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della Società Italiana di Analisi
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Proceedings
SIAMOC 2024

Stresa, 2-5 Ottobre 2024

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SIAMOC 2024

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INNOVAZIONI NELL'ANALISI DEL MOVIMENTO:

PROGRESSI NELLA PRATICA CLINICA, NELLA RIABILITAZIONE E NELLO SPORT

Il congresso annuale della Società Italiana di Analisi del Movimento in Clinica (SIAMOC), giunto quest'anno alla sua ventiquattresima edizione, approda per la prima volta a Stresa, sulle sponde del Lago Maggiore.

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

Nell'edizione congressuale di quest'anno, l'obiettivo è quello di proseguire a creare il confronto e il dialogo tra i ricercatori, così che possano arricchirsi vicendevolmente nello scambio della loro attività. Inoltre, grazie agli ospiti internazionali, si vuole continuare a conferire ulteriore respiro ed impatto internazionale ad una società in crescita, in cui spicca anche la buona adesione di giovani ricercatori.

Ad affiancare le tematiche cardine della società, quali la ricerca di base e applicata in ambito clinico, nel congresso SIAMOC 2024 vi è spazio per le nuove strumentazioni, per l'utilizzo sempre maggiore dell'intelligenza artificiale come aiuto nell'analisi del movimento e, nell'anno olimpionico, per un risalto particolare all'ambito sportivo, dove si mirano a risultati sempre più elevati grazie alla comprensione di come migliorare il proprio stesso gesto sportivo.

SIAMOC continua quindi il suo viaggio nei meandri dell'analisi del movimento, a servizio dei differenti ambiti e con le sempre sfidanti nuove prospettive future.

LETTURE MAGISTRALI

Quale aiuto può offrire l'esercizio fisico per i disturbi di cammino ed equilibrio nei soggetti con malattia di Parkinson?

Alice Nieuwboer, Professoressa emerita al Dipartimento di Scienze riabilitative di KU Leuven, Belgio

Le compromissioni della deambulazione e dell'equilibrio sono onnipresenti tra le persone con malattia di Parkinson (PD) e contribuiscono al verificarsi di freezing del cammino e cadute. I trattamenti farmacologici e chirurgici portano solo a miglioramenti modesti nella deambulazione, evidenziando la necessità di interventi riabilitativi. Sottili cambiamenti nella deambulazione, come una riduzione del pendolarismo degli arti superiori, difficoltà nel girare, riduzione della lunghezza del passo e aumento della variabilità, si manifestano nelle prime fasi e progrediscono verso caratteristiche più invalidanti. Le compromissioni della deambulazione e dell'equilibrio riducono la quantità, l'intensità e la qualità della camminata quotidiana. In questa lettura magistrale, è descritta innanzitutto la neuropatologia sottostante ai problemi di mobilità nella malattia di Parkinson e successivamente sono discussi, basandosi sulle evidenze scientifiche, interventi innovativi relativi all'esercizio, alle strategie terapeutiche e allo stile di vita, mirati alle reti compensatorie per affrontare le disfunzioni della deambulazione. Sono riassunte inoltre le evidenze sulle tecnologie accessibili per interventi volti ad agire su circuiti neurali specifici in fase iniziale e avanzata della malattia. Infine, sono riassunti i principali approcci emergenti per gestire la festinazione e il freezing della marcia.

Come si sono evoluti gli esseri umani prima per camminare e poi per correre? E perché questo è importante?

Daniel E. Lieberman, Professore titolare della cattedra Edwin M. Lerner II di Scienze Biologiche e Presidente del Dipartimento di Biologia Evoluzionistica Umana dell'Università di Harvard, USA

Gli esseri umani si sono evoluti per essere fisicamente attivi, in particolare per camminare e correre su due gambe. La presente lezione magistrale inizia delineando alcuni principi fondamentali per utilizzare prospettive evolutive nello studio di ciò che rende la locomozione umana così speciale e perché il modo in cui camminiamo e corriamo è così importante. Successivamente, sono esaminate le prove su come e perché il cambiamento climatico abbia guidato la selezione naturale umana, attraverso adattamenti a camminare bipedalmente; si cerca di riflettere sul perché proprio la deambulazione eretta abbia messo la linea evolutiva umana su un percorso separato dagli altri primati africani. Poiché gli esseri umani corrono anche, sono poi esaminate le prove su come e perché il cambiamento climatico abbia portato ad ulteriori adattamenti alla corsa di resistenza e si fanno ipotesi sul perché la corsa su lunga distanza abbia svolto un ruolo chiave nella nostra storia evolutiva. Per concludere, è utilizzata la lente dell'evoluzione per considerare il fenomeno moderno, nonchè paradosso, dell'esercizio fisico. Perché l'esercizio è salutare? E perché così poche persone lo praticano, nonostante sia noto che aiuti la salute e rallenti l'invecchiamento?

Il dilemma globale-locale in riabilitazione. L'attenzione ai dettagli riduce la considerazione della persona?

Derick Wade, Professore e consulente in Riabilitazione Neurologica presso la Oxford Brookes University, UK

La riabilitazione è incentrata sulla persona. Gli obiettivi delle persone sono correlati ad ambizioni che soddisfano i bisogni di Maslow, principalmente quelli di ordine superiore quali aspirazioni a lungo termine, inquadrate come ruoli sociali o successi. La riabilitazione è inserita nel modello olistico biopsicosociale della malattia e aiuta la persona ad adattarsi alla propria condizione, spesso richiedendo molte azioni specifiche per alleviare le menomazioni o i fattori contestuali. A volte, ciò implica una valutazione dettagliata che possa orientare al meglio i trattamenti. La sfida che devono affrontare i clinici è assicurarsi che la loro dettagliata valutazione "locale" e il loro trattamento siano allineati con gli obiettivi "globali" della persona. Il rischio è quello che i clinici rincorrano una tecnologia che interessa loro e che possa alleviare una menomazione specifica, ma non aiuta la persona a raggiungere i propri obiettivi reali. Questo può portare a sprechi di tempo ed altre risorse, comportando rischi ingiustificati. Nella presente lezione magistrale sono quindi discusse alcune tecniche per evitare che ciò possa accadere.

Camminare lungo percorsi non lineari: prevenzione delle cadute e procedure di riabilitazione mirate

Marco Schieppati, è stato Professore di Fisiologia Umana e Neurofisiologia nelle Università di Milano, Genova e Pavia

Con l'invecchiamento della popolazione, le persone anziane e fragili sono destinate ad aumentare. Le cadute durante la locomozione aumentano esponenzialmente con l'età e si verificano soprattutto durante i cambi di direzione.

Durante la deambulazione lungo percorsi non rettilinei, la simmetria viene annullata, i passi hanno lunghezze diverse e il tronco si inclina verso l'interno della traiettoria. La gravità viene sfruttata e contrastata durante la deambulazione curva creando una coppia medio-laterale. Le strategie di rotazione comprendono il controllo del tronco (muscoli obliqui esterni e interni) e della intrarotazione ed extrarotazione del bacino e degli arti inferiori (muscoli che collegano le ossa del bacino al femore).

Camminare e girare sul posto è un compito semplice che può essere facilmente eseguito da persone e pazienti anziani e fragili. La stimolazione vestibolare è evitata da un dispositivo dotato di un disco orizzontale rotante sul quale le persone “camminano sul posto” con la testa e il tronco stabilizzati dalla presa di un corrimano fisso.

Oltre i marker: svelare il movimento umano attraverso l'analisi video senza marker

Maura Casadio, Professoressa associata in Ingegneria Biomedica all'Università di Genova

Comprendere e misurare il movimento umano è cruciale in vari campi, tra cui le neuroscienze, la riabilitazione e la biomeccanica sportiva. Tradizionalmente, questa analisi si è fondata su tecniche basate sull'utilizzo di marker e sistemi di motion capture che, sebbene precisi e affidabili, possono essere costosi ed ingombranti, richiedendo molto tempo. In risposta a queste sfide, sono emersi recenti progressi nelle tecniche senza marker, che offrono alternative accessibili per l'analisi del movimento sia in contesti quotidiani che clinici. In particolare, sono stati compiuti progressi significativi nello sviluppo e nell'applicazione di algoritmi di visione artificiale e apprendimento automatico che analizzano le registrazioni video standard dei movimenti umani. Questo approccio innovativo consente l'estrazione di caratteristiche sia qualitative che quantitative del movimento, facilitando la rilevazione, la caratterizzazione e la comprensione dei comportamenti motori e dei deficit associati a condizioni neurologiche. Questa lezione magistrale esplora il potenziale e i limiti dell'analisi del movimento umano senza marker basata su registrazioni video RGB, con particolare attenzione ai movimenti spontanei nei neonati e ai modelli di deambulazione nelle persone con disturbi neurologici.

ELENCO DEI CONTRIBUTI PRESENTATI AL CONGRESSO

Best task and best gait measure to identify de novo and moderate Parkinson's disease: a lesson learned from a machine learning point of view

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Introduction

Gait disturbances are common symptoms in people with Parkinson's disease (PD), and they can be present from early stage [1]. Although wearable sensors have proven their value in identifying digital mobility biomarkers in PD [2,3], it remains unclear whether challenging gait with a cognitive task or fast walking best distinguishes individuals with de-novo or moderate PD from healthy controls (HC). Here, we used a machine learning (ML) approach to identify the optimal subset of digital gait biomarkers for differentiating people with de novo and moderate PD from age-matched HC based on different gait tasks.

Methods

Cross-sectional data was collected from a total of 164 PD patients and 99 HC who participated in two studies: Study I, de-novo, untreated PD, n = 27 age: 69.1 ± 6.4 yrs [52-78]; disease duration: 0.92 ± 0.73 yrs [0.04-2.67]; MDS-UPDRS-III total score: 26.2 ± 7.8 [15-46]; HC, n = 18, age: 66.2 ± 9.8yrs [46-79] and Study II, moderate-PD assessed in the off levodopa state, n = 137, age: 68.9 ± 8.1 yrs [50-88]; disease duration: 6.22 ± 4.87 yrs [0.04-24.66]; MDS-UPDRS-III total score: 40.6 ± 12.4 [13-82]; HC, n = 81, age: 68.2 ± 8.1yrs [50-83]. Participants completed 1) walking at comfortable speed single task (ST), 2) walking at comfortable speed with cognitive dual-task (DT), and 3) fast walking. They wore seven Opal sensors (APDM Wearable Technologies, a Clario company, Portland) from which we extracted 26 gait metrics using APDM Mobility Lab Software. The dataset was split into 70% for training and 30% for testing. Five ML models (Random Forest, SVC, XGBoost, GradientBoostClassifier, KNeighborsClassifier) were optimized using GridSearchCV with 5-fold cross-validation and assessed based on mean cross-validation score (MCV) and ROC-AUC.

Results

Table 1 shows that Fast walk is the most effective task in distinguishing de-novo PD from HC, with minor differences compared to Walk DT when using Random Forest. Meanwhile, Walk DT is the most effective for distinguishing moderate-PD from HC with GradientBoostClassifier (GBM). We applied a feature importance ranking, which revealed turn velocity as the most significant feature for moderate PD, while trunk transverse range of motion was the most significant for de-novo PD.

Table 1. Machine Learning Models Performance across different conditions.

ML Models	de-novo PD vs HC						moderate-PD vs HC					
	Walk ST		*Walk DT*		*Fast Walk*		*Walk ST*		*Walk DT*		*Fast Walk*	
	MCV Score	ROC AUC	MCV Score	ROC AUC	MCV Score	ROC AUC	MCV Score	ROC AUC	MCV Score	ROC AUC	MCV Score	ROC AUC
Random Forest	0.81	0.82	0.85	0.90	0.82	0.96	0.89	0.93	0.89	0.97	0.88	0.93
SVC	0.78	0.77	0.75	0.83	0.76	0.80	0.85	0.90	0.85	0.95	0.87	0.93
XGBoost	0.78	0.74	0.78	0.68	0.76	0.94	0.90	0.92	0.87	0.97	0.89	0.90
GBM	0.81	0.90	0.85	0.82	0.84	0.83	0.90	0.94	0.90	0.97	0.88	0.93
KNN	0.78	0.83	0.78	0.68	0.76	0.92	0.84	0.91	0.85	0.93	0.83	0.85

Discussion

Our findings align with the literature and this study suggests that fast walking does not add significant value compared to walking DT to distinguish between de-novo/moderate PD and HC. Next steps will focus on applying more comprehensive analyses of the ML models using SHAP values towards their explainability.

