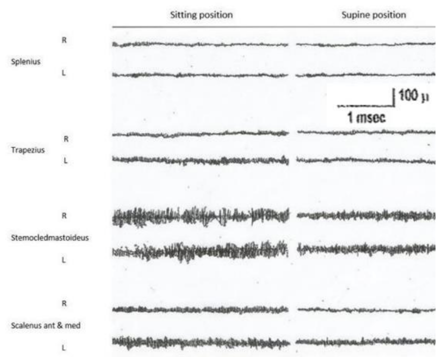

Fig.1
Polygraph recordings of EMG activities of the anterior and posterior neck muscles at sitting and supine position

Dynamic electromyography: reduction of abnormal tonic hyperactivity of the inoculated muscles, associated with an increase in cervical spine strength.

DISCUSSION

In PD patients with anterocollis without weakness, electromyography findings may be abnormal, if the patients have dystonia underlying their abnormal head positioning [2]. Without targeting superficial and deep flexor muscles with botulinum toxin, it may not be possible to get meaningful clinical improvement in anterocollis. Early diagnosis and prompt treatment with botulinum toxin in the dystonic flexor muscles is necessary to prevent muscle damage associated with longterm overstretch of extensor neck muscles [3].

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High-Density surface electromyography during fatiguing frequency-dependent lifting activities at different risk levels in people with and without low back pain

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INTRODUCTION

Workers often develop low back pain (LBP) due to manual material handling activities, especially lifting tasks. To prevent the onset of these work-related disorders, it is crucial to perform an accurate biomechanical risk assessment. In recent years, in addition to traditional methods (NIOSH equation, [1]) several instrumental-based assessment tools for risk assessment have been developed ([2]) and these have been implemented during fatiguing lifting tasks ([2,3]). This study aims to test the hypothesis that, during the execution of repetitive lifting tasks, high-density surface electromyography (HDsEMG) allows discrimination of: i) healthy controls (HCs) and people with LBP (LBPs); ii) biomechanical risk levels.

METHODS

Fifteen HCs and seven people with LBP lifted a load of 10 kg in 3 different sessions performed on 3 different days, one for each risk level (Lifting Index: LI=1, 2, and 3 from NIOSH equation [1], Fig.1A), obtained by changing the frequency of execution (4, 11 and 15 lifts per minute respectively). An inertial sensor (myoMotion Research PRO IMU, Noraxon) placed on the load, was used to define the start and end of lifting [3]. The tasks lasted 15 minutes or as long as the participant could. Lumbar erector spinae activity was recorded bilaterally using HDsEMG with two 64 channels grids (OT Bioelettronica, Torino, Italy) placed following skin preparation [3,4]. To characterize the spatial distribution of muscle activity, the root mean square (RMS) values were computed from each of 59 bipolar signals [3,4] in each lifting cycle and these values were used to create a topographical map of erector spinae activity [4] (Fig. 1A). Furthermore, the RMS in the region of activation (RMS_{RoA}, [3]) were computed for each cycle and the mean overall all task duration was computed for each risk condition. For each condition (LI=1, 2 and 3) of all the lifting tasks, RMS_{RoA} were expressed as a percentage relative to the initial value (value of the first cycle of the task) [4]. Statistical analysis was performed to verify the difference between those with and without LBP, and the effect of the risk levels on HDsEMG parameters.

RESULTS

The RMS_{RoA} parameter can significantly discriminate risk levels and the two groups (see Fig.1B).

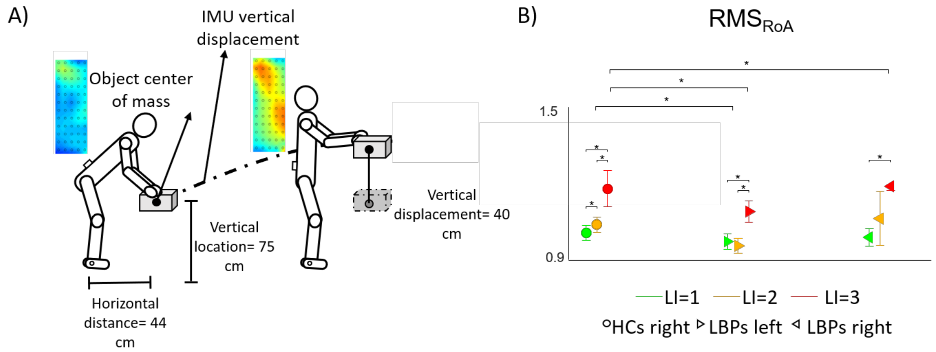

Figure 1. Set up configuration (A) and results of the RMS in the region of activation (RMS_{RoA}) for HCs and LBPs.

DISCUSSION

The results of this study showed that HDsEMG measures can be used to determine differences between people with and without LBP as they perform a lifting task. Moreover, it was possible to discriminate the biomechanical risk levels. This methodology could be used to monitor fatigue and extend the possibilities offered by currently available instrumental-based approaches.

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Trunk muscles co-activation in single vs team lifting at different risk levels.

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INTRODUCTION

Work-related low-back disorders (WLBDs) are the most common and costly musculoskeletal disorders and are caused by manual lifting tasks (Violante et al., 2020). Due to the WLBDs high incidence (Violante et al., 2020), economic cost and impact on quality of life, many ergonomic interventions have been proposed during the past three decades to mitigate them. In some work conditions a collaborative lifting (team lifting) executed by more than one person (ISO 11228-1, ISO TR 12295) is a common and safety practice for reducing WLBDs, but no studies analyzed until now the trunk muscle co-activation during a two-person team lifting. Therefore, this work aims to evaluate trunk muscles co-activation in one-person versus two-person lifting task at different risk levels.

METHODS

Eleven healthy subjects (with no history of orthopaedic or neurological disease) were enrolled in the study. Trunk muscles (right erector spinae longissimus and right rectus abdominis) bipolar surface electromyography (sEMG) was recorded while performing a one-person (single) and two-person (team) lifting tasks at three different risk levels conditions (LI=1, 2, 3) according to the Revised NIOSH Lifting Equation (Waters et al.,1994), Fig.1 A and B. The co-activation of the four trunk muscles during each lifting task was computed using the time-varying multi-muscle co-activation function (TMCf) (Ranavolo et al., 2015).

RESULTS

Two-way repeated-measures ANOVA and post-hoc analysis showed that the area of the TMCf significantly increases with LI both in single and team lifting, and that the area is significantly lower in team lifting with respect to the single lifting at each risk level, Fig. 1 C.

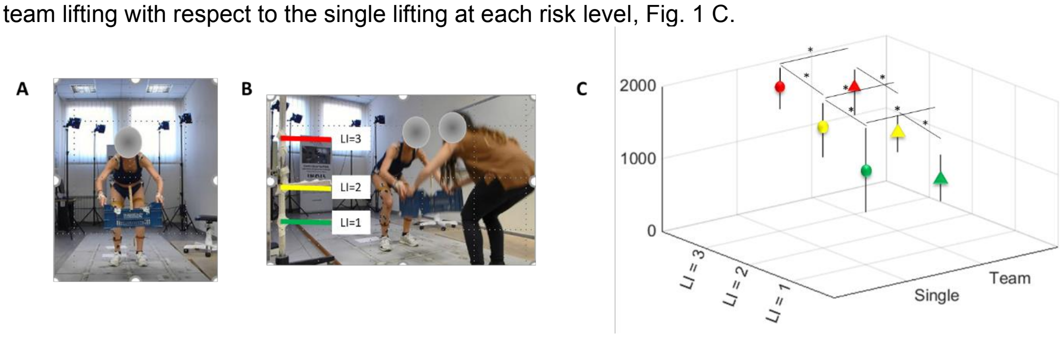

Figure 1. Panels A and B show the experimental setup and panel C illustrates the mean over all the subjects of the area of the TMCf at the three risk levels (LI=1 green, LI=2 yellow, LI=3 red) for single (circle) and team lifting (triangle).

DISCUSSION

The results highlight the sensitivity of the TMCf to discriminate different risk levels both in single and team lifting tasks, so this could be used as an operative tool both in laboratory and on field to evaluate the biomechanical risk. Moreover, the results confirm the utility of the team lifting as an ergonomic intervention to decrease the biomechanical effort on lower spine and to reduce the risk to develop WLBDs.

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Shoulder kinematics and electromyography of patients with trapezius muscle palsy.

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INTRODUCTION

The trapezius muscle is innervated by the accessory nerve that travels along the inner wall of the skull towards the jugular foramen. The lesion of this nerve may be a consequence of trauma or neck surgery [1]. Although Trapezius Muscle Palsy (TMP) is known especially in otolaryngology and is described like limiting the shoulder functionality, its clinical assessment is fragmented and there are not validated tests nor scales to evaluate it [1,2]. The aim of this study is to investigate the feasibility and the utility of the Constant-Murley Score (CMS), kinematic analysis and dynamic surface electromyography (sEMG) in the evaluation of patients with TMP.

METHODS

The study included 9 patients with TMP resulting from a neck surgery procedure (time since surgery 24±58 months). All patients presented a contralateral asymptomatic side that was considered as reference. Each subject was evaluated bilaterally, including the administration of the CMS and the quantitative analysis of the scapulo-humeral coordination by means of stereophotogrammetry and concurrent sEMG (upper, middle and lower trapezius). Electrodes were applied according to the Basmajian and Blank minor cross-talk protocol [3]. The ULEMA software was used to reconstruct joint angles, following ISB guidelines [4]. All patients performed 5 repetitive movements of humerus flexion (FLEX) and abduction (ABD). Scapula kinematics were assessed by comparing each coordination pattern with both the contralateral side and the relevant reference band [5]. sEMG was qualitatively analyzed through a visual inspection of the signal morphology and activity between consecutive movements. Possible statistically significant differences between CMS of pathological and contralateral sides were analyzed with non-parametric statistics (Wilcoxon rank sum test).

RESULTS

The statistical analysis shows that for CMS there are significant differences between the pathological and the contralateral shoulder. The analysis of the scapula orientation in static pose shows an increase of all rotations in almost all patients. The analysis of humeral ROMs indicates lower values in the pathological sides, both in FLEX (104° vs. 146°) and ABD (75° vs. 148°). The analysis of the scapula orientation during humerus elevation shows: increase in protraction for the 55% of patients, both in FLEX and ABD; an increase of lateral rotation during ABD (44% of patients); an increase of both the anterior tilt (33% in FLEX and 22% in ABD) and the posterior tilt (22% in FLEX and 44% in ABD). The analysis of the EMG signal activation and morphology is reported in Table 1.

Table 1. Patients (%) presenting an altered EMG signal for the pathological side VS the contralateral.

EMG analysis	**Movements**	**Upper TM**	**Medium TM**	**Lower TM**
Morphology	FLEX	44%	77%	55%
	ABD	33%	44%	77%
Activity between consecutive movements	FLEX	55%	100%	88%
	ABD	55%	66%	88%

DISCUSSION

This is the first time that the feasibility of CMS, kinematic analysis and sEMG was tested in patients with TMP. These investigation tools are all noninvasive and already well known in movement analysis. Preliminary results confirms that each tool can support the assessment of functional limitations due to TMP. This study does not find comparison in the literature, leading to the need for further studies.