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Validation of a new method for center of mass trajectory estimation in simulated daily life activities based on inertial and barometric pressure data fusion

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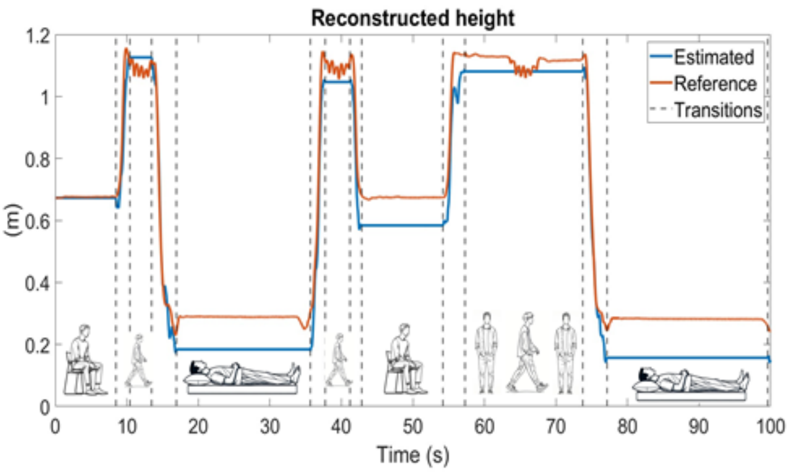
Introduction

Analyzing the body center of mass (BCoM) during real-world activities is crucial in biomechanics and rehabilitation, aiding in identifying musculoskeletal disorders, assessing energy consumption, and evaluating balance and mobility, especially for the elderly or those with impairments [1]. This study innovatively employs a high-resolution barometric pressure sensor, an altimeter in avionics [2], to measure height variations. The approach leverages a sensor fusion framework using complementary inertial signals to reduce displacement errors from environmental interference [3].

Methods

The optimal sample size was determined through statistical testing at 0.05 reliability level [4]. The study was approved by the ethical committee of Politecnico di Torino (protocol number: 27213). Twenty healthy subjects wore a triaxial inertial unit (IMU) and a barometer on their lower back (sample frequency= 100Hz). The barometer was specifically integrated into our INDIP multi-sensor system [5] at both firmware and hardware levels. Twelve-cameras marker-based stereophotogrammetry was used as trajectory reference. Subjects performed daily activities, such as sit-to-stand (StS) transitions from and to a chair at comfortable and slower speeds and lying down on a bed. First, the barometric signal was converted to height using a barometric formula [2], low-pass filtered, and differentiated to identify activity transitions. Then, double-integrated gravity-free acceleration [6] during transitions was combined with barometer-derived height using a Kalman filter [3] to track BCoM height. Between transitions, height was forced constant (Fig. 1). Performance was quantified by sensitivity, precision, and delay for transitions detection, and root-mean-square error (RMSE) for height reconstruction. Consistency across different transition types and subjects was assessed by comparing the distributions of absolute deviations between estimated and reference heights, grouped by transition type (80 regular-speed StS, 80 slower-speed StS, 160 lying) and subject, using the Kruskal-Wallis test.

Results



Transitions detection achieved 100% sensitivity, 97.3% precision, and average delay of 0.01 seconds, compared to manual labeling of reference. The BCoM trajectory reconstruction exhibited a mean RMSE of (24.5±14.0) cm during the whole recording, and of (-5.5±1.0) cm during transitions. No significant differences were found among all groups at significance level α=0.05.

Figure 1. A comparison between the estimated vertical displacement and the reference, showing the actions performed by the participant.

Discussion

The proposed method showed great accuracy in detecting transitions and reconstructing the vertical trajectory of the pelvis during simulated daily activities. Statistical analysis confirmed consistency across all subjects independently on the transition type. Integrating a high-resolution barometer and IMU proved to be an effective solution for accurately measuring height changes, offering important perspectives for biomechanical analysis and energy consumption assessment during daily activities.

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Biomechanical efficacy of botulinum toxin treatment on synergy between spine and lower limbs in camptocormia in Parkinson's disease

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Introduction

Camptocormia is an abnormal uncontrollable forward flexion of the spine while standing or walking, with an overall incidence of 5–19% in Parkinson's disease. The presented study was designed to understand abdominal and thigh muscle activation. Botulinum toxin treatment is a therapeutic option because a pathogenesis of camptocormia is axial dystonia [1-3]. These patients show a reduction of gait velocity, stride length, hip extension in stance and knee peak flexion in swing. Because trunk flexion is associated with an increased risk of falling, pain and diminished quality of life, their proper prevention and management is warranted.

Methods

16 patients (7 females and 9 males with an average age of 73 years) with upper camptocormia (UCC with C7-L1 angle ≥ 45°) [4] participated in this study. 9 tests were performed for each patient with the optoelectronic system 3-D SMART (BTS, Milan, Italy), with dynamic EMG. The patients were subjected to clinical evaluation with gait analysis at inclusion and 1 month after botulinum toxin injection. EMG showed a pattern of abnormal tonic hyperactivity, with potential of more than 100 µVolts/sec. for more than 500 msec. of rectus inferior abdominis, external oblique, ileo-psoas and rectus femoris bilaterally, as previously published [5]. Using electromyographic and ultrasound guidance [5], we injected botulinum toxin (Dysport®) into these muscles. Patients underwent a rehabilitation programme for 4 weeks.

Results

One-way ANOVA revealed that gait velocity and stride length were different among pre and post-botulinum toxin (p=0.018 and p=0.014). Significant improvement was observed in the UCC angles (from 48.2° ± 7.5° to 38.6° ± 5.4°, p=0.012). There is a reduction in the inclination of the pelvis on the sagittal plane during the stance; the knee show reduction of flexion throughout the stance and increase in the maximum knee flexion in the swing. The kinetics records an increase in the hip extension moment in stance and especially in pre-swing, a reduction of the hip adduction moment, a reduction of the knee flexion moment at the initial stance (Fig. 1), an increase in the ankle flexion moment at the terminal stance. The co-contraction of abdominal and thigh muscles is reduced.

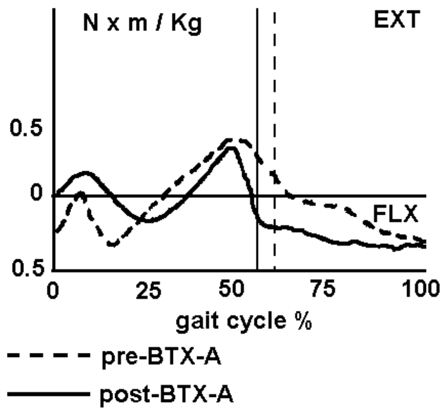

Figure 1. Increased knee flexion moment post-botulinum toxin.

Discussion

The joint moments demonstrate a recovery of the push capacity of the lower limb. By unlocking the constraints of the inoculated muscles, the activation of the other muscles improves. The transition of the gait pattern from anserine pre-toxin to sagittal post-toxin is completed, with the possibility of reducing the falls [6].

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Assessing upper limb motor impairments in post-stroke patients using optoelectronic and electromyographic systems during the Action Research Arm Test

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Introduction

Stroke is a major neurological disease causing significant upper limb motor deficits, such as impaired movement, dexterity, and coordination [1]. Choosing the correct rehabilitation approach is crucial to maximize functional recovery and improve quality of life, reducing disability in activities of daily living. Various clinical assessments are used to assess upper limb motor impairment, focusing on dexterity and coordinated movement [2]. Combining instrumented analysis with clinical evaluation can provide quantitative and objective information about motion deficits [3]. This work aims to assess upper limb motor impairment of post-stroke subjects using an optoelectronic system and electromyographic sensors during the Action Research Arm Test (ARAT).

Methods

We plan to recruit a total of 60 post-stroke individuals over the next 2 years. To date, eight persons with stroke (age 71.8 ± 13.1 years, 6 males) and ten healthy subjects (age 63.5 ± 12.7 years, 5 males) were recruited. A motor instrumented assessment of the upper limb was conducted using an optoelectronic system including recording 12 muscles for each arm while performing the ARAT. Tasks included four exercises of reaching, grasping, and lifting objects (7.5 cm cube, 2.5 cm cube, ball, cylinder), and two free-hand exercises (hand to mouth, hand to head). Each task was executed five times for both sides. Joint angles of the upper arm and fingers were computed, and time spent during each action phase (reaching, lifting, return) was estimated. Muscle synergies were extracted using a non-negative factorization algorithm for each arm. Statistical analysis was performed with the Mann-Whitney U-test with a significance level of 5%.

Results

Initial data focused on detection and segmentation of phases of reaching the object, lifting it to the target, and returning. Preliminary results showed that post-stroke subjects took longer to grasp the small cube with the paretic limb (0.2 ± 0.3 s, mean ± deviation standard) and to release the bigger cube with both paretic and non-paretic limb (1.1 ± 0.4 s, and 0.8 ± 0.3 s) compared to healthy subjects (p-values of 0.01, 0.001, and 0.02, respectively).

Discussion

Preliminary results are coherent with literature underlining that hand motor performance of hemiparetic persons is linked to disturbances in grasping control and manipulation skills [4]. Future works will involve increasing the sample size and a deep analysis related to joint angles to obtain more quantitative information as support for clinical assessments in the definition of upper limb motor impairments in people with stroke.

Acknowledgments

This work was carried out within the framework of the project "RAISE - Robotics and AI for Socio-economic Empowerment" and has been supported by European Union – NextGenerationEU (GB, MF, IC, AV). This work includes also the support of the Italian Ministry of Health through the project OTHELLO GR-2021-12372038 (FL, MC, AN, TL, FR).

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The RAISE-FitFES Project: usability and acceptability of a Functional Electro-stimulator controlled by electromyographic signal for post-stroke in-patients

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Introduction

Hemiparesis, a primary consequence of stroke, disrupts the transmission of motor commands from the cortex to the spinal cord compromising upper limb functionality [1]. Functional Electrical Stimulation (FES) is a promising technique to induce muscle contraction of paretic muscles during task execution, aiming to improve performance in persons post-stroke [2]. Moreover, previous research focused on the exploitation of residual myoelectric activity of paretic muscles to control the stimulation applied to the same or synergistic muscles. This technique improves the motor performance of affected limb of subjects with stroke [3]. Recently, a new prototype has been developed, called FitFES, using a user-centered approach that focuses on wearability and ease of use in rehabilitation [4]. This work aims to present the study protocol established to evaluate usability and acceptability of the FitFES.

Methods

The study consists of two phases: 1) design of experimental protocol setup; 2) usability testing of FitFES. In phase 1, a set of exercises was identified based on stroke severity. In phase 2, ten post-stroke in-patients and ten healthcare professionals will be recruited to use and evaluate the device. Participants will perform task-oriented upper limb exercises in a one-hour session while wearing the FitFES in active mode. Through surface electromyographic (EMG) electrodes, FitFES will record the EMG signal generated during muscle contraction while executing a task, processing this information in real-time to generate a pulsed current whose amplitude is proportional to the recorded muscle activity. Electrical stimulation will be applied via surface stimulation electrodes to muscles requiring assistance to complete the task. Usability of the device will be assessed through the System Usability Scale, the Borg scale, the Unified Theory of Acceptance and Use of Technology, and the Stroke Rehabilitation Motivation Scale for post-stroke subjects. To date, phase 1 was completed.