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Quantification of face mobility in spinal muscular atrophy

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INTRODUCTION

Spinal muscular atrophy (SMA) is a neuromuscular disease affecting motor neurons in the spinal cord and is caused by the deletion of the Survival Motor Neuron (SMN1) gene on chromosome 5. Symptoms vary significantly among subjects depending on the SMA type, though they usually include progressive muscle atrophy, weakness and paralysis in the trunk and limbs as well as muscles involved in facial, jaw, and respiratory tasks [1]. While impairment in gross motor functions has been widely investigated in SMA, there is a paucity of research on oro-facial and bulbar functions. We propose a method to quantitatively evaluate face mobility through an easy-to-interpret index based on a face tracking algorithm that exploits Facial Action Coding System (FACS) [2] in subjects affected by SMA. Three areas of the face were investigated: upper, middle and lower parts.

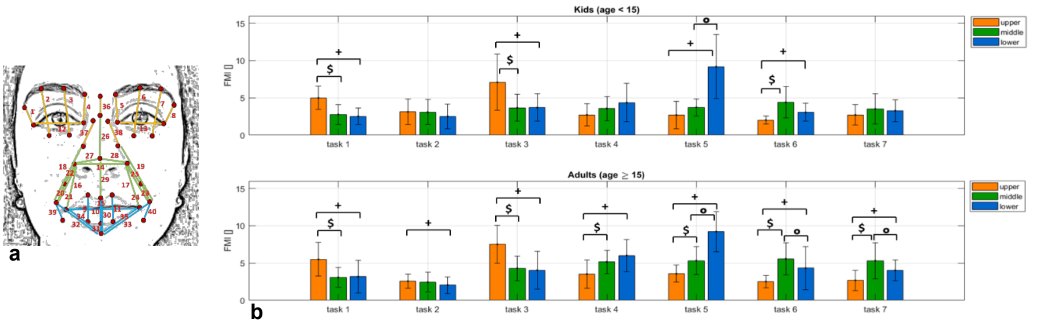
METHODS

Data from 20 adults (mean(±SD) age: 32.3 (±13.17) years) and 11 kids (mean(±SD) age: 8.73(±3.32) years) affected by SMA (SMA 1, SMA 2 and SMA 3) were evaluated. Frontal face videos were recorded while subjects were comfortably seated with a neutral background behind them at 1.36 m from a commercial video camera placed at eye level. Subjects were instructed to perform the following tasks: (1)frowning, (2) eye closure without exertion, (3)eye closure with exertion, (4)tight-lipped smile, (5)smile, (6)kiss, (7)cheeks inflation. A neutral face expression was acquired as reference. Based on the FACS encoding system, a set of 56 facial landmarks was defined and tracked in the 2D image space per each expression and frame, using a self-developed software (TrackOnField, BBSoFS.r.l.) [3]. The local coordinates of these features were employed in order to define 40 distances; each distance was then normalized to the corresponding one of the neutral expression (*ratio*). A face mobility index (FMI) was defined and calculated per each subject as follows: $FMI_j = \frac{\sum_{i=1}^{n\_dist} |1-ratio_j| \cdot 100\%}{n\_dist}$ $\quad j = 1 \ldots 7$(Figure 1a). Three sub-indexes were also defined for each face area and compared through Wilkoxon signed rank test ($p<0.05$).

RESULTS

Results obtained in the two cohorts of subjects are presented in Figure 1b.

Figure 1a. Graphical representation of the distances included in the three FMIs. **1b.** Results of the analysis divided per cohort. Statistically significant results are highlighted, and different symbols indicate comparison between different FMIs.



DISCUSSION

A new index is proposed to quantitatively assess the face mobility in subjects affected by SMA. Encouraging results were achieved, suggesting the possibility to adopt this metric to track the effect of rehabilitative and new pharmacological treatments aiming at restoring muscle function, including face muscles mobility.

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A face tracking algorithm to quantitatively evaluate hypomimia in Parkinson's Disease

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INTRODUCTION

Parkinson's disease (PD) is a neurodegenerative disease that mainly affects the motor system. Among other symptoms (tremor, rigidity, and bradykinesia), PD subjects may experience an impaired facial expression with respect to healthy control (HC) individuals that can lead to a significant reduction of patients' quality of life [1]. Despite these impediments, measurements of hypomimia are not currently available. In this study, we propose a face tracking approach based on the Facial Action Coding System (FACS) [2] in order to quantitatively evaluate the degree of hypomimia comparing two cohorts of subjects: PD and HC. FACS describes facial expressions by means of action units (AUs). AUs are related to facial muscles mobility, and they can entirely describe the human basic emotions: anger, disgust, fear, happiness, sadness, surprise and neutral.

METHODS

Data of 50 PD (age (mean ± SD): 69.4 ± 7.79) and 17 HC subjects (age (mean ± SD): 66.56 ± 7.16) were analyzed. Frontal face videos of participants were recorded while they were instructed by a clinician to perform in random order the six basic facial expressions and the neutral one. Subjects were comfortably seated in front of a commercial camera (GoPro Hero 3, 1920x1080 pixels, 30 fps) placed at eye level at a distance of 1.36 m with a neutral background behind them. Per each emotion, videos were segmented into 4 frames; using an ad-hoc set of 56 features tracked in the 2D-image space (TrackOnField, self-developed software, BBSoF S.r.l.) [3], 40 distances were calculated and normalized to the correspondent distance in the neutral expression (*ratio*). A face mobility index (FMI) was defined and calculated per each emotion as follows:

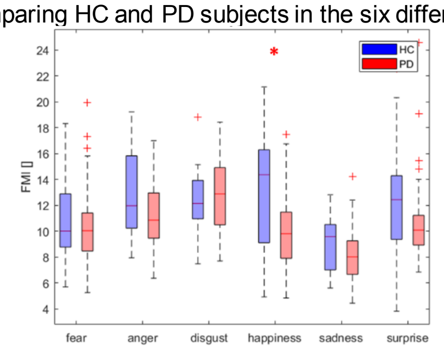
$$FMI_j = \frac{\sum_{i=1}^{n\_dist} \left|1 - ratio_j\right| \cdot 100\%}{n\_dist} \qquad j = 1 \dots 6$$

Wilcoxon rank sum test ($p<0.05$) was implemented to compare the different FMIs in the two cohorts of subjects.

RESULTS

Results (Figure 1) highlighted statistically significant differences in the FMI in the happiness expression.

Figure 1. Boxplot of FMI comparing HC and PD subjects in the six different emotions.



DISCUSSION

As expected, face mobility is greater in HC than PD subjects. Besides some limitations (numerosity of the sample, subjectivity in the interpretation and expression of the emotion), the proposed face mobility index can be used as a quantitative measure for the degree of hypomimia in PD patients.

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Sessione Poster

Analisi del movimento: strumenti e metodi

Stabilization of stance by vision and touch. Distinctive characteristics.

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INTRODUCTION

Vision and touch produce stabilisation of stance [1]. However, the purpose of body stabilisation may be different in these two conditions [2,3]. The geometric features of body sway do not allow to detect distinct effects [4]. We hypothesised that the frequency of the body sway signal is a more appropriate marker for assessing the separate influence of vision and touch on the posture-stabilising processes.

METHODS

The Center of Pressure (CoP) position was recorded for 90s in 12 young healthy subjects (28.9±5.1 yrs) standing on a force platform under: 1. eyes closed with a foam pad (ECF), 2. eyes open with foam (EOF), 3. ECFT and 4. EOFT when subjects lightly touched with the index finger a stable surface, and 5. EC without foam pad (EC). CoP path length, sway area and frequency spectrum of medio-lateral (ML) and antero-posterior (AP) CoP position were calculated on the high pass filtered (cut off 0.01 Hz) signals. Six frequency windows were operationally selected based on the local minima of the power spectrum profile under ECF considered as the reference condition (Fig 1A). The mean level of the spectrum within each window was compared between conditions.

RESULTS

Compared to ECF, path length and sway area were reduced in EOF, ECFT and EOFT ($p<0.05$ for all paired comparisons) and under EOFT became similar to EC. The mean level of the total spectrum was significantly reduced with respect to ECF by vision or touch separately or combined in both ML and AP axes. However, vision and touch differently affected the selected frequency windows. With ECF, touch was more effective in reducing oscillations in the 0.055-0.16 Hz window compared to vision, while vision reduced the oscillations in the 0.16-0.8 Hz range more than touch (Fig.1B). Sway EC (no pad) was quite negligible compared to all foam conditions.

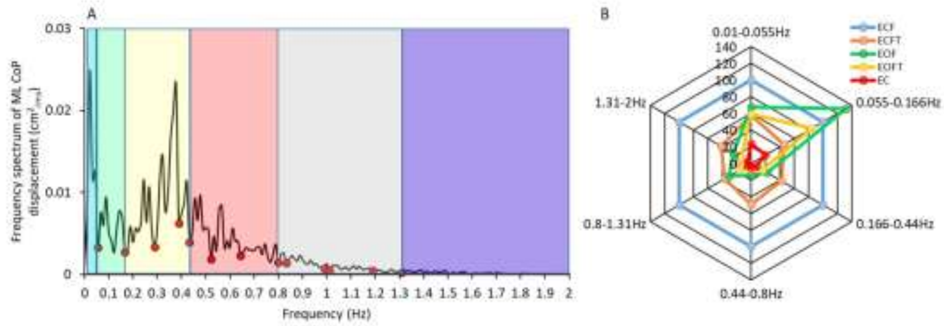

Fig.1. CoP analysis in frequency domain. (A) Frequency spectrum of ML CoP position under ECF condition. Red dots indicate local minima of the spectrum, colored bands indicate the frequency windows for the spectral analysis. (B) Mean level of the frequency spectrum within each frequency window for all tested conditions expressed as percent of the corresponding mean level of the ECF condition.

DISCUSSION

A simple oscillation frequency analysis gives information on subtle distinctions in the control of critical stance by addition of sensory visual and haptic inputs, not supplied by common geometrical measures. Further, by playing with several frequency windows operationally identified allows to disclose unique haptic and visual body stabilisation processes brought about by diverse tuning of the postural control mode. On foam, vision enhances the low-frequency oscillations, while touch diminishes the entire spectrum, but less than vision at the high frequencies, as if sway reduction by touch would be produced by rapid, repeated balance corrections.

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Grading visual stimuli in personalized action observation therapy: a kinematic-based approach

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INTRODUCTION

Action Observation Therapy (AOT) is an effective complementary method used in rehabilitation [1, 2]. To maximize AOT outcomes, it is fundamental to optimize the visual stimulus according to the type of movement to observe, the viewing perspective [3], and the actual functional limitations. Recently, 3D digital avatars have been introduced for this purpose. The main goal of this work was to develop a novel approach able to adapt the visual stimuli by grading the avatar's movements according to the actual performance of the observing subject with respect to a general reference.

METHODS

Kinematic data about 37 subjects while performing repeated reach-to-grasp tasks were collected by using a marker-based motion capture system (figure 1.a). After pre-processing [4], shoulder and elbow joint angles were normalized on the overall task duration. A general reference was defined by averaging all the normalized kinematics, considering 10 trials for each subject, and evaluating the average times for the completion of each phase (i.e., reaching, grasping, return). Additional trials for each subject were then used as paradigmatic of her/his strategy and a linear transformation (in terms of amplitude and time duration) was applied to generate novel kinematic patterns, that were intermediate between each subject-specific strategy and the reference one; one-hundred control points *k* were identified. Each new kinematic pattern was characterized in term of joints range of motion, movement fractionation, mean and maximum reaching velocity and smoothness velocity ratio [5]. Considering the first 2 principal components of these metrics and the planned number of rehabilitative sessions, pooled variance values were calculated on a defined progression window to weight the pace in the selection of kinematic pattern (i.e., the higher is the pooled variance, the lower the step between *k* has to be, and vice-versa).

RESULTS

Figure 1.b and 1.c report an example of generated kinematic patterns and the corresponding choice of the k path adjusted for variance, for a rehabilitation program consisting in 15 sessions.

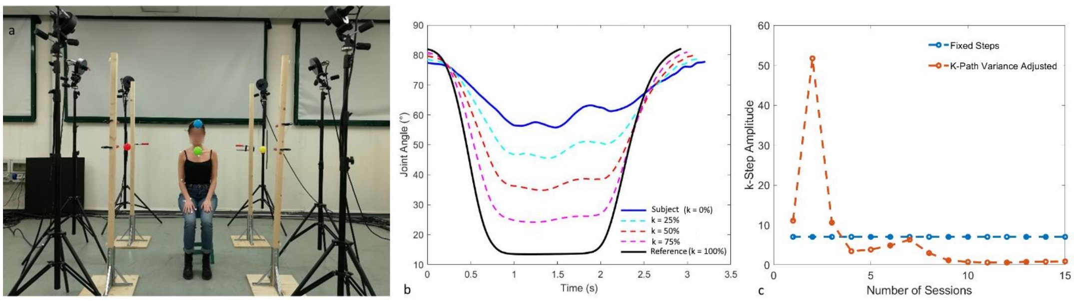

Figure 1.a Setup; **b.** Simulated shoulder flexion angle; **c.** adjusted *k* step amplitude with respect to fixed *k* step.

DISCUSSION

This study proposed a novel kinematic-based approach in the definition of optimized visual stimuli for AOT. By using this method, a rehabilitation path (vector of *k*) coherent with the identified number of sessions and customizable upon each subject's performance can be easily identified and implemented on a 3D digital avatar. In this way, it is possible to support the clinicians in the definition of an optimal patient-specific rehabilitation program integrating AOT.

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VisionTool: a Semantic Features Extraction Toolbox

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INTRODUCTION

Pose estimation is a key task in computer vision and for video-based human motion understanding. It consists in identifying the position of the human body in images or image sequences, and it involves key body landmarks detection in the image plane. Recently, big efforts have been done to study and implement computer vision methods for the estimation of the human pose and for the detection of body landmarks [1]. A sample of remarkable interesting fields are (i) *motion analysis*: pose estimation is used to predict and describe human behavior while performing different actions, which may be essential in neuroscience to better understand the brain in both physiological and pathological conditions [2]; (ii) *human-computer and human-robot interaction*: a computer/robot provided with a camera and able to perform accurate pose estimation can be controlled with dedicated gestures and can provide dedicated assistance [3].

In several application fields, human motion analysis is performed exploiting wearable sensors, motion capture systems and physical markers placed on the body skin. However, markers are intrusive, time consuming, they may limit the naturalness of the movements, and their location is assigned a priori, making the study of human motion problematic in some scenarios [4]. In this context, we developed VisionTool, an open source Python toolbox (available at https://github.com/Malga-Vision/VisionTool) to perform marker-less semantic landmarks detection. VisionTool is designed to give appropriate importance to (i) *simple and immediate adoption*: the toolbox is provided with an intuitive graphic user interface (GUI) that allows all the users to exploit the implemented features; (ii) *modularity and extensibility*: the toolbox is modular, new features and modules can be easily added to the package.

METHODS

VisionTool is a toolbox for landmark points detection that offers a user-friendly interface to perform manual annotation in the context of marker-less motion analysis. First, the user imports input videos and selects a number of frames to be annotated with the correct location of the points of interest (selected by the user). The user exploits the dedicated annotation interface, using the mouse to select the points he is interested in detecting (i.e., landmark points in the human body). An automatic assistance framework can be invoked after few frames have been annotated, to easily increase the dimension of the training data. A deep neural network can be finally chosen among the available ones and trained on the annotations. The trained model is then ready to be used to perform landmarks detection in seen and unseen videos. The generated model, if created with enough data, can be adopted to detect the selected points also in videos of new subjects acquired in different days/sessions.

RESULTS

VisionTool is available at https://github.com/Malga-Vision/VisionTool

DISCUSSION

In this abstract we present VisionTool, an open source toolbox to perform semantic landmarks extraction in the context of marker-less human motion analysis. Exploiting deep-neural networks, VisionTool is able to perform high-accuracy landmark points detection with few training data. Required annotations to users are further reduced by an automatic annotation procedure, where the results of a preliminary joints estimation can be checked and potentially corrected before the actual training. The toolbox is provided with a friendly GUI that allows even inexperienced users to easily exploit all the implemented features.

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INTEGRATING MICROSOFT HOLOLENS 2 AND INERTIAL SENSORS IN AN AUGMENTED REALITY ENVIRONMENT FOR PERSONALIZED MOTOR REHABILITATION

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INTRODUCTION

Virtual reality (VR) and augmented reality (AR) technologies are promising tools in motor rehabilitation. They promote multi-sensory stimulation and user interaction and can deliver real-time feedback potentially enhancing motor learning and skills acquisition [1]. Miniaturized magneto-inertial measurement units (MIMUs) are often used to quantitatively evaluate motor tasks [2]. The combined use of AR and kinematic measurements is effective in delivering fine-grained visual and auditory feedback based on gait and balance parameters [3]. In this context, augmented environments can be employed to challenge obstacle negotiation and to investigate stepping accuracy. Point of gaze accuracy could also be evaluated when an eye tracker device is included [4].

The aim of this work was to develop an AR based platform integrating the AR head mounted display (HMD) HoloLens 2 (Microsoft) and wearable MIMU (Shimmer3 GSR+Unit, Shimmer) technologies, to provide an enriched AR environment including augmented real-time feedback obtained from MIMU measurements.

METHODS

Ankles and low back are instrumented using three wearable MIMUs, while the head motion is tracked using the MIMU embedded in the HMD. A C# code was developed to acquire the signals obtained from the wearable MIMUs. C# was chosen to optimize the integration within the cross-platform 3D engine Unity used as an AR/VR development platform. The AR HMD is used to present custom AR environments to the subject wearing it and it can also track eye movements thanks to its two infrared cameras. Synchronization of the device network is crucial for an effective use of the integrated system. A mixed real-time HW-SW synchronization approach was implemented to this purpose, using low-latency synchronization modules allowing to simultaneously send a trigger signal directly to the wearable MIMUs and to the HMD. An Xbox controller connected to the HMD was used as a hardware interface between the HMD and the synchronization system. A software realignment of both wearable MIMUs and HMD signals is required by time shifting.

RESULTS

Figure 1 shows the technology integration. The Unity 3D engine gathers data from all sensors. The three wearable MIMUs record and stream data in real-time to Unity using a TCP/IP protocol developed in C#. The HMD works directly in Unity, with C# codes, offering the AR environment to the subject wearing it while recording the head motion data with its MIMU and the gaze data with its eye tracker.

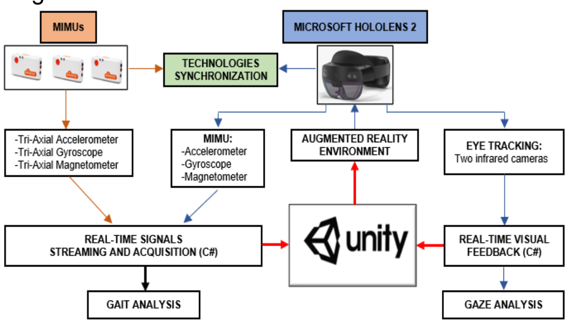

Figure 1. Technologies Integration

DISCUSSION

The proposed custom AR based platform, obtained by integrating different technologies is expected to enhance the motor rehabilitation capabilities of the selected HMD technology, by exploiting additional body motion information to be associated to the native gaze and head motion recordings therefore generating a more personalized real-time feedback to the user.

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DESIGN OF AUGMENTED REALITY ENVIRONMENTS: A STEP TOWARD A PERSONALIZED MOTOR REHABILITATION

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INTRODUCTION
After a few decades of developments, the use of Virtual Reality (VR) and augmented reality (AR) in rehabilitation is gaining attention. Both technologies place the user in a virtual environment by using a wearable head staged visor providing VR or AR feedback. In VR the user cannot see the external world, the visor occludes the surrounding environment, limiting the user awareness of the potential real world obstacles. AR solves this problem by making use of semi-transparent lenses merging virtual objects or scenarios into the real world as seen by the user. A key advantage brought by both technologies is the possibility to turn physical training sessions into a game, increasing the motivation and stimulating the patient to perform rehabilitation exercises [1]. Additionally, VR and AR combined with remote monitoring techniques, allows a richer interaction between users (having a complete view of the working area) and facilitators (providing experience and precise indications to the users) in real time [2].
The aim of this study is the creation of a personalized dynamic rehabilitation environment for patients with motor disorders or impairments. This setup is intended to reconstruct daily activities within the augmented environment where the user can reach increasing levels of mental and physical involvement while guaranteeing an improved level of safety, difficult to obtain in real life environments.

METHODS
The technology used to implement the AR is the HoloLens 2, (Microsoft). HoloLens features semi-transparent lenses that allow a total fusion between the real surrounding environment and virtual objects in a mixed-reality scenario. The HoloLens inertial sensor tracks the head movements. The eye and hand tracking allow for intuitive management and the execution of tasks. We selected the Unity 3D engine software to create custom mixed-reality environments aimed for the rehabilitation of people with motor disabilities. We designed an initial basic virtual environment using such technology by defining the physical characteristics of the augmented virtual objects (such as size, shape and color) interacting with the real world (gravity, collisions etc). These characteristics can be further refined by choosing the material of the virtual objects and therefore weight and rigidity. Prebuilt models of standard objects can be acquired and placed within the virtual environment through apps, without the use of a 3D engine.