Results

Four clusters of exercises were defined based on stroke severity (Fugl-Meyer Upper Limb): mild, mild-to-moderate, moderate-to-severe, severe. Briefly, in more compromised clusters recording involves proximal joints, and stimulation is provided in proximal and distal muscles, while less compromised clusters focus on distal muscle stimulation. Table 1 reports the most difficult exercises within each cluster.

Table 1. Example of tasks required to each cluster with corresponding muscles.

Severity	Task	Muscles
Mild	Reach and pinch a small ball to put it in a box	Recording: anterior deltoid Stimulation: carpus extensor
Mild-to-moderate	Reach, grasp, and create a tower of small objects	Recording: carpus extensor Stimulation: carpus extensor
Moderate-to-severe	Grasp an object with a hook grasp and release it into a box	Recording: triceps brachii Stimulation: carpus extensor
Severe	Place a stamp in the color and apply it on a paper sheet	Recording: anterior deltoid Stimulation: triceps brachii

Discussion

During phase 1 tasks based on stroke severity were outlined. For each exercise upper limb muscles to record and stimulate were identified. In phase 2, this protocol will be applied to assess the usability of the device FitFES. Future studies will be designed to evaluate the effectiveness of FitFES during a prolonged rehabilitation program.

Acknowledgments. This work was carried out within the framework of the project "RAISE - Robotics and AI for Socio-economic Empowerment" and has been supported by European Union - NextGenerationEU.

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Anterior cruciate ligament injury prevention and recovery: towards an ecological assessment of knee stability

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Introduction

Anterior Cruciate Ligament (ACL) rupture is critical in many sports. To investigate ACL injury mechanisms and return-to-sport criteria, gold standard methods (GSM), such as optoelectronic systems and force plates, have been used for knee stability assessment [1]. Nevertheless, these instruments are constrained to the laboratory setting, while Inertial Measurements Units (IMUs) allow movement to be analyzed in an ecological context [2]. However, the relationship between IMU- and GSM-based information must be assessed. The aim of the current work is to quantify this relationship in athletes with and without ACL reconstruction during landing.

Methods

Thirteen healthy (HC: 25±4 years, 72±6 kg, 1.78±0.7 m) and six soccer players with ACL reconstruction (ACLR: 25±6 years, 84±9 kg, 1.84±0.6 m, postoperative time: 8-12 months) participated to this study. Three Single-Leg Cross Drop Landing [3] were performed for each limb, landing on a force plate (AMTI, USA, 1000 Hz). The 3D trajectories of 52 markers were measured by an optoelectronic system (Vicon, UK, 200 Hz) [4]. Three IMUs (APDM, USA, 200 Hz) were located on the thigh, shank, and foot of each limb. The following parameters were obtained from GSM: peak of the vertical GRF (vGRFpeak), knee range of motion on the three planes (Add/Abdrange; Intra/Exrotrange; Flex/Extrange), peak of the knee internal abduction (M_Abdpeak), extrarotation (M_Exrotpeak) and extension moments (M_Extpeak). For IMUs, the angular velocity ranges (AVrange) on the anteroposterior (AP), mediolateral (ML), and craniocaudal (CC) axes were obtained for both shank (S) and thigh (T). Moreover, the acceleration attenuation coefficients from foot to shank to thigh (ACFS; ACFT; ACST) were considered [5]. After checking for normality of data distribution, the Spearman's correlation coefficient was calculated between GSM- and IMU-based parameters (α=0.05).

Results

The correlation results are shown in Table 1. Overall different significant correlations were found between both kinetic and kinematic GSM-based parameters and IMU-based output, especially in ACLR. In ACLR, the attenuation of accelerations between feet/shanks and thighs significantly correlated with both knee moments and ranges of motion. Interestingly, HC presented higher correlations between knee kinematics in the sagittal plane and IMU-based parameters, whereas in ACLR IMU-based information seems to have a stronger relationship with the knee kinetics.

ACLR		T_AVrange _CC [°/s]	T_AVrange _AP [°/s]	T_AVrange _ML [°/s]	S_AVrange _CC [°/s]	S_AVrange _AP [°/s]	S_AVrange _ML [°/s]	ACFS [%]	ACST [%]	ACFT [%]
vGRFpeak [N/Kg]	INJ	**0.71**	0.37	**0.77**	-0.03	0.14	0.26	0.03	**-0.66**	-0.60
	SAF	-0.09	0.20	0.49	**0.83**	0.37	**0.89**	**-0.60**	**0.83**	**0.60**
M_Abd peak [Nm/Kg]	INJ	**-1.00**	-0.49	-0.37	-0.03	**-0.71**	-0.60	**0.66**	0.60	**0.89**
	SAF	-0.26	-0.14	0.14	**0.77**	**0.66**	**0.66**	0.31	**0.77**	**0.94**
M_Exrot peak [Nm/Kg]	INJ	**-0.71**	-0.31	-0.09	0.60	-0.26	-0.14	0.37	**0.94**	**0.94**
	SAF	0.09	-0.03	0.03	0.37	**1.00**	0.49	0.26	0.37	0.43
M_Ext peak [Nm/Kg]	INJ	0.14	0.31	**0.83**	0.37	-0.14	0.09	0.43	-0.14	0.03
	SAF	-0.03	**0.66**	0.54	-0.03	-0.26	-0.09	**-0.83**	-0.03	-0.49
Add/Abd range [°]	INJ	0.03	0.37	-0.26	-0.54	0.14	-0.43	-0.31	-0.31	-0.26
	SAF	**0.66**	-0.43	**-0.60**	**-0.94**	-0.26	-0.54	0.37	**-0.94**	**-0.83**
Intra/Exrot range [°]	INJ	0.49	0.54	0.26	-0.60	0.09	-0.14	-0.14	**-0.94**	**-0.77**
	SAF	0.43	**-0.60**	-0.26	-0.09	-0.26	0.20	0.37	-0.09	0.09
Flex/Ext range [°]	INJ	0.37	0.60	**1.00**	0.20	0.03	-0.09	0.26	-0.31	-0.14
	SAF	-0.14	**0.60**	**0.60**	0.20	0.54	-0.03	0.03	0.20	-0.03

Table 1. Results from the correlation analysis of ACLR group (in bold: correlations > 0.6; in green: p < 0.05).

Discussion

The results obtained from this preliminary work show how IMUs could be a promising and viable option for obtaining information related to knee stability directly on the field.

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Assessment of Quantitative Metrics for Spontaneous Movement Analysis Using a Single RGB-D Camera: A Case Study of Twins with Divergent Health Profiles

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Introduction

Recently, we published a markerless protocol for studying upper limb movements in infants using a single RGB-D camera and DeepLabCut to extract 3D coordinates of upper limb points of interest (PoIs) in a home setting [1]. This method was designed to be robust against incidental movements [2] in uncontrolled environments. Additionally, a refined training set was introduced [3] including only essential frames to minimize manual labeling time. Quantitative metrics, predictive of movement disorders, were computed from the 3D PoI coordinates [4-6]. The study has two main objectives: (i) to assess this method in critical and uncontrolled scenarios and (ii) to investigate those metrics' potential as reliable indicators of developmental abnormalities. This investigation was conducted on twins with divergent health profiles, providing a unique case study.

Methods

A pair of 4-month-old twins was recruited and positioned in a baby seat in front of the Intel RealSense D435. One twin was typically developing (TD) and the other was diagnosed as at-risk (AR) for cerebral palsy. Video recordings of up to three minutes for each twin were captured at four time points, spaced about 30 days apart. 3D coordinates of seven PoIs (left and right shoulders, elbows, wrists, and navel) on each twin were tracked using DeepLabCut, trained as described in [3]. From the 3D PoI coordinates, nine metrics [4-6] were estimated at each timepoint: correlation between limb velocities and accelerations, stereotypy score, average velocity of limb movements, average range of motion of the elbow angles, area in which the trajectories/velocities of the wrists differed from the moving average, and area where the trajectories/velocities of the wrists were outside of the standard deviation (std).

Results

Table 1. Selected metrics computed for AR and TD subjects at each time point.

Months/Metrics	4		5		6		7		**Mean**	
	AR	*TD*	*AR*	*TD*	*AR*	*TD*	*AR*	*TD*	***AR***	***TD***
Correlation between wrist velocities	2.02	1.98	2.06	1.67	1.64	1.44	1.76	1.19	**1.87**	**1.57**
Stereotypy score	0.27	0.21	0.15	0.14	0.26	0.05	0.77	0.10	**0.36**	**0.12**
Wrist average tangential velocity [m/s]	0.06	0.06	0.04	0.05	0.08	0.09	0.04	0.09	**0.05**	**0.07**
Average elbow ROM [deg]	118	132	101	70	138	158	66	130	**105**	**122**
Correlation of wrist accelerations	0.27	0.19	0.37	0.34	0.33	0.34	0.32	0.20	**0.33**	**0.27**
Area out of mean of wrist trajectories [mm*s]	2456	1374	1085	2450	1960	2495	1401	2723	**1726**	**2261**
Area out of std of wrist trajectories [mm*s]	192	347	216	360	488	564	435	872	**333**	**536**
Area out of mean of wrist velocities [mm]	13284	6476	5957	10249	9814	13810	5477	12390	**8633**	**10731**
Area out of std of wrist velocities [mm]	413	559	519	516	1018	1432	370	1477	**580**	**996**

Discussion

This work has demonstrated that every metric follows the expected trend from the literature [4-6]. Correlation between wrist velocities and accelerations in AR is higher than TD, showing higher similarity between limbs movements. Average elbow ROM proves to be a good indicator of the observed difference between AR and TD in terms of range of motion. The average velocity of TD is higher than AR, with the difference increasing over time. A higher stereotypy score in AR is a key indicator of lack of variation. These findings are confirmed by both area out of mean and standard deviation of wrist trajectories/velocities. The results demonstrated that the methodology employed is able to extract metrics to be potentially used for early identification of movement disorders.

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Reliability of a 3D Model-Based Marker-less Approach for Clinical Gait Analysis with a Single RGB-Depth Camera

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Introduction

Thanks to advancements in depth sensing and machine learning models, markerless (MS) gait analysis protocols are becoming promising for children with cerebral palsy (CP) [1,2]. However, generic single-camera MS methods extract 2D anatomical landmark coordinates, neglecting out-of-plane movements and position changes between the subject and camera during gait [1-3]. To overcome these limitations, this study proposes a MS protocol based on a single RGB-Depth camera exploiting a 3D statistical lower-limb model to improve accuracy in estimating sagittal lower limb joint kinematics.

Methods

Five participants with CP and four with clubfeet were acquired in a gait analysis laboratory with Azure Kinect (30 fps) placed laterally to the walkway. A generic Skinned Multi Person Linear Model (SMPL) [4] embedding foot, shank, thigh, and pelvis interconnected by ankle, knee, and hip joints was used. A 3D subject-specific model (SMPL_ss) was created by calibrating the SMPL on three static recordings of the subject in upright posture (frontal, posterior, sagittal). Each participant underwent three gait trials at self-selected speed for both right and left side. The 3D coordinates of hip, knee, and ankle centers were extracted by matching SMPL_ss to each point cloud of the gait cycle, as in [5]. For validation purposes, a Qualisys system (100 Hz) was employed. However, due to the mutual interference of the IR sensors of both systems, gait trials were recorded separately under the hypothesis of gesture's repeatability. To assess this method's performance, seven clinical gait features (Figure 1.e) were extracted for each trial. The reliability of both methods was evaluated using the intraclass correlation (ICC).

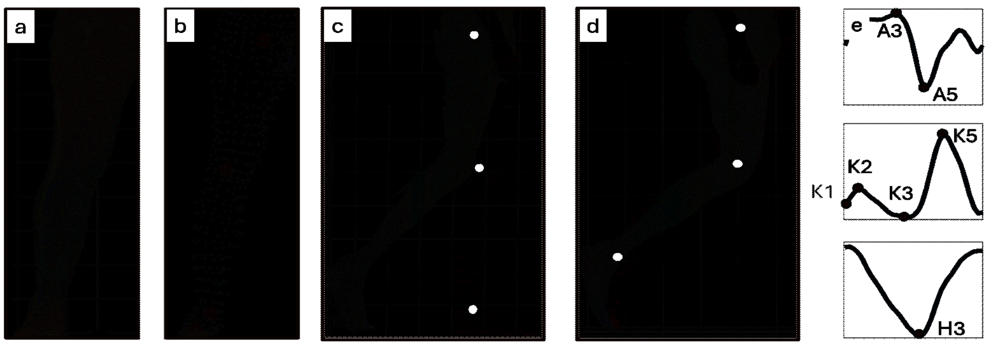

Figure 1. a) Frontal, sagittal, and posterior views b) $SMPL_{ss}$ c-d) Alignment between $SMPL_{ss}$ and a dynamic point cloud e) gait features from sagittal lower-limb kinematics.

Results

ICC values for each gait feature for MS and MB, respectively: A3: 0.86 vs 0.94, A5: 0.75 vs 0.95, K1: 0.83 vs 0.88, K2: 0.84 vs 0.85, K3: 0.80 vs 0.78, K5: 0.89 vs 0.89, H3: 0.85 vs 0.70.

Discussion

The proposed MS method demonstrated good reliability (ICC>0.75) for every gait feature. Residual errors in estimating A5 were due to technological limitations, as the depth sensor failed to reconstruct values during the swing phase (highest velocity). In conclusion, the proposed protocol, benefiting from a 3D model, can directly reconstruct 3D lower-limb joint centers, making the estimates more robust to movements outside the sagittal plane than 2D MS analysis [1]. This study was carried out within VISIONARY– funded by European Union – Next Generation EU within the PRIN 2022 program (D.D. 104 - 02/02/2022 Ministero dell'Università e della Ricerca).

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Instrumented Timed Up and Go Test: a reliable tool for elderly with femur fracture

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Introduction

The Timed Up and Go (TUG) test is the most widely used assessment tool in clinical practice to predict falls [1]. Recently, it has been enhanced with an inertial sensor, creating a technological version known as the instrumented Timed Up and Go test (iTUG). To date, the reliability of the iTUG has been evaluated in a few studies involving neurological and heterogeneous orthopaedic populations [2,3]. The aim of this study was to assess the intra-rater, inter-rater, and test-retest reliability of the iTUG in inpatients with femur fractures and to define an interpretative model of the iTUG for assessing the performance of these patients.

Methods

The reliability of 100 variables detected with the iTUG was evaluated using data from 48 inpatients with femur fractures (38 female, mean age 88.1±5.6 years) prior to their discharge from our rehabilitation ward. Each subject performed the iTUG test five times over two consecutive days, with the tests administered separately by two different physiotherapists. During the trials, patients wore an inertial sensor (EXLs3-m, mHealth Technologies, Italy) on their lower back and were allowed to use their usual walking aid. Test-retest, intra-rater, and inter-rater reliability were assessed through Intra-class Correlation Coefficients (ICCs) [4]. The iTUG variables that demonstrated excellent reliability in all three types of assessments were then used to create a correlation matrix. After removing the highly correlated variables (r>0.90), an exploratory factor analysis was conducted [5].

Results

The ICCs revealed that 11 out of the 100 variables obtained with the iTUG had "poor" reliability, while 27 variables demonstrated "excellent" reliability in all three types of assessments. Of these 27 variables, 6 were highly correlated (r>0.90) and were removed from subsequent analysis. The remaining 21 variables showed a good Kaiser-Meyer-Olkin measure (>0.70) and were distributed across 4 factors, as suggested by parallel analysis, with a cumulative variance of approximately 75%. Table 1 shows the factor loadings for each factor.

Table 1. Variables divided into 4 factor scores, with their respective factor loading.

Factor 1		Factor 2		Factor 3		Factor 4	
Range A-P Acc in W	0.67	Range M-L AV in STW	0.58	Mean Step Duration	0.85	Gait Speed	0.52
Range M-L Acc in W	0.81	RMS M-L AV in STW	0.60	Time-N Jerk M-L Acc in W	0.94	Walk Duration	-0.76
RMS M-L Acc in W	0.91	Peak AV of the 180° Turn	0.75	Speed-N Jerk A-P Acc in W	0.89	Total Number of Steps	-0.62
RMS V Acc in W	0.75	Peak AV of the Sit Turn	0.81			Total Duration till chair	-0.53
Range A-P AV in W	0.71	RMS V Acc in STW	0.49				
RMS A-P AV in W	0.74						
RMS M-L AV in W	0.59						
RMS V AV in W	0.59						
RMS A-P Acc in W	0.50						

Acc, Acceleration; A-P, antero-posterior; AV, angular velocity; M-L, medio-lateral; N, normalized; RMS, Root Mean Square; STW, sit-to-walk; V, vertical; W, walk.

Discussion

The iTUG test is not only a practical and easily applicable assessment tool, but also a reliable instrument for evaluating people with femur fracture. However, not all the extracted variables provide useful information; by reducing the number to reliable and non-redundant ones, it is possible to define an interpretative model for the assessment of physical performance in people with femur fracture. This model provides more detailed information on specific domains, than just the total time of TUG test measured with a stopwatch.

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Application of dynamic time warping to Fragile X syndrome's gait patterns: a supervised approach

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Introduction

FXS, the leading cause of inherited intellectual disability and autism [1], is defined by the expansion of fully methylated CGG triplets (FXSFull), leading to protein silencing and loss of expression. Within FXFull, mosaicism (FXSMos) can significantly modulate the FXS phenotype. The exact number of FXS individuals is unknown as children who express autism spectrum disorders are not always referred for genetic screening. The possibility to identify specific characteristics that can be associated with FXS from gait analysis has recently attracted attention. This study aims to identify biomarkers of FXS from gait analysis data and possibly to extend the classification to the different FXS phenotypes. Dynamic Time Warping (DTW) is known for its effectiveness in extracting relevant features from movement patterns [2]. In this study we explore DTW-derived features for FXS classification.

Methods

The gait patterns of 30 FXS individuals (BMI:18.5±5kg/m^2; Age:9.71±3.36years) and 15 (only 5 included in the present analysis) typically developing children, age- and BMI-matched were analysed. The FXS group included 21 FXSFull and 9 FXSmos. Multiple gait trials were recorded at self-selected speeds using four synchronized cameras (GoPro Hero7, 30fps) and a surface electromyographic system (sEMG) (Cometa, 2000 Hz) acquired the activity of tibialis anterior, gastrocnemius lateral is, biceps and rectus femoris bilaterally. Lower limb joint flexion-extension angles [3], the envelope peak, its occurrence within the gait cycle, on-off, and duration of muscle activity were determined [4]. DTW analysis was performed on joint kinematic patterns (S1), and on muscle envelopes (S2) in order to classify FXS phenotypes, by taking as reference signal the mean value of each feature in the control group. Features such as distance and path energy from DTW were used to train a support vector machine model (SVM), evaluating its accuracy by varying gamma and C parameters.

Results

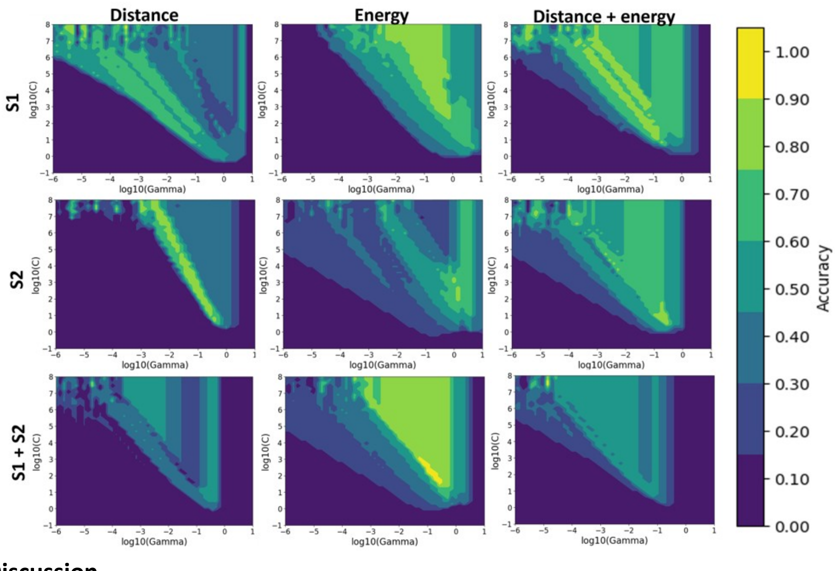

Figure 1. Accuracy of the SVM model when varying the values of gamma and C in a logarithmic scale. Different combinations of S1 and S2 groups of features have been considered.

Discussion

Superior accuracy was achieved using only muscle activity features (S2), while using only angles (S1) yielded greater consistency. Combining both types of features (S1 and S2) seems leading to inferior results. This is likely due to the high number of features being employed in this combined case, that is causing high variance in the estimators. Further investigations will explore alternative feature selection steps with supervised model structures.

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The effect of functional electrical stimulation on freezing of gait in people with parkinsons' disease: a pilot study

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Introduction

Freezing of gait (FOG) is a common problem in people with Parkinson's disease (pwPD) which restricts mobility, increases the risk of falls, and reduces quality of life. Optimization of dopaminergic therapeutic medication, rehabilitation strategies and different modalities of electrical stimulation are used to reduce this phenomenon but an effective treatment for FOG is still missing. Functional peripheral sensory stimulation of the peroneal nerve is one easy reachable therapeutic tool that showed some interesting results in literature [1,2]. The aim of this study is to demonstrate in pwPD that bilateral application of FES at a sensory perception thresh-old in the peroneal region can influence FOG.

Methods

6 pwPD (5 M and 1 W, age: 66.88±9.22, disease duration: 13.33±6.02, H&Y: 3.17±0.98, UPDRS Motor score: 51.17±7.93, UPDRS FOG score: 2.83±1.17, n-FOGQ: 23±4.56, LEDD (mg): 23±4.56, ON phase) with FOG (n-FOGQ>1) received bilateral application of FES (Odstock Dropped Foot Stimulator, CE marked) at a sensory perception threshold in the peroneal region for a short period of time (< 1 hour) in a laboratory setting equipped with optoelectronic system in combination with EMGs and IMUs. They were tested during various tasks such as initiating gait, turning, walking passing through doors or performing linear walking. The same tests were performed without FES. Other outcome measures are gait speed and spatio-temporal parameters of gait.

Results

The result of this study shows, even considering some intersubject variability in the perception of the stimulation, a significant reduction of the time of FOG during doorways walking in the narrower door, as can be seen in Table 1.

	Time (s)		Time spent freezing (%)	
Subject	**No FES**	**FES**	**No FES**	**FES**
1	53	39	66.04	48.72
2	18	16	11.11	6.25
3	43	38	55.81	50
4	14	11	0	0
5	26	23	0	0
6	28	30	39.28	33.33
Mean ± SD	30.33 ± 12.91	26.17 ± 11.51 (*)	28.71 ± 25.46	23.05 ± 23.81 (*)

Table 1. Passing through doorway trial. TF% with FES and time spent passing through the door decreased significantly by (P<0.05) in trials with FES. Bolded with (*) indicating statistically significant differences (Wilcoxon test, P<0.5).

Discussion

Preliminary findings in our cohort of freezers add support to the hypothesis that FES may have an immediate clinically meaningful effect on interfering with FOG phenomenon even in a single treatment without any adaptation. This kind of electrical stimulation could be interpreted as an external sensory cue, that is able to reduce the emotional distress related with this specific task and to influence the retraining "adaptive" strategies of walking, in particular through narrow doorways. All subjects considered this experience feasible without side effects. Future studies are needed focusing on the use of FES for longer periods of time to enhance sensory motor learning possibly in a rehabilitation setting and/ or in an ecological environment.