RESULTS
The figure shows a basic augmented motor rehabilitation environment created using some of the 3D models provided, featuring virtual objects interacting with the real environment (a balloon and a dumbbell resting on treadmills, traffic cones and tiles on the floor). In the present case, a rehabilitation environment was set up to let the user walk along a simple path with obstacles. The four cones define a specific path for the subject to take, while the two white tiles represent obstacles to be avoided.

DISCUSSION
The proposed approach may soon become a common tool for creating truly personalized motor rehabilitation, since it offers several advantages: in terms of safety during training, ease in switching between multiple training configurations, dynamically generated feedback. Moreover, it monitors and records numerous aspects of the subject training session. Being fully wearable, the proposed setup can be easily employed in spaces not originally intended for physical rehabilitation.

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Recording infants' motion with a single 3D camera and a markerless tracking algorithm: evaluation of an occlusion recovery method.

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INTRODUCTION

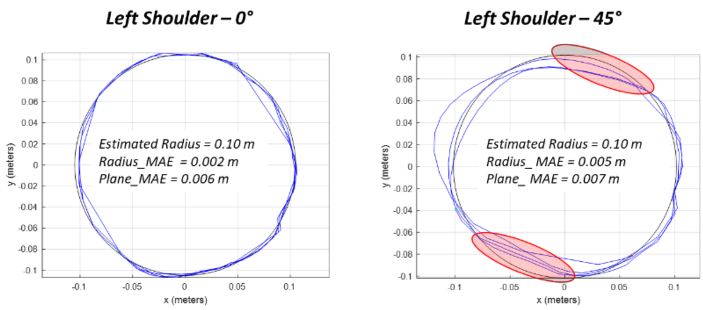
The neuromotor foundation for upper extremity use is laid down in the prenatal period and built upon during infancy. During the first year of life, neuromaturation is clinically assessed, and future motor disability predicted, through structured observation of infants' spontaneous, circular, "fidgety," general movements (GM) [1]. It is important that deviations from the typical course of development be detected as early as possible so interventions can leverage the neuroplasticity of early infancy. Detecting and quantifying infants' motion with marker-based systems (MB) is difficult due to the logistical and compliance issues inherent in placing markers on an infant's body [2]. The aim of this study was to propose an alternative approach to MB measurements providing satisfactory reliability using a single RGB-Depth camera, an automatic markerless (ML) position tracking algorithm and a purposely developed method for dealing with occlusions of points of interest.

METHODS

RGB images from an IntelRealSense D435) camera were converted to video (.avi) files and fed to DeepLabCut (http://www.mackenziemathislab.org/deeplabcut), tracking software that uses deep learning neural networks to perform ML tracking. Six anatomical landmarks (ALs): left and right shoulders, elbows, and wrists were manually marked on 10% of the video frames (randomly selected) to create a training set. The tracking software provided AL positions in all RGB frames, with relevant confidence level. The 3D position of tracked ALs was obtained by exploiting the depth information of their corresponding pixels. An ad-hoc solution was implemented to deal with AL occlusions resulting from infants' movements, which corrupted the reconstruction of the AL 3D position. The occlusion duration was identified using the prediction confidence level (a low confidence levels may be due to occlusions). All gaps resulting from occlusions were filled by applying a spline interpolation.
To evaluate the performance of the proposed method for correcting depth coordinates, two recordings were made of a doll positioned on a turntable rotating at 33⅓ rpm. One recording captured the image plane parallel to the turntable rotation plane; the other was tilted at 45°. The latter allowed to replicate occlusions occurring during live infants' motion recordings. The doll's left shoulder trajectory was reconstructed using the same methods applied to the infants and its rotation plane and the best fitting circle were determined. The AL trajectory deviations from a perfect circle were calculated for both configurations and used as metrics for occlusion recovery quality.

RESULTS

Figure 1: The mean absolute error (MAE) of the instantaneous distance from the center with respect to the best fitting circle radius and of the trajectory distance from the best fitting plane.



DISCUSSION

This promising procedure will be applied on infants where it is expected that the occlusions will be of greater time duration and will also include additional upper body ALs.

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Development of a prototype for the recognition of the gait phases using the laser flight time

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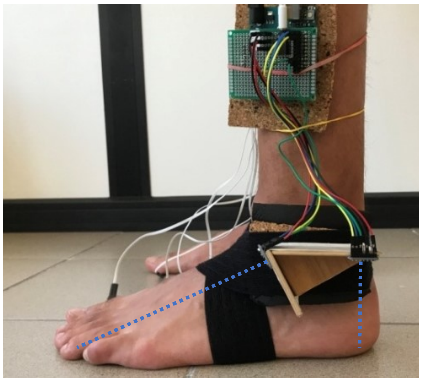
INTRODUCTION

Walking is a simple and natural movement, which allows the person to move, but at the same time it is complex because it involves many parts of the human body. Gait analysis is in rapid evolution, in particular the last frontier is the world of the wearable. In recent years the laser technology has been introduced, it is an innovative and easy-to-use approach [1, 2]. The aim of this study is to develop the prototype of a wearable device for the recognition of the phases of the walk using only laser sensors. Two VL53L0X Time-of-Flight (ToF) laser measurement modules were used, characterized by small size, low price, frequency equal to 50 Hz and an I2C system through which it is possible to interface easily with an Arduino Uno board.

METHODS

The idea is to study the movement of the foot during walking, in particular to identify the distance from the ground of the toe and heel and subsequently recognize the heel-strike and toe-off phase. Following a preliminary study of the distance measurements obtained, a correlation with the orientation of the foot during walking was found. With the aim of developing a practical and wearable prototype, the system consisting of two laser sensors is positioned near the subject's malleolus. The Footswitch ©Cometa S.r.l. (Italy) sensors were used as validation device and the trigger system was used to collect the synchronized data from both instruments (Fig.1).



With the data obtained from the two methodologies (prototype and Footswitch) of some walks, an algorithm was developed in MATLAB® able to recognizing the phases. The prototype and the algorithm were validated by 10 subjects who were asked to walk 10 meter at 3 different speeds (Preferred Walking Speed-PWS, slow and fast).
Statistical analysis (mean value, standard deviation, coefficient of variation, Wilcoxon test, Spearman correlation and Bland-Altaman graph) was performed by analyzing the instants of time of the phases identified by these two methodologies.

Figure 1. Prototype: Two VL53L0X Time-of-Flight (ToF) laser, Footswitch ©Cometa S.r.l. (Italy) and Arduino Uno board.

RESULTS

From the analysis of duration of the step cycle, data showed that if the duration of the gait cycle identified by the phases recognized by the Footswitch increases, the same happens also for the one based on the recognition by the algorithm. By comparing the time instants of the phases identified by the Footswitch and those detected by the algorithm, it is possible to observe that most seems to coincide; in some tests, there are discrepancies relating to single steps or to some steps in succession, probably caused by the movement of the prototype or by different movements performed by the subject that did not allow the algorithm to accurately recognize the step phase.
In PWS, the average of errors and standard deviations of all recognized heel-strike phase is:-0,014 s ±0,066 s and for toe-off phase is 0,013 s ±0,093 s.

DISCUSSION

The results confirm that the prototype has some limitations to be solved but it could be considered promising in the field of wearable and innovative device for gait analysis.

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Base of support estimation during gait using wearable sensors: validation on healthy subjects

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INTRODUCTION

The knowledge of the base of support (BoS) during gait is informative for dynamic stability and risk of falling [1], but it requires both feet relative orientation and distance to be described. While BoS determination is straightforward when stereophotogrammetric (SP) systems or instrumented mats are used [1], its estimation in free-living conditions is still a challenge. Only few studies have proposed wearable solutions for BoS estimation based on ultrasound or infrared technologies, requiring both feet to be instrumented [2,3].

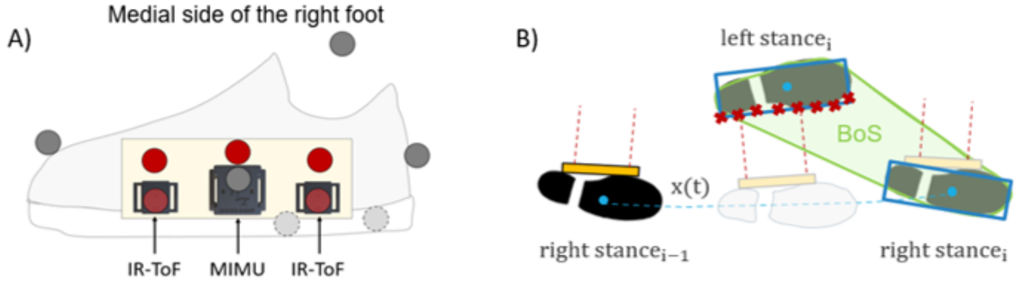
In this study, we proposed an alternative solution which integrates a magneto-inertial measurement unit (MIMU) with two infrared time-of-flight (IR-ToF) distance sensors [4]. This configuration allows to estimate BoS by instrumenting one foot only thus minimizing encumbrance and subject's discomfort. Results were compared with respect to the concurrent SP data, used as gold standard.

METHODS

The wearable system includes one MIMU (fs=100 Hz) and two IR-ToF sensors (fs=50 Hz), positioned as described in Figure 1A. The algorithm for the BoS estimation consists of the following steps: *i)* estimation of the instrumented foot orientation using an optimized complementary filter; *ii)* estimation of the instrumented foot centroid trajectory using a drift reduction technique; *iii*) identification of the position of the non-instrumented foot by fitting a planar model to the cloud of 3D points detected by the IR-ToF sensors; *iv*) determination of the BoS area (see Figure 1B).

Data were collected on seven healthy subjects walking at a self-selected speed along a 5m-straight path for 10 times. The method performance was assessed in terms of overlap percentage between BoS areas as estimated by the SP and by the wearable systems and errors in the identification of both right and left foot centroid position.

Figure 1. A) Experimental setup: the dots are the SP markers. The red markers were used only for calibration purposes, while the light grey ones were attached on the opposite shoe side. B) BoS area (in green): sum of the footprints (in blue) and the area between them. The red crosses represent the points of the left foot medial side detected by the IR-ToF sensors. The light blue dots are the feet centroids.



RESULTS

A total of 228 BoS areas were analyzed. Overlap percentage was 90.4 ± 7.6% (mean ± standard deviation). Errors in the foot centroid position estimates were 51 ± 35 mm and 45 ± 31 mm for the right and left foot, respectively.

DISCUSSION

The combined use of inertial and IR-ToF distance sensors appears to be a viable solution for dynamic estimation of BoS both in terms of total area and position estimation. The key feature of the proposed method is that it requires to instrument one foot only, however effectiveness of the fitting procedure may vary on pathological gaits and further validation is required.

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Benchmarking of Novel Wearable Smart Socks with Optoelectronic Gait Analysis System in Assessing Walking Cadence

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INTRODUCTION

Remote monitoring of patients' motor performance during daily-life activities has received increasing interest in recent times. To this end, in this paper we present a wearable sock in e-textile technology, named SWEET Sock, able to detect angular velocities of the lower limbs, using Inertial Measurement Units (IMUs), and plantar pressures, by means of textile sensors [1]. This novel device allows to assess gait tasks with the advantage of being non-invasive and adoptable in any environment, having a simple experimental setting and not requiring the presence of healthcare professionals. The system is intended to provide the assessment of spatio-temporal gait parameters by processing the angular velocities signals. In this analysis we focus on the analysis of device performances in detecting walking cadence.