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Reliability of average daily steps measured through a consumer smartwatch in people with Parkinson's disease across disease severity and subtypes

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Introduction

Consumer smartwatches could be useful to estimate daily steps step and monitoring ambulatory activity in a real-world environment [1]. However, although previous studies investigated validity and reliability of smartwatches in step counting in people with Parkinson's disease (PwPD) [2-4], no study considered disease phenotypes and stage when evaluating metrological characteristics of these devices.

Methods

Average daily steps (aDS) were collected at home through a Garmin Vivosmart 4 smartwatch for 5 consecutive days in 104 PwPD with no dementia [33% females; age 68.0 ± 8.4 years; disease duration 6.4 ± 3.4 years; Hoehn and Yahr (H&Y) stage 2 (2-2.5)]. PwPD were dichotomized according to tremor dominant (TD) or postural instability and gait disorder (PIGD) phenotype, early (mHY 1-2) or intermediate (mHY 2.5-3) disease stage, reported presence or absence of tremor. In the overall population and in each subgroup, a two-way intraclass correlation coefficient (ICC) with a fixed set of raters and averaged ratings was used [ICC (3,k)]. The a priori threshold for acceptable ICC was set at a point estimate ≥ 0.80 with a lower bound of 95% Confidence Interval (CI) ≥ 0.75. Student's t-test and analysis of 83.4% CI overlap were used to compare ICCs between subgroups pairs [5]. Standard error of measurement (SEM) and minimal detectable change (MDC) with a confidence interval of 95% were also calculated.

Results

ADS showed acceptable reliability in the overall population and in all subgroups. A SEM below 10% was found in the overall population, in PIGD subtype, in PwPD without tremor and with intermediate disease stage. Conversely, in TD subtype, in PwPD with tremor and with early disease stage, SEM was >10% of criterion (Table 1). T-test and CI 83.4% analysis showed a significant difference in ICC between participants with and without tremor (P=0.030) and in early and intermediate disease stage (P=0.003).

Table 1. ICC (3,k) values with 95% CI, Absolute and percentage values of SEM and MDC95 for the overall population and each subgroup. For subgroups 83.4% CI to assess intervals overlap are also reported. CI: confidence interval; ICC: intraclass correlation coefficient; MDC: minimal detectable change; mHY: modified Hoehn and Yahr scale; PIGD: postural instability and gait disorder; SEM: Standard error of measurement; TD: tremor dominant.

	Overall (N=104)	TD (N=39)	PIGD (N=65)	Tremor (N=57)	No tremor (N=47)	mHY 1-2 (N=68)	mHY 2.5-3 (N=36)
ICC (3,k)	0.888	0.854	0.899	0.838	0.914	0.839	0.939
Lower 95%CI	0.850	0.767	0.855	0.760	0.868	0.769	0.900
Upper 95%CI	0.919	0.916	0.933	0.896	0.947	0.892	0.966
Lower 83.4%CI	-	0.797	0.869	0.786	0.883	0.792	0.914
Upper 83.4%CI	-	0.901	0.925	0.881	0.939	0.878	0.959
SEM	570	742	495	506	609	817	267
SEM%	9.6	11.1	9.0	11.0	8.7	11.9	6.4
MDC95	1580	2056	1372	1401	1687	2263	741
MDC95%	26.7	30.9	25.0	30.5	24.0	33.1	17.7

Discussion

ADS measured at home for 5 consecutive days through a consumer smartwatch were reliable in all examined disease phenotypes and stages. However, a lower reliability and higher MCD and SEM was found in PwPD with tremor and with an earlier disease stage. This could be due to a reduced step detection performance linked to tremor and a higher heterogeneity in PwPD in early disease stages. These results underline the importance of considering disease phenotype and stage when analyzing mobility data from wrist-worn smartwatches.

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A 'Fingerprint' of fine motor control maturation: motor development descriptors and reference development bands in primary school children

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Introduction

The assessment of fine motor competence plays a pivotal role in neuropsychological examinations for the identification of developmental deficits. The PlacingBricks (PB) test evaluates fine motor competence across the lifespan relying on the measurement of time to completion: participants are requested to attach 18 square-shaped (2×2) Duplo™ bricks on a board (3 × 6 bricks size) as fast as possible [1]. Recently, the PB-test was instrumented using wearable inertial sensors to complement PB standard assessment with reliable and objective process-oriented measures of performance (i.e. cycle and placing durations) [2]. This work aims at extending the metrics that allow a quantitative fine motor assessment of the PBtest and at providing a reference trajectory for fine motor development from 6 to 10 years of age.

Methods

100 typically developing school-children (age groups: 6-, 7/8-, 9/10 years) performed the PBtest while wearing 2 inertial sensors (OPAL, APDM, USA, sampling frequency, 128Hz), one per wrist; both hands were tested. Temporal parameters (Cycle (s) and Placing (%Cycle) [1]), their variability (interquartile, IQR, and short-term and long-term variability, via Poicaré plots) were calculated on angular velocities, and nonlinear metrics (multiscale entropy, and recurrence quantification analysis) on acceleration data. Effect of age was analysed (Kruskal-Wallis test 5%) on the different parameters, divided by dominant/non-dominant hand, and a graphical polar plot was defined to represent parameters that showed age effect.

Results

Age effect was shown on temporal parameters, IQRs, multiscale entropy and recurrence quantification analysis. Specifically, Placing and Cycle durations and their variability decreased with age, multiscale entropy increased (on the three axis) and recurrence, calculated on the forearm longitudinal direction, decreased. These parameters were selected for monitoring fine motor development and presented on an ad-hoc designed polar plot showing age-group reference bands.

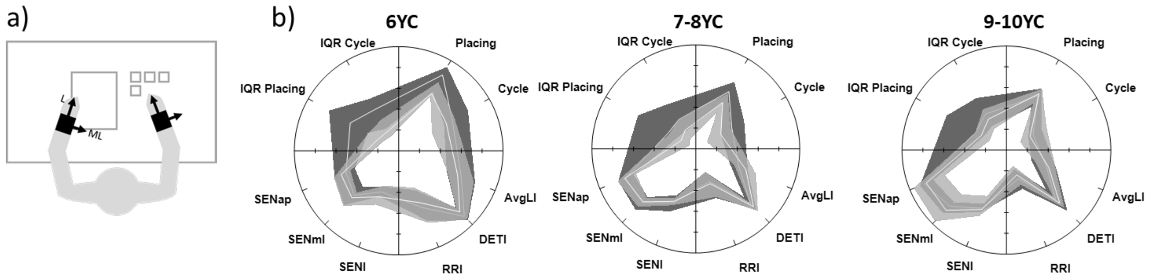

Figure 1. a) protocol setup; b) age bans for dominant- (light grey) and non-dominant (dark grey) hand. Sectors represent temporal parameters (Cycle, Placing), temporal parameter variability (IQR Cycle, IQR Placing), motor complexity (SEN on AP, ML and L axix, for τ = 6) and pattern regularity (RR, DET and AvgL on L axis) for 6-, 7/8-, 9/10-year-old children (6YC, 8-8YC, 9-10YC).

Discussion

Graphic results outline fine differences with maturation at first glance. The patterns allow to characterize specific aspects of fine motor maturation, to evaluate in which area changes occur and towards which direction, divided per dominant and non-dominant hand. Older children showed shorter and less variable cycle duration than younger children, possibly related to the expected maturation and the fine motor skills training during school years. On the other hand, older children showed less regular and more complex movement patterns, showing that their motor control allow the exploration of more flexible movements. In the future younger and older participants should be included to complete developmental motor trajectory.

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Gait development in very-preterm toddlers: does locomotor trajectory differ from full-term pears' one?

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Introduction

Preterm children have a high risk of motor impairment, with very-preterm (VPT, i.e., gestational-age <32weeks) being at higher risk [1]. Sensor-based gait analysis resulted effective in distinguishing gait performance between 24-month-old preterm and full-term (FT) toddlers, and among preterm at varying risks of motor delay [2]. However, to implement effective longitudinal monitoring of motor development and identify deviations from typical path, it is essential to understand how motor differences evolve during the early years. Using the approach described in [2], this study aimed to compare VPT and FT children at 18 and 24 months (18m and 24m), considering both their corrected age and walking experience (WE).

Methods

Fifty-two VPTs and nineteen (twelve 18-month-old and seven 24-month-old) FTs participated in the study. VPT data were collected longitudinally resulting in fifty-two tests at 18m and thirty-one at 24m. Children walked along a corridor while wearing 3 inertial sensors (MMR, mBient, USA) on the lower back and on the ankles [1]. Gait temporal parameters, their variability, and nonlinear metrics of trunk kinematics (i.e. harmonic ratio, recurrence quantification analysis, multiscale entropy) were extracted. Children were divided based on corrected age (18m and 24m) and on WE: 0-2months, 3-5months, >5months. As the relatively low sample size did not allow multi-factorial analysis, results were compared among age/WE groups separately (Wilcoxon-rank-sum test, 0.05).

Results

No difference was found in normalized stride-time among groups. VPT exhibited longer double-support and stance than FT at 18m, 24m, and with a WE > 5 months. VPT also showed higher variability in temporal parameters across all comparisons, including at WE < 5 months. At 24m, VPT showed lower medio-lateral harmonic-ratio, while no difference was found at 18m or when analysed with respect of WE. VPT showed lower multiscale entropy values in medio-lateral direction across all comparisons, with no difference observed in antero-posterior and vertical one. Regardless of age and WE, VPT recurrence parameters were lower in the sagittal plane, and the recurrence-rate higher in medio-lateral direction.

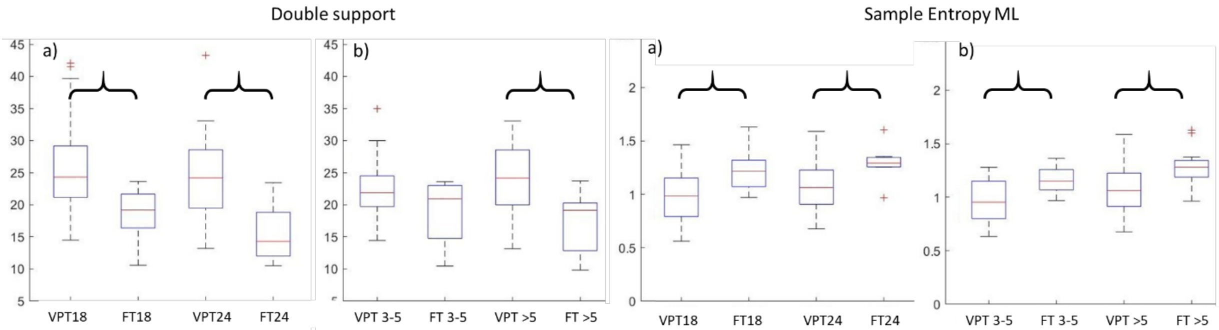

Figure 1. Double support and Sample Entropy in medio-lateral direction (ML) for very-preterm (VPT) and full-term (FT) children divided per age (a) and per WE (b). Brackets indicate significant differences.

Discussion

VPT children exhibited less mature motor performance during gait, characterized by lower stability (i.e., longer support phases) and higher variability. However, this variability did not indicate a structured exploration of more complex movements, as evidenced by lower recurrence in the sagittal plane and lower entropy in ML. The ongoing longitudinal data collection for both VPT and FT participants will increase the sample size and provide an effective means to monitor early locomotor development.

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IMU-Based balance assessment as an alternative to gold standard COP-based posturography: are we there yet?

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Introduction

Inertial sensors have been proposed as a portable alternative to force plates for posturography [1]. Although it is known that acceleration signals (ACC) from wearable sensors and center-of-pressure signals (COP) from a force platform cannot be directly compared, a recent review suggested that this is irrelevant if wearable sensors provide useful information on postural balance [2], still highlighting the need for ACC-based posturograhy validation, as sensitivity of the outcome measures is still missing. This work aims to compare ACC- or COP-based measures of postural response to variations in visual and surface conditions in healthy individuals.