METHODS

Thirty-six records were acquired on three healthy subjects (one female, ages 27,26 and 25). Each subject wore the sensorized socks and was equipped with the markers of the stereophotogrammetric system (SMART-DX 700 by BTS Bioengineering), in order to perform simultaneous recording of the walking tasks with the two systems. Trials were performed at fixed normal, slow and high speed, forced with the use of a metronome. Metronome rate was set at 100%, 67%, and 133% of subject's average cadence. Subjects performed four walking trials at each speed. Starting from gyroscope signals measured by SWEET Sock, gait cadence was computed using a threshold algorithm [2] developed in MATLAB. The percentage errors between measured cadence values and reference values fixed by the metronome were assessed. Moreover, parametric one-way ANOVA, with gait velocity as a blocking factor, was performed to investigate whether a significative difference occurs between cadence measures provided by the smart socks and the reference gait analysis system. The parametric form of ANOVA test was selected after checking the assumptions of normal distribution of residuals and homoscedasticity of the datasets. Statistical analysis was performed using JMP software (SAS).

RESULTS

In the left part of Table 1 the comparison between the cadence assessed by the smart socks and the nominal value set by the metronome in terms of percentage error is reported. The statistics of the computed errors are provided for each of the gait velocities used in the test. In the right part of the Table, the statistical results of one-way ANOVA test are shown. The p-value is only reported for the analysis on the different systems (SWEET vs BTS), as it is the only factor analyzed.

Table 1. Results of statistical analyses.

Percent Error (%) – SWEET vs. Metronome			**SWEET vs. BTS**				
Velocity	**Mean**	**Std.Dev**	**Factor**	**DF**	**Sum Sq.**	**F**	**p value**
Slow	0.784	0.614	System	1	2.82	0.302	0.585
Normal	2.01	0.942	Velocity (Block)	2	5.85e4		
Fast	2.45	1.90	Error	68	6.35e2		
Overall	1.75	1.43	Total	71	5.91e4		

DISCUSSION

Results underline that the novel wearable system is able to detect gait cadence with an acceptable level of precision. The percent error of the provided measures, with respect to the fixed frequency of the metronome, is small and it increases at faster gait velocities. Since experimental walking cadence might be different from the imposed ones, we compared these measures with those obtained by the reference gait analysis system. Results of one-way ANOVA suggest that the null hypothesis should not be rejected, so that no significant difference exists between the two systems in measuring walking cadence.

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Qualitative and quantitative differences in plantar pressure distribution during quiet stance and gait in healthy individuals.

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INTRODUCTION

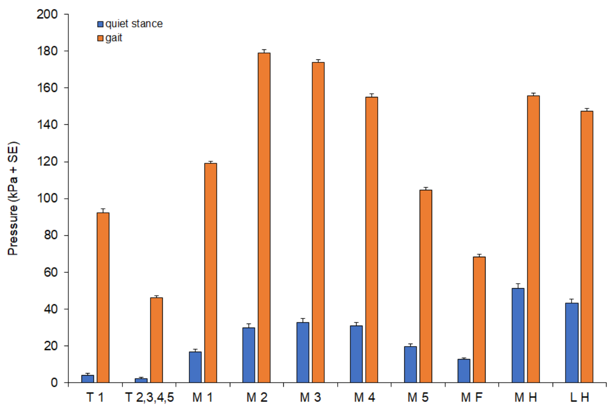
Foot plantar pressure during standing and walking can be recorded with a baropodometric walkway [1] in order to assess pressure distribution [2]. It is known that this is unevenly distributed under the footsole with higher pressure at the metatarsal bones and heel [3]. However, foot pressure distribution under quiet stance and during gait has never been compared in the same group of healthy subjects. Therefore, we tested if foot pressure distribution is similar during quiet stance and gait, and if any difference regards only absolute values being likely higher during gait. Furthermore, we investigated possible relationship between foot pressure values and body mass index (BMI), body sway during quiet stance, gait speed.

METHODS

We enrolled 36 healthy subjects (20 women) mean age of 30.4 ± 9.4 years. Plantar pressure was recorded with a baropodometric walkway (P-walk, BTS, Italy). Each subjects performed two trials for each condition (quiet stance and gait). Under quiet stance, path and surface of centre of pressure (CoP) were recorded with eyes open. During gait, subjects were required to walk at their usual speed. Foot plantar pressure was recorded from 10 areas of the footsole (Fig. 1): T1, big toe; T 2,3,4,5, 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. 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, mean surface of the CoP ellipse was 53.5 ± 88.9 mm^2, mean CoP path 78.9 ± 69.1 mm. The highest pressure occurred at MH, significantly higher than at LH (rmANOVA, $p<0.05$) and at all the remaining areas ($p<0.0001$). During gait, mean speed was 1.17 ± 0.18 m/s. Plantar pressure distribution was similar to that during quiet stance except for absolute values that were higher (rmANOVA, $p<0.0001$) during gait in all areas (Fig. 1b). The highest pressures were found in M2 and M3 areas, significantly higher ($p<0.0001$) than in the other ones. A significant correlation was found between corresponding areas of foot pressure during gait and quiet stance. No relationship was found between foot pressure values in any area and BMI, surface or path of CoP during quiet stance, and gait speed.



DISCUSSION

Results show that the pattern of distribution of foot pressure during quiet stance and gait is similar in healthy subjects. As expected, pressures in all foot areas are significantly higher during gait. This is in accordance with the larger dynamic components of gait. In addition, during gait plantar pressures were recorded in single stance support whilst under quiet stance in double support, thus halving the forces acting on the ground. During quiet stance, subjects loaded more on heels, while during gait pressures were higher in the metatarsal areas, a finding presumably connected with the forward propulsion of the centre of mass during gait. Finally, the results suggest that in healthy subjects it is possible to estimate pressure distribution during gait from their distribution during quiet stance.

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Finite element assessment of pressure reducing insoles for diabetic patients

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INTRODUCTION

About 10% of the world population is affected by diabetes mellitus and 25% of these subjects develops an ulcer, with the rate of ulcer recurrence continuously increasing [1]. The causes of the diabetic foot ulceration process lies in ischemic, neurological and biomechanical impairments [1], in particular diabetic neuropathic subjects exhibited excessive internal stresses and strains on plantar tissues[2]. Clinicians usually prescribe customized plantar foot insoles to treat or prevent foot ulceration with the aim to spread excessive plantar pressure, provide support to the arches, and unload critical areas. To date the design and production of insoles is often pursued through manual techniques, where the experience in designing and producing foot insoles plays a relevant role, resulting in no standardization in the design decision process. In this context it has been demonstrated that the use of virtual simulations with numerical modeling techniques offers a potential approach to quantitatively estimate the benefit of plantar foot orthotics in term of soft tissue deformation, plantar pressures and internal stresses according to the insole shape and material and it can also offer the possibility to further optimize the insole [3]. The aim of this study was to devise a simplified pipeline to apply this methodology at the orthotic manufacturers site without the constraints of a gait laboratory.

METHODS

The subjects cohort was composed by 9 diabetic neuropathic subjects (mean (SD) age 60.9 (17.4) years and BMI 29.4 (5.4) Kg/m^2). Their foot geometry was captured with a 3D scanner (Structure 3D) in static unloaded condition and their plantar pressures (PP) data were registered while walking on a treadmill (2 km/h) by means of PedarX insole system (Novel gmbh). A foot finite element model (FEM) was developed as in [2] but in this case the foot geometry was meshed from the scanned foot volume and the foot bones were scaled based on each subjects' foot morphology. Each subject's insole geometry was scanned and meshed with tetrahedral elements and material properties were assigned according to the characteristics declared by the insole manufacturer. For simulation purposes, both ground reaction forces and ankle flexion-extension angles during gait were adopted as boundary conditions. Four critical instants of the stance phase of gait were simulated as in [3] in 2 conditions: with and without the plantar foot orthotics. The comparison between the experimental PP and the simulated ones (peak and distribution) was used for validation purposes. Root Mean Square Distance was computed to compare simulated PP and internal Von Mises stresses in plantar soft tissues across the different conditions.

RESULTS

The comparison between the experimental and the simulated PP resulted in a good agreement. The redistribution of high PP was not reached with the simulated insole, however the Von Mises stresses in the internal soft tissues were reduced at the plantar aspect of the foot (see figure 1).

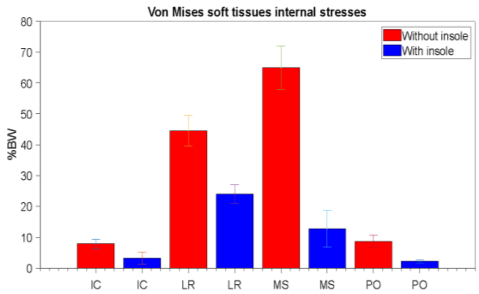

Figure 1. Von Mises stresses at the plantar soft tissues. Results of the simulations without the insoles (red) and with the insoles (blu).

DISCUSSION

The proposed experimental protocol was applicable at the orthotic manufacturers and allowed to simulate the effect of the produced insole on the foot internal stresses prior to subject's use. This approach could be used to optimize the design of plantar foot orthotics in diabetic subjects. Future development will include the coupling between the shoe and the orthosis in order to obtain more complete results.

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A Novel Framework for Motion A.I. Consumer Products by means of Wearable Devices

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INTRODUCTION

Sensing technology such as inertial and magnetic sensors are nowadays commonly available as integrated components in common portable devices (smartphones and smartwatches). Despite of the continuous cost reduction for this technology and the many applications (navigation, display interaction, gaming, trackers), their potential has not been unleashed for applications involving measurement of human joints kinematics, monitoring of exercises during rehabilitation, optimization of exoskeletons based on real-time measurement. Several attempts have shown great progress in the creation of methodologies in several fields (rehabilitation, ergonomics) [1,2,3] but lacking real specs and solutions to the common technologies' limitations (e.g., magnetic disturbances). The purpose of this study is to present an innovative framework for the creation of products for consumer markets based on wearable sensing technologies.

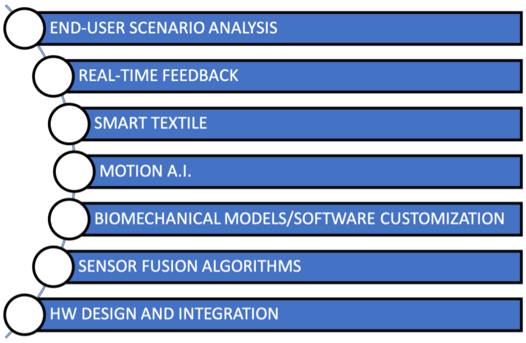

Fig.1 Major components of the framework for the design and implementation of products based on wearable sensing

METHODS

The framework takes in consideration both the technical challenges at the base of the usage of wearable sensing technology and the demanding and ambiguous specs from end-user scenarios (fig.1). The motion capture has been made easy to be performed by non-technicians without any aid. Several algorithms take into account the various variability sources to optimize the overall 3D human body representation to be acceptable for a vast majority of non-technical users.

RESULTS

Limitations in the application of magnetic sensing technology in disturbed environment has been overcome by the introduction of "magnetometer-free" techniques [4]; cumbersome and tricky positioning of sensors on the body have been solved by integrating sensors directly into shirt and pants [5]; generic motion capture software limited to research labs have been converted into software platforms for quick and customized development [6]; movement visualization evolved from "lab-oriented" stick figures to real-time 3D avatars for visual feedback [7]; user-machine interaction has been enhanced by means of scalable and interactive content creation using Motion A.I. [4].

DISCUSSION

The present study shows a framework that has been successfully applied to consumer products (www.pivot.yoga) allowing people to track their movements and verify the correct poses at home. It is continuously under evolution and customization to enable new applications. The framework is also suitable for entering among the methods that can be used for Big Data in Human Motion Tracking.

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Smart motion capture based on deep learning: a proof-of-concept

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INTRODUCTION

To overcome the intrinsic limitations of marker-based gait analysis, the markerless motion techniques are becoming valid alternatives. A methodology based on deep neural networks is proposed and the capability of convolutional layers to capture spatial correlations at different scales in images is exploited. The system is applied also to data acquired in a challenging environment, the underwater, to move a step towards the estimation of natural poses on field. By considering the application in a clinical domain the pose in terms of joints' angles is compared with standard gait analysis.

METHODS

The dataset was acquired with a set of 6 synchronized color analog wide-angle cameras (720×576 pixel resolution TS-6021PSC). The synchronization was obtained employing a custom-made software application as in [1] with a synchronization delay inferior to a frame duration (20 ms). Three subjects (mean age 27.3 ± 5.5 years, mean BMI 21.3 ± 2.6 kg/m2) were acquired both in a laboratory (out-of-water, OW) and underwater (UW) in a swimming pool (total: 42 trials). Intrinsic parameters calibration was performed with the aid of a black and white checkerboard in OW and proper corrections applied when used in the UW [1]. The extrinsic calibration was performed with the aid of a 12-control points calibration grid (2 m×1.1 m×1.1 m) [1]. The system is flexible to future updates because of its highly modularity. Moreover, the described system can be applied to the data both offline and simulating a real-time acquisition. First, the video frames are extracted and undistorted; then a person detector [2] identifies the subject's presence in the set of 6 synchronized frames and, if found, the region of interest in the image is processed by a pose estimator [3] that provides the probability maps for each joint in the 6 regions of interest, separately. After, the information from the cameras are triangulated to reconstruct the 3D pose. To fulfill the clinically oriented requirements, a subject-specific model is utilized to match the lengths of the subject's limbs in the obtained pose model. Finally, the planar angles between anatomical segments are estimated for each gait cycle for the knee joints and low-pass filtered. A subset of the same gait trials were processed by video tracking the markers on the subjects skin (Track on Filed, BBSOF S.r.l.) according to CAST [4] ffor validation purposes: both coefficient of multiple correlation (CMC) and root mean squared distance (RMSD) were computed between the two dataset.

RESULTS

Results in both UW and OW are reported in Figure 1.

CMC (UW): 0.9424; (OW): 0.8600

RMSD (UW): 5.0517° ± 6.3586°, max 20.4421° [78% GC], min. 0.0037° [28% GC];

(OW): 9.1219° ± 5.5731°, max 17.4510° [84% GC], min 0.1861° [18% GC]

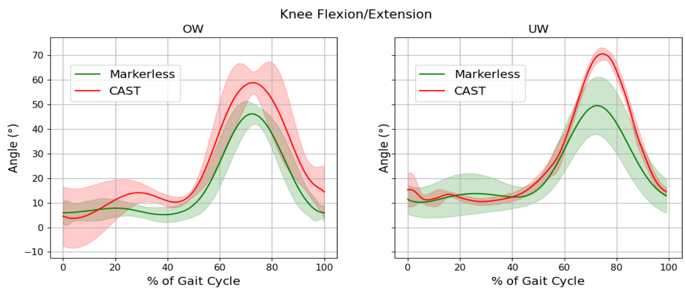

Figure 1: Knee flexion-extension angles (mean ± SD) during gait in OW and UW environments.

DISCUSSION

Results show the possibility to track the gait of the subjects in both environments similarly to state of the art gait analysis protocols. Future research will address the development of a low computational complexity system and a real-time markerless labeling even in challenging environments. Further improvements are expected with a model trained on a dataset annotated following a clinical protocol.

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EDAM: A Diagnosis Recommender System based on Explainable Artificial Intelligence and the Combination of Motion Analysis and Others Clinical Biomarkers

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INTRODUCTION

Studying the process of walking and gait dynamics may help to produce an automatic, non-invasive method to obtain information on general health [3], cognitive decline [5], and longevity [4]. Several approaches based on Machine Learning (ML) techniques have been proposed in the literature for monitoring and predicting specific diseases by analyzing gait and posture data acquired with motion analysis systems (see e.g., [2]). Such approaches generally perform univariate analyses, whereby the results of posture and gait measurements are considered independently of other clinical biomarkers. This simplifies the approach but may increase the risk of missing important information that can be derived from clinical biomarkers [1]. Furthermore, the prediction made by such systems is often seen by the specialist as "black magic", as it is difficult to understand the "reasoning" that led the ML system to make a certain prediction.

METHODS

The objective of this project is to overcome the above limitations by defining an approach able to make explainable prediction of specific diseases by combining data from the analysis of posture and gait of an individual with other clinical biomarkers. The proposed approach is based on advanced ML techniques, such as decision trees and artificial neural networks, data visualization and natural language processing techniques for making the prediction explainable.

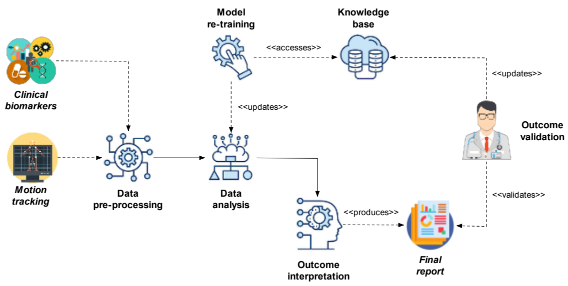

Figure 1. EDAM workflow.

RESULTS

Figure 1 depicts the workflow of the proposed approach, namely EDAM (Explainable DiAgnosis recoMmender). The acquired data are provided to a module of data preprocessing. Besides canonical data preprocessing, this module makes EDAM *device agnostic*. Especially, templates have been defined to describe the format of the data required to EDAM. Based on such templates, specific drivers can be implemented and integrated into the module "Data pre-processing" to make the acquired data complaint with EDAM. Once pre-processed, the data are provided to a data analysis module. Such a module, based on a pre-trained ML model, analyzes the data to identify specific diseases. The outcome is then provided to the module "Outcome interpretation". This module makes the prediction *explainable*. Especially, it generates a description, in natural language, of the conditions that led to the prediction of the specific diseases, providing the specialist with a draft report (pre-report) that facilitates the quantitative analysis of the prediction obtained. As highlighted in Figure 1, the proposed approach is also based on the concept of *continuous learning*. The outcome of EDAM is validated by a specialist. Such a validation enriches the knowledge base of EDAM, providing new validated data points. Once enough new data points are provided, the machine learning model is re-trained aiming at enriching its accuracy.

DISCUSSION

EDAM is a unique system particularly suitable in the fundamental process of early diagnosis of specific diseases. Using EDAM, the specialist can make data-informed decisions, i.e., not only based on the quantitative analysis of data as happens in data-driven decisions, but also on the qualitative assessment of the analyses performed, on intuition, judgment, and experience.

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Simulation of knee clinical-functional tests through a musculoskeletal model: quantification of knee joint stiffness and ligaments tension

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* *presenting author*

INTRODUCTION

Knee clinical-functional tests are typically performed to assess the joint stability during passive movements and therefore the health condition of the ligaments. However, these tests provide purely qualitative information, closely linked to the operator experience, no information about the ligaments tension during the maneuvers, nor joint stiffness and laxity magnitudes are provided. A deeper knowledge of each ligament role in stabilizing the knee joint during passive movements could provide important guidelines for more effective rehabilitative and surgical treatments. In this study a musculoskeletal model of an intact knee joint, equipped with 6 degrees of freedom, is used to simulate functional tests and to quantify ligaments tension, characteristic response curves, stiffness and laxity.

METHODS

The knee joint model included bones, muscles and a detailed ligaments structure, represented by 13 non-linear springs attached to the bones at specific points and with specific elastic characteristics. For the sake of brevity, interested readers are referred to [1] for a detailed description of model implementation and validation. The whole ligaments structure included anterior (ACL) and posterior (PCL) cruciate ligaments, lateral (LCL) and medial (subdivided in superficial, MCL, and deep bundles, MCL-d) collateral ligaments and fibrous capsule, subdivided in anterolateral (Cap-Ant-L) and posterior portions. The knee model was subjected to anterior-posterior drawer, varus-valgus and internal-external rotation tests. Each test was performed under passive conditions on five different flexion angles: 0°, 20°, 60°, 90°, 135°. Keeping the femur fixed, a linearly increasing force was applied to the proximal tibia to simulate the drawer test, while varus-valgus and internal-external rotation stresses were simulated through linearly increasing torques. For each test, the tension developed by the ligaments was quantified and force-displacement or torque-rotation curves were recorded thanks to the “G&S mechanism”, a kinematic measuring device included in the model. Mid-range and terminal stiffness, as well as laxity of the joint, were quantified at the different configurations by reproducing the experimental tests described in [2].

RESULTS

Stiffness and laxity parameters were relatively in good agreement with the experimental results reported in literature [2], as well as the ligaments recruitment for the different tests and flexion angles. In general, the ligaments tension was in the range 0-450 N. As expected, PCL was the primary stabilizer to posterior drawer, showing an increasing slope in linear tension response as knee flexion angle increases. Contribution of ACL to anterior drawer stability gradually reduces for angles greater than 20°, in which MCL, LCL and Cap-Ant-L effectively cooperated for stabilizing the joint. LCL showed a peculiar behavior: at 0° and 20° of flexion angle, it contributed to stabilize the joint in response to posterior drawer, while for wider angles it gradually assumed a consistent role as anterior drawer stabilizer. Predictably, MCL and MCL-d were the primary stabilizers to valgus stress, while LCL to varus stress. As regards the external rotation test, PCL was the primary stabilizer for all the flexion configurations, eventually supported by LCL, while in complete extension collateral ligaments stabilized the joint. Internal rotation test stressed PCL only when the knee was completely extended, while the flexion configurations required the contribution of Cap-Ant-L, supported by ACL at 20°, MCL and MCL-d at 60°, LCL at 90° and 135°.