Methods

Twenty-one healthy participants (11females/10males, 24±3years, 1.71±0.1m, 64±10kg) were asked to maintain static posture under 8 different randomized conditions (4 support surfaces: without-foam, soft-foam (E=33KPa), medium-foam (E=52kPa), rigid-foam (E=139kPa); 2 visual conditions: eyes-open, EO, eyes-closed, EC). Posture data were collected utilizing a force platform (Bertec, USA, 800Hz) and an inertial sensor at L5 level (Cometa, Italy, 200Hz) [1,2]. COP signals were lowpass-filtered at 10Hz. In absence of gold standard for ACC filtering [2], ACC were lowpass-filtered at: 0.5Hz, 3.5Hz, 10Hz, 50Hz. Time- and frequency-domain postural parameters (Table1) [2] were extracted from both COP and ACC. As distribution was not normal, Scheirer–Ray–Hare test (significance level, 0.05) was applied to test the effect of surface and visual condition on COP and ACC. Foam-stiffness effect was also analysed separately for EO and EC (Kruskal-Wallis, 0.05), to evaluate sensitivity to subtle changes.

Results

No interaction between the analysed factors was found. 3.5Hz-filtered-ACC resulted most similar to COP and, for brevity, only these results are reported. Surface affected: i) COP for all time-domain parameters, POWER and CF; ii) 3.5Hz-filtered-ACC for all time- and frequency-domain parameters. Visual condition affected: i) COP on some time-domain parameters calculated on the module or in AP direction; ii) ACC on mean- and centroidal frequency in ML (See Table 1). For foam effect, COP highlighted differences in AP (EO: PATHap, MVap, F95AP; EC: RMSap, RANGE, and RANGEap) while ACC in ML (EO: FDml, EC: RMSml, PATHml, MVml, POWER, POWERml).

	SURFACE		**EYE**		**FOAM**			
					EO		**EC**	
	COP-based	ACC-based	COP-based	ACC-based	COP-based	ACC-based	COP-based	ACC-based
Mean Distance	*	*						
Root Mean Square	*	*	* (AP)				* (AP)	* (ML)
PATH	*	*	* (AP)		* (AP)			* (ML)
Range	*	*	* (AP)				* (AP)	
Mean Velocity (MV)	*	*	* (AP)		* (AP)			* (ML)
Sway Area	*	*	*					
Mean Frequency		*	* (AP)	* (ML)				
Power	*	*	* (AP)					* (ML)
F50		*	* (AP)					
F95		*			* (AP)			
Centroidal Frequency (CF)	*	*		* (ML)				
Frequency Dispersion (FD)		*	*			* (ML)		

Table 1. Asterisks show significant effects of surface/eye/foam condition for each COP-based and 3.5Hz-ACC-based parameter.

Discussion

Present results highlighted differences in COP- and ACC-based posturography, as changes detected by the two approaches differed. ACC-based measures appear less sensitive to visual condition than COP-based ones; COP appeared to best discriminate balance performance in AP direction while ACC in ML, in agreement with literature [2]. Further research must investigate the physiological correlates of ACC-based measures to apply this method with interpretative purposes.

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Quantitative analysis of motor performance in patients with Mowat Wilson Syndrome using inertial sensors

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Introduction

Mowat Wilson Syndrome (MWS) is a rare genetic disorder. Patients exhibit distinctive facial features, musculoskeletal anomalies, congenital heart disease, ocular issues, gastrointestinal and urogenital anomalies, and severe nervous system dysfunctions [1]. A unique gait characterized by a wide base and elevated, flexed arms has been reported [2]. However, quantitative studies on motor performance in these patients are scarce. Inertial sensors can provide valuable insights, especially in outpatient settings [3]. This study aims to conduct a quantitative analysis of gait patterns in individuals with MWS to better define their motor characteristics.

Methods

Thirteen MWS patients participated in the study (age range, 4-26 years). Gait data were recorded using three inertial sensors (MMRL, Mbient, USA) placed on the trunk (L5-level) and on the shanks (sampling-frequency, 200Hz). Gait temporal parameter, their variability, and nonlinear metrics (harmonic ratio, HR, recurrence-quantification-analysis, RQA, and sample-entropy, SEN) were compared with a typically developing control group (n=112, 6-25 years, TD) [3]. Statistical analyses (Mann-Whitney U tests, significance level 5%) evaluated

i) differences between MWS and TD

ii) the effects of sex (4M/9F), assistance in gait (9/13), use of orthotic insoles (8/13), and agenesis of the corpus callosum (2/13) among MWS participants.

Results

All MWS patients exhibited longer double-support durations and higher temporal variability compared to TD. MWS also showed i) lower harmonic ratio on the three axes, ii) higher values of SEN and lower values of RQA in the vertical direction, and iii) lower values of SEN in medio-lateral. No significant effect of sex and gait assistance were found. MWS using orthotic insoles showed lower values of HR and lower levels of SEN in vertical and antero-posterior. Agenesis of the corpus callosum led to higher temporal variability, lower SEN in vertical direction and higher in antero-posterior and medio-lateral ones.

Discussion

Present results suggest a search for stability (longer double-support phases) and the implementation of compensatory strategies such as widening the base of support to increase medio-lateral stability (lower SEN in medio-lateral direction) and forward projection to facilitate progression in the absence of effective push-off action (higher SEN on the vertical axis), similarly to what observed in patients with Dravet syndrome [3]. The use of orthotic insoles and the presence of agenesis of the corpus callosum highlight further deviations from typical gait, demonstrating the phenotypic heterogeneity of MWS motor patterns. The limited sample size is due to the rarity of the disease (1:50.000 to 1:70.000 live births [5]).

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Sex differences in motor unit behavior in young, middle-aged and old adults during moderate isometric contractions

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Introduction

Aging is a physiological and morphological process characterized by a progressive loss of muscle mass, strength, and power accompanied by a decline in neuromuscular function [1,2]. Regarding neural changes, lower motor unit (MU) discharge rates and increased variability were previously reported in old with respect to young adults [3]. Furthermore, it was observed that the firing rate (FR) of early-recruited MUs increases to a lesser extent in old people during increasing force contractions. It is worth noting that current knowledge on MU FR in aging is mainly based on studies performed on male populations [4]. Considering the evidence of sex differences in MU behavior and the aging process [5], differentiating the analysis between the two sexes may provide additional insights to better understand age-related adaptations. In this study, we analyzed sex differences in MU recruitment and FR in young, middle-aged, and old adults.

Methods

Thirty middle-aged (MA) adults (15 females, 59±9 years), twenty-eight old (OLD) adults (12 females, 76±4 years), and ten young (YG) as control group (5 females, 26±2 years) were recruited. High-density electromyographic (HDEMG) signals were recorded from the vastus lateralis muscle using a grid of 64 channels during isometric ramp contractions from 0 to 30% and 50% of the maximum voluntary contraction (MVC) The MUs obtained from HDEMG decomposition were grouped according to their recruitment thresholds in steps of 10% MVC (0-10%, 10-20%, etc. Figure 1). Changes in MU FR was compared between age groups and sexes.

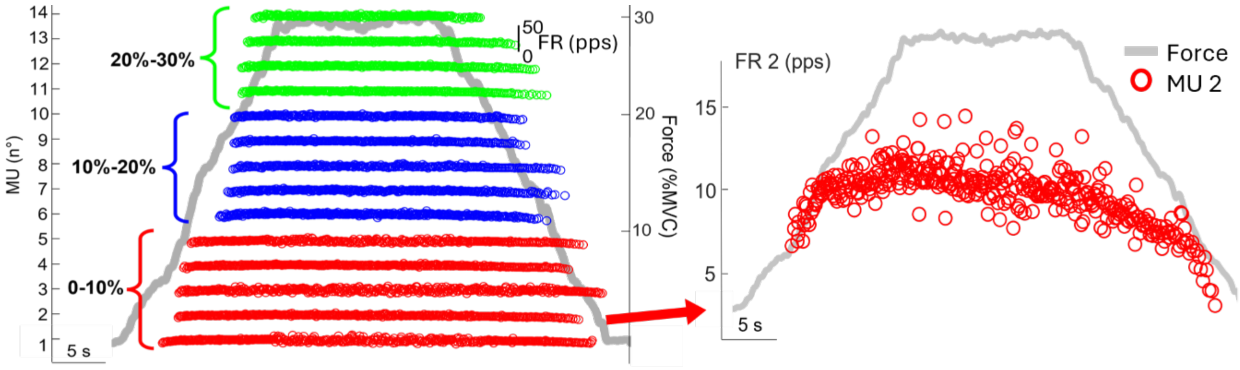

Figure 1. Separation of MUs according incremental range of force. Example of firing rate MU 2.

Results

The mean FR of all the MUs recruited was significantly lower ($p<0.001$) in OLD (9.3±1.5 pps at 30% MVC and 10.1±1.8 pps at 50% MVC) with respect to YG (10.3±1.6 pps at 30% MVC and 11.4±1.5 pps at 50% MVC), and MA (10.2±1.9 pps at 30% MVC and 11.2±2.3 pps at 50% MVC). When compared to males of the same age group, females showed higher FR in YG (+11.7%, $p<0.001$) and MA (+8.9%, $p<0.001$) but not OLD (+2.9%, $p=0.60$). In comparison to YG and MA, the MU FR of the OLD group increased to a lesser extent with the force increase. Interestingly, this behavior was significantly more pronounced in the female subgroup (i.e. lower FR modulation with force increase).

Discussion

The observed differences in the FR between sexes and age groups indicate that the trajectory of neuromuscular aging could differentiate between males and females, emphasizing the significance of accounting for sex in aging studies.

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Protocol for upper limb motion analysis in children with cerebral palsy: a proposal for clinical practice

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Introduction

Manipulation stands as one of the most complex adaptive functions in humans. Evaluating manipulation, particularly in individuals with Cerebral Palsy (CP), poses a challenge due to its heterogeneity and the lack of standardized protocols [1]. This study proposes a protocol for evaluating the upper limb functionality of children with CP using optoelectronic analysis, designed for clinical practice.

Methods

The setting was defined based on a literature review of existing protocols and the clinical needs of CP patients at the Children Rehabilitation Unit of AUSL-IRCCS di Reggio Emilia. It was tested on a typically developed subject (TD) and a child with hemiplegic CP. The equipment used included a VICON® optoelectronic system with 8 cameras. Marker placement was based on ISB [2] and U.L.E.M.A [3] guidelines, adjusted for data analysis facilitation. Thirteen markers were positioned at anatomical landmarks: C7, acromions, T8, jugular notch, lateral epicondyle, radial and ulnar styloid processes, metacarpals, and fingernails. The starting position required the subject to sit on a chair with a backrest, with feet flat on the floor. The forearm rested on a table with the elbow bent at 90°. Tasks included reaching, ball grasp, and pinch grasp, with both grasp tasks associated with precision and gross release. Each task was repeated three times. The position of the objects was determined considering the subject's anthropometric characteristics. The analysis included the following parameters: movement duration, peak velocity, movement units, curvature index, and trunk displacement.

Results

The preparation of the subjects took less than 10 minutes. The markers were clearly visible and stable during the acquisition, with the same camera setup used for gait analysis. The hemiplegic child exhibited greater execution times compared to the TD child, even with variable peak velocities (Table 1). Movement units were higher for the CP child, indicating less fluid movement. Curvature index values were increased, reflecting less linear trajectories. Trunk displacement was significantly greater, indicating more compensatory movement.

Table 1. Measured parameters for the TD subject and the child with CP.