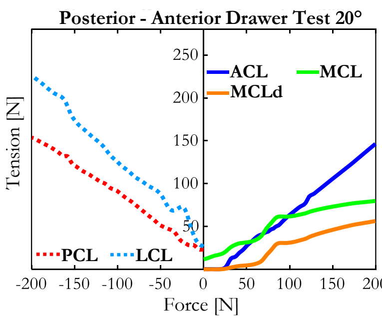

Figure 1. Ligaments tension during posterior (left side) and anterior (right side) drawer test at 20° of flexion angle.

DISCUSSION

This study demonstrates that a musculoskeletal model is an effective tool for quantifying ligaments tension, stiffness and laxity parameters. Our results can help understanding the role of the knee joint ligaments during typical clinical maneuvers.

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Quantitative Outcome Assessment of Ankle Foot Orthosis Using Biomechanical Modelling and Simulation of Gait: a Case Study.

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INTRODUCTION

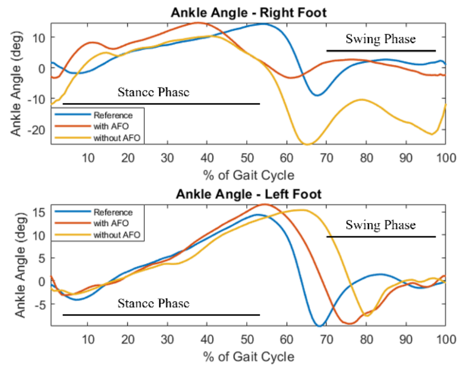
Ankle-Foot Orthosis (AFO) is a brace that is worn on the lower leg and foot to support and hold the foot and ankle in the correct position during movement. AFOs are used to control the movement of drop foot, which is the inability to lift the front part of the foot. Gait analysis is a powerful tool to study the level of the impairment and quantify the improvements brought about using an AFO. A specific characterization of gait can be obtained using biomechanical modelling and simulation. In this study we use the OpenSim software to model the walking biomechanics of a patient to further explore his gait features and evaluate the AFO performances during walking.

METHODS

The study was conducted on a male subject (age 47, weight 58 kg, height 165 cm, BMI 21.3) with unilateral (right) foot drop caused by a brain tumor. The 3D multicamera system SMART DX-700 by BTS Bioengineering (Milan, Italy), was used to collect motion data regarding patient's walking over a 11 meters walkway, in two conditions: wearing and not wearing the AFO. Data relating the motion of 22 markers, positioned on patient's body following the Davis protocol, were imported in OpenSim, where the 'Gait2392' model was used, which is characterized by 23 degrees of freedom and 92 muscle-tendon actuators. The model was first scaled to match subject's anthropometric measures and then an inverse kinematic evaluation was executed on the scaled model to reproduce the walking and evaluate body joints angles. Joints angles signals were then exported and analyzed using MATLAB (2019a).

RESULTS

Figure 1a shows the evolution over the gait cycle of the ankle angle. Positive values represent dorsiflexion, while negative values are related to plantar flexion movement. Ankle angles signals with and without AFO are obtained as the average of successive steps performed by the subject during the analysis. Reference signals have been obtained by sample data in OpenSim repository. Figure 1b reports the main quantitative features extracted from the signals.



a.

Right Foot

	Reference	With AFO	Without AFO
Mean (deg)	4.226	4.426	-4.701
Range (deg)	23.37	17.99	35.39
RMS (deg)	7.169	7.041	12.52
Power (deg2)	51.39	49.57	156.6

Left Foot

	Reference	With AFO	Without AFO
Mean (deg)	2.672	3.129	4.215
Range (deg)	24.15	25.90	22.95
RMS (deg)	6.754	7.957	7.787
Power (deg2)	45.62	63.32	60.64

b.

Figure 1 - a. Comparative graph between reference/with AFO/without AFO ankle angles; b. Quantitative features extracted from signals.

DISCUSSION

Results show that the left ankle angle follows a physiological evolution during gait cycle, with a slight alteration for the mutual duration of swing and stance phase, probably performed to balance the impairment of the opposite foot. The right ankle angle signal without AFO clearly shows the prevailing plantar flexion of the foot during the swing phase. The use of the AFO supports the foot drop patient in achieving a physiological gait: the main signal quantitative metrics get closer to reference values and the range of motion is reduced due to the restriction given by the AFO. The use of biomechanical modelling and simulation of gait allows the quantitative evaluation of the effective support provided by the AFO in walking biomechanics and can extend the idea of gait analysis. This working pattern can be used in a wide area of study and for different pathologies. Future perspective in the biomechanical simulation of the AFO will focus on the customization of the orthosis by importing the different AFO models in the OpenSim software and analyze its interaction and effects on walking biomechanics.

IN VIVO BIOMECHANICS ASSESSMENT OF A CR TOTAL KNEE PROSTHESIS DURING SIT TO STAND: COUPLING DYNAMIC RSA AND FE ANALYSIS

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INTRODUCTION

Total knee arthroplasty (TKA) is the gold standard treatment for patients with primary osteoporosis, as it can relief pain and restore joint function. Generally, the prosthesis implant has a survival rate of 82% at 25 years [1] and it provides a patient satisfaction 81% [2]. However, there is stillroom for improvement as far as prosthesis behavior are concerned.

Roentgen Stereophotogrammetric Analysis (RSA) is the most accurate technique assessing the in-vivo joint kinematics.

In this study, an innovative technique, combining RSA dynamic and patient-specific finite element models, was applied to analyze a group of 15 patients who underwent total knee arthroplasty with a cemented PCL highly congruent MB TKA during the execution of a sit to stand from chair.

The aim of our study was to evaluate the position and translation of the femoral polyethylene insert contact points.

METHODS

A cohort of 15 patients, underwent cemented CR highly congruent MB TKA (Gemini, Waldemar LINK GmbH & Co. KG, Barkhausenweg 10, 22339 Hamburg, Germany) with patella resurfacing for primary OA, was evaluated after a minimum nine-month follow-up using Model-based dynamic RSA in weight-bearing conditions and during the execution of a sit to stand from chair. The in vivo kinematic data obtained from RSA Dynamic was used as an input for a patient specific finite element models of the implants to calculate condylar contact points between the femoral component and polyethylene insert. The contact points were determined by the FE software as the centroid of the pressure distribution between the femoral condyles and the polyethylene insert.

RESULTS

As shown in figure 1, greater displacements were founded in lateral contact area for AP movement compared with medial area, with peak values of -7.14 mm (LC) and of -3.52 mm (MC). For ML movements, a perfect symmetry was founded comparing LC and MC trends.

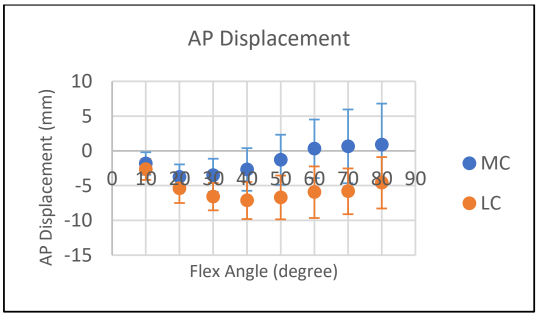

Figure 1: Graph show AP movement of the medial (MC) and lateral (LC) contact points using the FE technique during sit to stand from chair.

DISCUSSION

This study evaluated the knee kinematics in terms of articular surface contacts. The wider AP displacement of the LC could be interpretated with a slight medial pivot pattern. Concerning the ML movements, results showed a parallel displacement of both condyles with the same wide magnitude, which is in line with the role of the symmetric deep dishes insert.

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Comparison of three different approaches for calculating the CoM acceleration directly on field

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INTRODUCTION

Field Hockey is an Olympic sport, played by men and women both at recreational and professional levels. Field Hockey is very popular worldwide as demonstrated by the large numbers of nations that are members of the International Hockey Federation (IHF) [1]. The aim of this study is to find a strategy to calculate the acceleration of the center of mass (CoM) of the hockey player while performing a sport-specific task (sprint with the hockey stick) directly on the field. By considering that the instrumentation used for acquiring data on field is different from the instrumentation available in a motion analysis laboratory three different approaches for assessing the CoM acceleration were adopted: 1. Consider the instantaneous acceleration of the anatomical point L5; 2. Consider the instantaneous acceleration of the CoM calculated through the anthropometric formula of De Leva [2]; 3. Consider the Winter's formula using plantar pressure data [3].

METHODS

Nine female athletes of the CUS Padova Hockey team signed the informed consent and took part in the study (mean (SD); age: 21.56 (4.67) years; BMI: 22.01 (0.99) kg/m^2). The athletes were acquired directly on the hockey field while performing a 10m sprint task holding the hockey stick, by means of four GoPro Hero 3 cameras (placed at the four corners of the running lane) and a Novel Pedar plantar system, placed in the shoes of every subject. For performing the video tracking TrackOnField software (BBSoF S.r.l) was used, while for calculating the acceleration with the three different approaches Matlab codes were developed. The following pipeline was adopted: 1. The trajectory of the anatomical point L5 was extracted from the video sequences and its instantaneous acceleration calculated 2; the anthropometric measures of every athlete were retrieved from anatomical landmarks, and De Leva's anthropometric formula [2] was applied to calculate the instantaneous acceleration of the CoM; 3. The center of pressure (CoP) was extracted from the plantar pressure system and the Winter's formula [3] was applied for calculating the CoM acceleration as follows:

$$CoP - CoM = k * C\ddot{o}M \quad (1)$$

Where k is the ratio between the inertial moment of the human body and the product of the body force subject and the height of the CoM:

$$k = \frac{I}{W * h} \quad (2)$$

RESULTS

The results demonstrated a good agreement between the first two methods: the anthropometric approach and the trajectory of the anatomical point L5; meanwhile, CoM acceleration calculated using the Winter's formula was lower compared to the other two methodologies (Fig. 1)

DISCUSSION

This study showed that in dynamic condition (running task), CoM acceleration could be estimated using different approaches however not all the methodologies bring to similar results. For validation purposes this approach should be further applied in static condition in a gait laboratory using the stereophotogrammetric system and the force plate as gold standard.

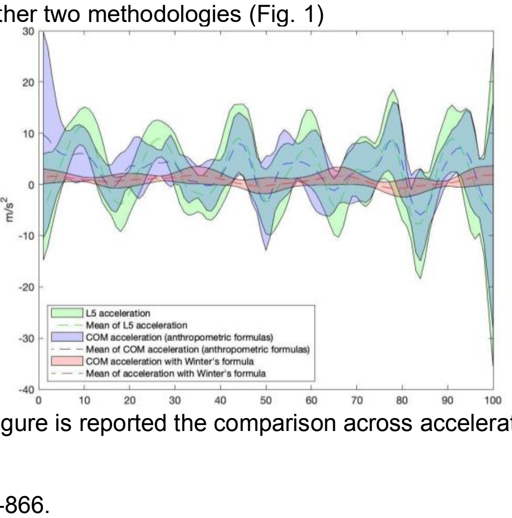

Figure 1: In the figure is reported the comparison across acceleration

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Wavelet-based detection of muscular activity in EMG signals affected by low SNR

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INTRODUCTION

Timing of muscular activity is one of most useful clinical information which could be extracted from surface EMG signal (sEMG). However, a reference method for doing this is not available yet. Moreover, most of methods proposed in literature present performances affected by low values of signal-to-noise ratio (SNR) [1]. Aim of the study is to investigate the reliability of a novel wavelet-based approach in detecting onset and offset timing of muscle activation in sEMG signals characterized by low SNR.