	Duration (sec)		Peak Vel. (m/s)		Movement Units		Curvature Index				Trunk Displacement (deg)			
							Reaching		Transport		Reaching		Transport	
	TD	CP	TD	CP	TD	CP	TD	CP	TD	CP	TD	CP	TD	CP
Reaching	1.0	1.2	0.51	0.50	2	2	1.0	1.1	NA	NA	4.8	20.9	NA	NA
Grasping–Ball Gross Release	1.5	1.7	0.67	0.58	3.3	5	1.1	1.1	1.1	1.2	7.3	28.1	7.0	24.1
Grasping–Pinch Gross Release	1.6	2.3	0.60	0.62	3	6	1.1	1.2	1.0	1.2	6.9	29.2	5.3	21.9
Grasping–Ball Precision Release	2.2	2.6	0.55	0.63	3	12	1.1	1.5	1.1	1.9	7.3	19.3	6.6	8.8
Grasping-Pinch Precision Release	2.3	2.4	0.52	0.72	3.3	5	1.1	1.1	1.1	1.2	6.4	26.0	5.1	10.1

Discussion

The TD subject's results aligned with theoretical expectations, supporting the protocol's validity. The CP subject demonstrated increased movement duration, higher movement units, greater curvature index, and increased trunk displacement, consistent with literature findings [4,5]. Further validation on a larger sample is required to establish reference values and ensure reliability. This protocol could enhance clinical evaluations, particularly in surgical or botulinum toxin treatment contexts, by providing objective movement analysis before and after interventions.

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The role of an explicit strategy in muscle synergy recruitment and structure during adaptation to virtual surgeries

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Introduction

When we are exposed to a perturbed environment, both explicit processes (based on cognitive motor strategies) and implicit processes (which proceed automatically) are involved in motor learning [1]. Improving movement effectiveness during motor learning often requires altering the muscle activation patterns, which may be generated through the combination of muscle synergies [2]. This study aims to investigate how the presence of a cue favoring the adaption of an explicit strategy affects motor learning in tasks requiring or not requiring new muscle synergies.

Methods

Thirty-six right-handed participants practiced 'virtual surgeries' [3], involving perturbations in the pulling directions of a5 upper-limb muscles during a myo-electrically controlled isometric force-reaching task in virtual reality. Half of the participants practiced a compatible surgery, which required a recombination of the original synergies to reach all targets, while the other half practiced an incompatible surgery, which required the coordination of muscles in new patterns. Half of the participants were also informed, verbally and with a tactile cue, about which muscle was more effective in compensating for the perturbation. Thus, participants were assigned to one of four groups based on whether they were provided with the cue or not and whether they practiced the compatible or incompatible surgery.

Results

Participants who were provided with a cue successfully reached the target in a larger fraction of trials than those who practiced the perturbation without explicit information (Figure 1). However, the presence of the cue did not affect the performance of participants exposed to the incompatible surgery when aiming at targets that required a significant alteration in muscle patterns compared to original synergies, thus, suggesting that explicit processes promote the uses of existing synergies, without altering their structure.

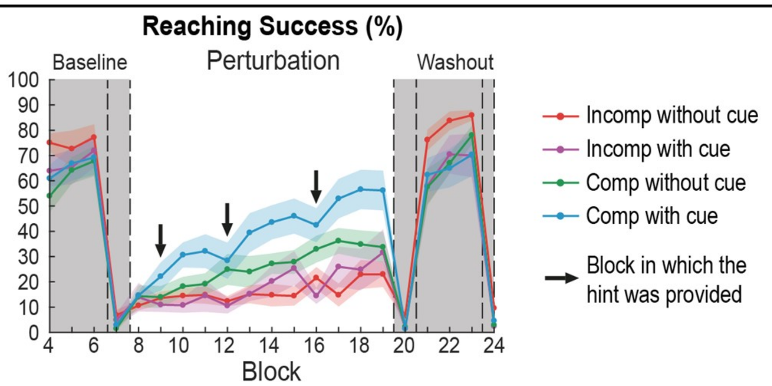

Figure 1. Percentage of successfully reached targets

Discussion

This study suggested that an explicit motor strategy, driven by the presence of a sensory cue, improves motor adaptation when the required changes in muscle patterns can be achieved by modifying the recruitment of existing synergies or by small changes in their structure. These results suggest that, in a modular control architecture, an explicit adaptive strategy is implemented at the level of synergy combinations rather that synergy structure.

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Assessing upper body compensatory movements in people with upper limb prosthetics using the Arm Profile Score: a preliminary evaluation on healthy subjects

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Introduction

Wrist mobility is fundamental for performing daily activities. Most trans-radial amputees with prosthetic devices compensate for the lack of wrist mobility by varying their kinematics patterns [1]. Several indexes have been proposed in the literature to assess task specific upper limb kinematic performance, among them, the Arm Profile Score (APS), which derives from the Arm Variable Score (AVS) computed from seven kinematic patterns (the three rotations of the trunk and of the shoulder and the elbow flexion/extension) during the execution of specific tasks [2].

This preliminary ongoing study aims at evaluating compensatory strategies in healthy subjects with artificially limited wrist mobility during the execution of four grip tasks.

Methods

Eight right-handed healthy subjects (5 males; 39±11 y.o.) were recruited. Participants performed four types of grips from a sitting position, recorded with a 10-camera motion tracking system (Vicon, UK). Data were processed using the Upper Limb Kinematics model [3]. The four grip tasks were lateral (pick up a card), cylindrical (lift an empty glass), prone extension, and supine extension (pick up a sheet), in two experimental conditions: wrist unconstrained (control group, CG) and wrist immobilized with a static brace (experimental group, EG) to simulate the prosthetic condition.

Each kinematic pattern was resampled between beginning and end of the task. For each task, the APS was computed from the joint/segment Arm Variable Scores (AVSs), which are defined as the root mean square (RMS) differences between the tested individual's kinematic patterns (CG and EG) and the relevant reference pattern (CG average) [2].

Results

On a subject basis, the APS in the EG was higher than in the CG (+68.7 [11.0, 109.5]% in the lateral grip, +27.9 [8.2, 65.4]% in the cylindrical grip, +27.6 [2.8, 62.4]% in the prone extension grip, +44.8 [35.5, 60.1]% in the supine extension grip). Figure 1 illustrates task-specific bar plots of each AVS for both groups.

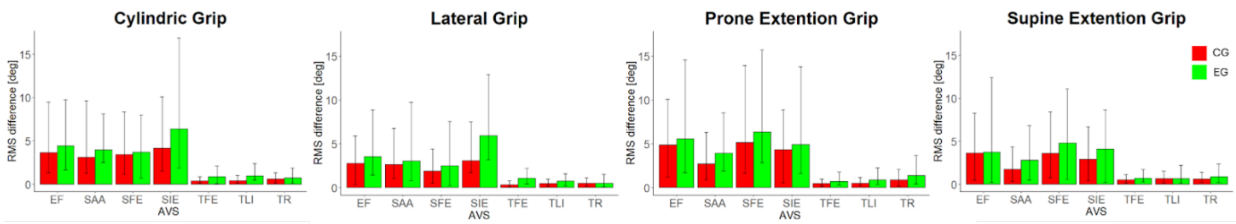

Figure 1. The median of the Arm Variable Score (AVS) determined for the subjects with unconstrained wrist (CG) and with immobilized wrist (EG). Error bars represent interquartile range (1^{st} - 3^{rd} quartile) around the median. EF: elbow flexion, SAA: shoulder abduction-adduction, SFE: shoulder flexion-extension, SIE: shoulder intra-extra rotation, TFE: trunk flexion-extension, TLI: trunk lateral inclination, TR: trunk rotation.

Discussion

Higher APS values for grips performed with the immobilized wrist are capable of highlighting the presence of compensatory movements. The individual AVS values show that they occur mostly at the shoulder and elbow level, while the contribution at the trunk level appears to be limited.

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Enhancing soccer athletes' performance: a kinematic analysis of agility training

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Introduction

In contemporary sports science research, understanding the effects of training programs on athletic performance is crucial. The Agility T-test is a fundamental tool for assessing movement proficiency in athletes, particularly in sports like football characterized by multidirectional movements. The aim of the study was to determine how a particular training program affected the agility and kinematic performance of young soccer players during the Agility T-test.

Methods

21 football players were initially recruited, but after excluding 4 participants, the final analysis was conducted on 17 players. The agility was assessed using an agility T-test, which consisted of 5 phases: forward run, 3 side runs (right, left, right, and left, right, left), and backward run. The test was considered "dominant" if the first change of direction was executed in the dominant foot's direction, and "non-dominant" otherwise. Each player performed the agility T-test two times per each time points: pre-period training and post-period training. The performance was assessed by measuring the test execution time. Kinematic data were collected using a set of 7 inertial sensors (Xsens MTW Awinda). The kinematics parameters analyzed were the peaks and range of motion (ROM) of the knee, hip, and ankle joints. A paired t-test was used to compare all the parameters (pre vs post training).

Results

The study results showed an improvement in test performance, with a mean reduction of 1 second for the dominant side ($p<0.001$) and 0.9 seconds for the non-dominant side ($p<0.001$) after the training. In terms of kinematic analysis, significant differences in the joints' ROM at different phases were found. There was a noticeable increase in both sides' knee joint ROM throughout the forward run. There was a significant increase in hip internal and external rotation ROM for both the dominant ($p=0.018$) and non-dominant ($p=0.047$) sides. The ankle showed a substantial decrease in plantar/dorsiflexion ROM ($p=0.001$) and an increase in pronation/supination ROM ($p<0.001$). Variations in knee flexion/extension ROM were noticeable throughout the lateral runs, and they were statistically significant for both the dominant ($p=0.002$) and non-dominant ($p=0.03$) sides. Comparing the backward run to the forward run, similar outcomes were seen. All the knee motions showed significant differences, and the hip internal/external rotation (only in dominant side).

Discussion

In conclusion, the study highlights the effectiveness of targeted training for agility and kinematic performance in soccer. Exercises focusing on strength, coordination, and speed over four months notably reduced test times, linked to improved lower limb strength and coordination.

Gender differences in ankle kinematic during a change of direction in U18 basketball players

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Introduction

Change of direction (COD) significantly impacts athletic performance in basketball, as players frequently execute rapid accelerations and decelerations with abrupt changes in direction. Therefore, proficient COD performance is crucial for basketball players. The National Basketball Association reported that ankle injuries are the most prevalent, comprising 61.6% of all injuries in basketball players. Given the varying injury rates between male and female athletes, exploring kinematic differences between genders is of interest. The objective of this comparative analysis is to investigate ankle kinematics during COD maneuvers between male and female U18 basketball players.

Methods

A total of 19 basketball players (7 female – 12 male) were enrolled. The players were tested on the same day following a proper 10-minute warm-up. Each player performed two agility tests: V-cut dribbling test without ball (NB) and with ball (WB). The tests consisted in a 25-m sprint with 4 COD of 45° each 5 meters. Kinematic data were collected using a set of 17 inertial sensors (Xsens MTW Awinda). The kinematics parameters analysed were the minimum and maximum peaks, and range of motion (ROM) of the dominant foot's ankle joint. The Mann-Whitney U test was used to compare all the kinematic parameters. The paired comparison between the two conditions WB and NB was evaluated using the Wilcoxon test.

Results

Male players showed greater abduction ($p=0.003$), and lower dorsiflexion ($p<0.001$), internal rotation ($p<0.001$) of the ankle during the COD of the Vcut test WB than female ones. Similarly in the NB condition, male players shower greater abduction ($p=0.048$) and lower dorsiflexion ($p<0.001$). Concerning the comparison between WB and NB conditions, kinematic analysis data showed a significant difference in ankle abduction/adduction ROM ($p=0.008$) in both genders. In particular, in the WB condition, the ROM was approximately 2.5° greater compared to the NB condition. This difference is mainly attributable to the maximum peak values ($p=0.01$).

Discussion

The study highlights significant differences in joint ROM between WB and NB conditions, and between males and females. These findings could contribute to the design of sex-specific training programs aimed at improving performance and reducing injuries in basketball.