METHODS

A dataset of 125 simulated sEMG signals characterized by SNR = 3 dB and stratified for time support is created. To generate each sEMG signal, uncorrelated noise is superimposed to a band-limited stochastic process with zero-mean Gaussian distribution of amplitude, following the procedure described [1]. Each simulated sEMG signal is generated with a sampling frequency = 2000 Hz and a time window of 1 s. The Gaussian distribution is truncated to simulate the sEMG activity due to muscle activation. The timing of muscle activation (onset and offset) is detected in this 125-signal dataset by means of Continuous Wavelet Transform (CWT), a time-scale analysis method for multiresolution decomposition of continuous time signals. CWT coefficients allow to reconstruct the scalogram function, providing an estimate of the local time-frequency energy density of a signal [2]. Then, onset and offset events are identified as the interval where the scalogram is exceeding the 1% of the peak value of energy density in each simulated sEMG signal. The ground truth of muscle activity is the vector composed of same number of samples of the simulated sEMG signal, where samples can assume only two values: "0" and "1". The ground truth is "1" in correspondence of the samples where the truncated Gaussian distribution assumes values > 0, and it is "0" otherwise. Validation is performed against the well-known double thresholding algorithm (DT) [1].

RESULTS

Performances of onset and offset prediction provided by CWT (blue) and DT (red) approaches are reported in Figure 1, in terms of F1-score and mean (± standard error, SE) absolute error (MAE) over all true positives. An increment of 6.3 percentage points in offset F1-score is achieved by CWT approach compared to DT algorithm. A concomitant reduction of MAE value is detected in CWT prediction for both onset (14%, $p > 0.05$) and offset (47%, $p < 0.05$).

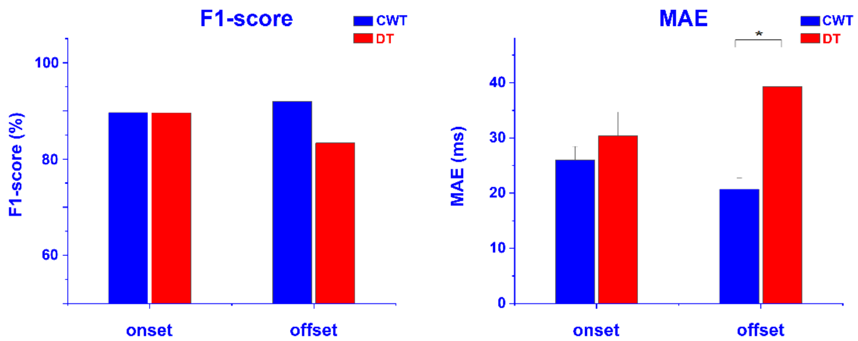

Figure 1. Average F1-score and MAE (±SE) provided in onset and offset prediction by the present CWT approach (blue bars) vs. DT algorithm (red bars). * indicates statistically significant difference ($p < 0.05$).

DISCUSSION

Results suggest that the wavelet-based approach introduced in the present study is able to provide a reliable prediction of muscle onset and offset events in a large dataset of noisy simulated sEMG signals, (SNR = 3 dB). When directly compared with the reference DT algorithm, it seems to introduce a relevant improvement mainly in the performances associated to the prediction of offset timing.

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Forearm muscle excitation analysis for different professional piano players: preliminary results.

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INTRODUCTION

From 60% to 87% of professional musicians will, at some point of their career, develop a playing-related musculoskeletal disorder (PRMD) [1, 2]. Injuries most often take place at the forearm and could be prevented by using the right playing strategies, minimizing excessive muscle loading. Intervention strategies based on the use of EMG biofeedback have been proposed with such aim, even though no account has addressed the question: is there a specific forearm region where muscles are most likely to be excited when professional pianists perform different, classic excerpts? In this study we will address this question for a sample of professional musicians, to be tested in the following weeks. At the moment, only preliminary results from a single subject are reported.

METHODS

Monopolar EMGs were collected from a single, professional pianist with three high-density grids of 32 electrodes each (2 rows x 16 columns; LISiN-Politecnico di Torino). In parallel, upper body kinematics were assessed with 12, infrared camera system (Vicon, UK). The subject was asked to perform 14 tasks divided into two groups. First group comprises octaves with four different conditions (forearm octaves, wrist octaves, finger octaves and broken octaves) and two different speeds (self-paced speed and as fast as possible). The second group includes three classical musical excerpts and 5 min of improvisation. The RMS amplitude of each monopolar EMG in the grid was first computed, over periods corresponding to up and down movements of the right-hand marker for octaves and over the whole performance for classical music trails. Regions of muscle excitation were inferred from the automatic segmentation of RMS images [3]. After collecting EMGs from a sample of subjects, the distribution of frequencies with which each electrode in the grid was positioned over a skin region providing highest EMG amplitude values will be considered to address the question posed here.

RESULTS

Preliminary results have been obtained after the pilot test with one subject. For the octaves, centroids of the RMS images were found around the extension and flexion regions of the forearm when the hand moved up and down respectively. For the classical music tasks, activity was mostly centered at rows 2 and 3, starting from the lateral epicondyle, and varying along the columns through time (Fig. 1).

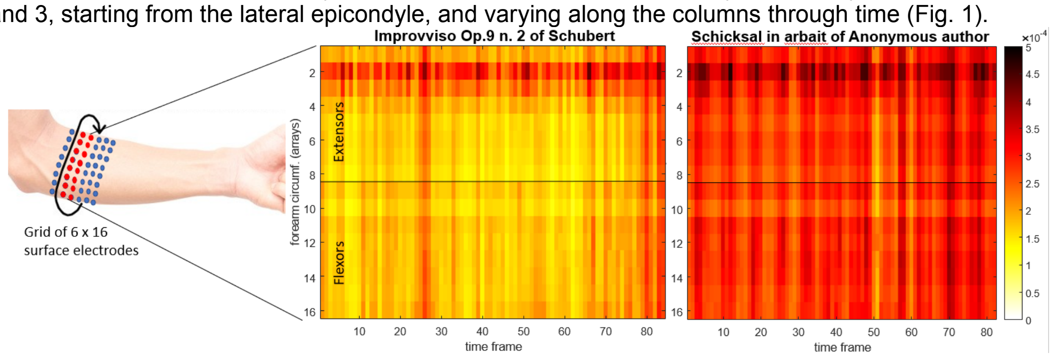

Figure 1: *RMS amplitude distribution in time and space for 2 classic excerpts. RMS values were averaged across rows 2 and 3 (red circles). Dark pixels indicate high muscle excitation*

DISCUSSION

There seems to be, at least for the pilot test subject, specific regions on the forearm where excitation occurs, which vary accordingly to the piano playing movements associated. The upcoming results might prove if these regions are similar and valid for all the subjects. It is our aim to understand whether, notwithstanding inter-individual variabilities in performance style and anthropometry, professional musicians consistently load muscles in specific forearm regions.

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Rediscovery and rethinking about a forgotten parameter: EMG/Force Ratio.

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INTRODUCTION

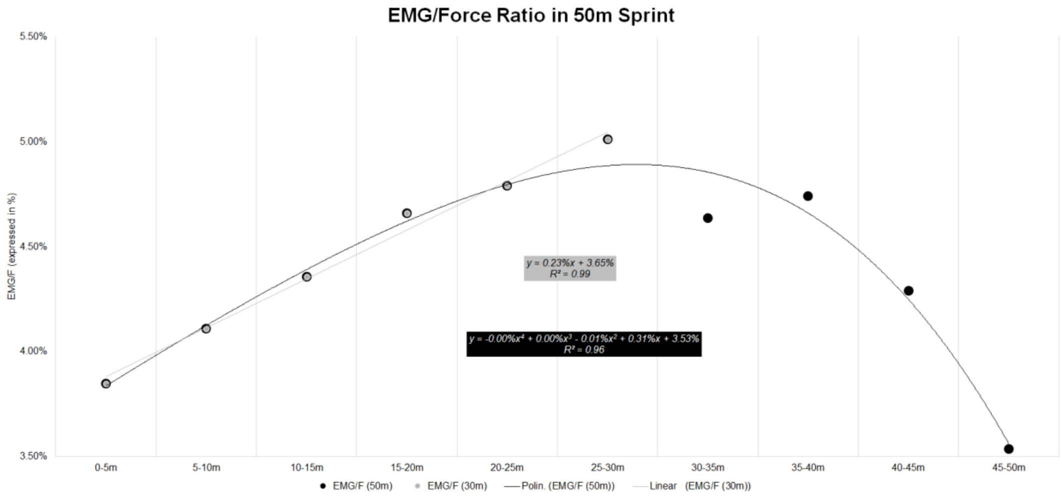
Since the last decades of the 20th century, for the study of neuromuscular activation at a determined force corresponding compared these two parameters with the EMG/Force ratio (EMG/F), to synthetically represent the actual neuromuscular commitment, both at its increase and decrease [1,2]. The aim of this study was to observe the trend of a parameter in disuse as the EMG/F during linear sprints in elite players of youth soccer, to verify its actual usefulness.

METHODS

The data were acquired in 16 elite U17 soccer players (mass 64.63kg±4.35, height 177.44cm±4.34) with GPS-IMU Spinitalia v2 and EMG Myontec M-Body 2 resampled at 100 Hz. The EMG signals of quadriceps, hamstrings and gluteus muscles were stored bilaterally to determine the EMG/F. EMG was normalized respect to the peak value in accordance with Kyröläinen H. et al. 2005 [3], instead the force was obtained from the integration of the three axes of the accelerations detected by the GPS-IMU. Players were tested on a 50-meter linear sprint; the sprint was subsequently divided into 5-meter splits during analysis.

RESULTS

During linear sprints, EMG/F results were linear up to 30 meters (r^2=0.99), changing this trend after 30 meters, fitting the overall test with a 4th degree polynomial (r^2=0.96).



DISCUSSION

During linear sprints, it appears to linearly increase EMG/F, until a ‘’breakpoint’’, where a decrease occurs. It could be important to verify the behavior of this parameter in other populations of athletes (e.g., sprinters), assuming that the decay of this parameter should be postponed as much as possible for those who must perform linear sprints; conversely, for soccer players it may not be optimal to perform over linear sprint distances where EMG/F decreases. This parameter could be rediscovered, with appropriate adjustments, to be taken into greater consideration soon.

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