Locomotion characterization of stroke patients through machine learning and feature selection techniques

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Introduction

Traditional clinical assessments of stroke patients are increasingly integrating instrumented gait analysis using wearable technologies and computational methods, supporting ecological evaluations [1]. In this context, identifying the most informative features to characterize pathological gait is essential [2]. Feature selection can be used to find the set of features that maximize classification performance of machine learning algorithms providing insights into gait characteristics after stroke [3]. Nevertheless, existing studies often present poor results generalizability due to methodological choices [2]. This study proposes a features selection approach to identify the most informative features to characterize gait after stroke.

Methods

Seventy-seven healthy participants (HP) and 68 patients with stroke (PS) performed a ten-meter walk test wearing five inertial sensors (Opal APDM, US, 128Hz) on their shanks, lower back (LB), sternum (ST), and forehead (FH). Shank sensors were used to estimate gait spatiotemporal parameters, while LB, ST, and FH sensors were used to assess gait quality, estimating features related to symmetry, variability, smoothness, and stability along the anterior-posterior (AP), medio-lateral (ML), and cranio-caudal (CC) components. The median over three trials was calculated for each participant. Features selection involved the identification of between-groups significant differences, redundant features elimination through correlation analysis, and sequential backward feature selection (SBS) [4]. SBS was iteratively executed using three machine learning algorithms (KNN, SVM, and decision TREE). Each algorithm was trained/validated on ten subsets of 54 and 48 randomly chosen HP and PS, using a 5fold cross-validation. Subsequently, the algorithms were tested on ten datasets of 20 HP and 17 PS each. Common features across the ten iterations and three algorithms were retained.

Results

Of the 80 initial features, 20 were retained after correlation analysis and used for SBS, whose results are displayed in Figure 1.

FEATURES	***KNN*** 88.1±5.7%	***SVM*** 89.8±5.1%	***TREE*** 81.2±5.7%	**TOTAL OCCURENCES**
LB ML SYMMETRY	*10*	*10*	*7*	27
STANCE DURATION VARIABILITY	*9*	*10*	*6*	25
STRIDE SPEED	*9*	*6*	*9*	24
SWING DURATION	*5*	*9*	*6*	20
FH ML SMOOTHNESS	*3*	*9*	*6*	18
FH AP SMOOTHNESS	*2*	*7*	*7*	16
LB to FH ML STABILITY (Attenuation coefficient)	*3*	*4*	*7*	14
ST AP SMOOTHNESS	*3*	*3*	*5*	11
FH AP STABILITY	*2*	*2*	*6*	10

10

0

Figure 1. The figure illustrates the frequency of each feature's occurrence across three algorithms over ten iterations, along with the total number of occurrences. The mean accuracy and standard deviation for each algorithm, averaged over the ten iterations, are displayed in the first raw.

Discussion

With a mean accuracy >80%, the three analyzed algorithms showed different tendencies in feature selection. This study highlights that feature selection results vary with the different algorithms, posing challenges for generalizability (when the aim is to find the most informative features). Using multiple iterations helps ensuring both generalizability and maximization of classification performance. The implemented procedure allowed the identification of nine features related to different domains of movement quality that most frequently maximized the discrimination between HP and PS locomotion. These features, mainly related to spatiotemporal characteristics, symmetry and smoothness of gait, may be used in clinical practice to evaluate disease progression, plan effective treatments and monitor their efficacy.

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Clinical and instrumental gait phenotyping in subjects with GLUT-1 deficiency syndrome

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Introduction

GLUT-1 deficiency syndrome (GLUT1-DS) [1] is a rare neurological disease characterized by gait disturbances, movement disorders, seizures and cognitive dysfunction [2]. This study aimed to assess the ability of a set of instrumental gait indexes to identify gait disorders in GLUT1-DS, and to detect potential correlations with the clinical phenotype and biochemical parameters.

Methods

We recorded a 30-meter gait of 16 subjects with GLUT1-DS and of 16 matched healthy subjects (HS). We performed gait analysis with an inertial sensor (G-Walk, BTS Bioengineering). Based on trunk acceleration, we calculated: spatio-temporal gait parameters, pelvic kinematics, harmonic ratios (HR), recurrence quantification analysis (RQA), stride length coefficient of variation (CV), the longest short-term Lyapunov's exponent (sLLE), and the log dimensionless jerk score (LDLJ). Along with the instrumental gait recording, we performed a comprehensive clinical and biochemical phenotyping.

Results

GLUT 1-DS showed lower values of HR and single support phase (Fig. 1; $p<0.05$), indicating impaired gait smoothness. Moreover, they showed higher values of CV and sLLE ($p<0.01$), suggestive of high dynamic instability and variability of gait. In patients under ketogenic diet, the CV negatively correlated with ketonemia ($r = -0.61$, $p<0.05$). Nine subjects (52%) had clinically evident gait disorders, mainly characterized by choreo-ataxic gait.

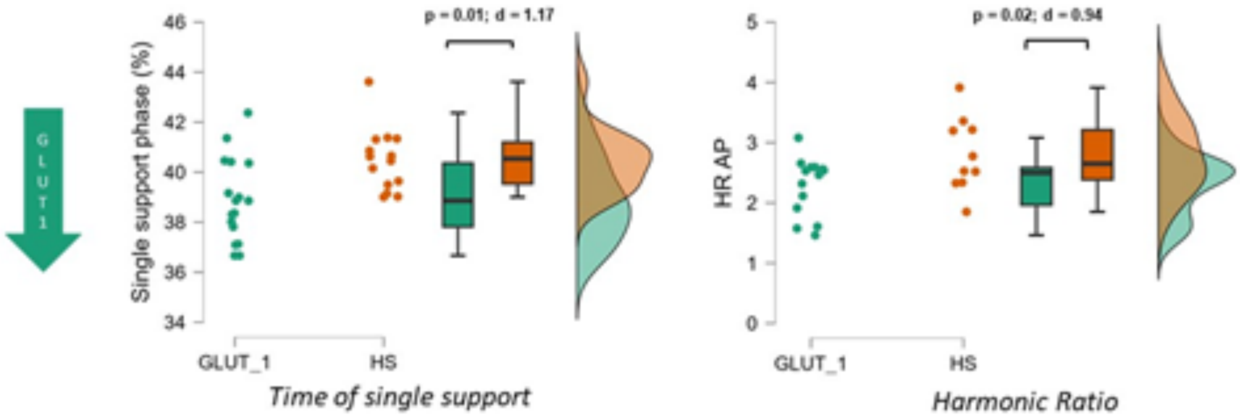

Figure 1. Differences in single support phase (SS) and harmonic ratio (HR) between HS (orange) and GLUT1-DS (green).

Discussion

GLUT1-DS exhibited multiple alterations in the trunk acceleration-derived gait indexes, which were suggestive of impaired gait stability and smoothness. Interestingly, increased gait variability correlated with low ketonemia, possibly suggesting this feature as a marker of poor therapeutic adherence.

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Virtual Reality and Mirror Therapy during Upper Limb Movements. An EEG Study

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Introduction

Stroke is one of the leading causes of disability worldwide [1]. In particular, impairments in arm function have the most relevant impact on quality of life. Neuroplasticity plays a key role in rehabilitation protocols, and Virtual Reality (VR) and Mirror Therapy (MT) are two of the most innovative techniques based on this concept. Electroencephalography (EEG) allows researchers to delve deeper into the physiological basis of neural functioning.

We aim to analyze, using EEG registration, the cerebral functioning during the execution of tasks performed with the upper limb, including exercises in both real and virtual environments, as well as using Mirror Therapy in both settings.

Methods

A single-session repeated measures study was conducted on healthy subjects from June to December 2023. Participants performed a reaching and grasping movement, then moved the object from left to right on a magnetic board in a real environment and along a virtual path in VR. The experiment included five tasks: real and mirror movements with both hands, and rest, each repeated three times for one minute in random order. EEG recording used twenty electrodes on the scalp, following the international 10-20 system. The EEG tracks were analyzed using EEGLAB software based on the Independent Component Analysis (ICA) and the Power Spectral Density (PSD) of signals at 10 and 15 Hz frequencies. For statistical comparative analysis, α was settled at .01.

Results

Ten healthy subjects were enrolled (5 men and 5 women). EEG analyses performed during the resting tasks revealed intense and widespread oscillations at a frequency of 10 Hz, which were significantly different compared to the motor tasks and uniform across the participants, specifically on central and posterior channels. Brain activation during movements under virtual and real conditions is largely overlapping in terms of activation and 15 Hz PSD at prefrontal, central, temporal and occipital levels. However, VR is associated with different activation patterns in parietal areas (P4, P3) and 10 Hz PSD in prefrontal, temporal and occipital areas. Mirror therapy has been shown to reduce the interhemispheric asymmetry associated with unilateral movement, indicating a beta-band activation ipsilaterally to the same in central and parietal and prefrontal regions.

Discussion

The results confirmed the validity of the acquisition and processing of EEG data we used. This study represents the first step in a research pathway that will involve stroke patients to understand the neurophysiological basis for using virtual reality and mirror therapy.

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Identification of compensatory movements by a single low-cost inertial sensor during rehabilitation exercises

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Introduction

Telerehabilitation represents a new mode of physical therapy that can complement conventional rehabilitation ensuring an improvement in physical performance, better treatment compliance [1], and effective monitoring of the quantity and quality of movement in a home environment [2]. The integration of machine learning models can be used to recognize incorrect movements [3,4]. The aim of this study is to develop a classifier to detect compensatory movements using affordable inertial sensors and simulated data. Another goal is to find out if this classifier can also work with real-world data.

Methods

The compensations to be detected were selected by an experienced kinesiologist following guidelines [5]. Seven young kinesiologists both executed the exercises accurately and simulated the compensatory movements. Five exercises were performed, targeting different body regions, using both prototype inertial sensors (MPU-9250, InvenSense, United States; @26 frames/s) and commercial ones (OPAL, APDM, United States; @128 frames/s). This abstract describes the classifier's development for one of the five selected exercises: sitting knee extension without lumbar support, performed in 2 set (with/without compensation) of 3 trials of 10 repetitions. For this exercise, the compensatory movement was an excessive lumbar extension in combination with knee extension. To identify it, sensors were placed on the lumbar region. For each repetition, ninety-four features were calculated. A feature selection was then performed using a lasso regression technique to remove correlated features. Different classifiers (Table 1) were developed, trained, and tested on the kinesiologists' data. A leave-one-out cross-validation (LoA) was performed to limit overfitting problems. Afterward, each classifier was also tested with 20 repetitions performed by a healthy elderly person who had the same compensation, using the prototypes.

Results

The lasso regression reduced the number of features to 67 for the prototype and to 81 for the commercial. The LoA results of the different models are shown in Table 1, in terms of accuracy and precision. The test on the elderly subject, identifies the Decision Tree as the best classifier (Accuracy = 88%, Precision = 100%).

	**Models**	**Hyper-parameters**	**Kinesiologist simulated data**				**Elderly data**	
			Prototype		**Commercial**			
			Acc	**Prec**	**Acc**	**Prec**	**Acc**	**Prec**
	RF	N=5	0.99	0.99	0.99	0.99	0.66	0.66
	DT	D=3, S=5	0.98	0.98	0.94	1.00	0.88	1.00
	GB	N=2	0.99	0.96	0.98	0.99	0.88	0.98

Table 1. Result of the different classification models developed. RF: Radom Forrest classier; DT: Decision Tree classier; GB: Gradient Boosting classier. Acc: accuracy value; Prec: precision value. N: number of estimators; D: maximum depth of each tree. S: the minimum number of samples required to split a node.

Discussion

All developed classifiers allowed to classify movements when compensatory, with no difference in their quality does changing sensor type. Moreover, the tested classifiers demonstrated their potential to identify compensatory movements in a real scenario using a single low-cost inertial sensor. Future work will include analyzing additional exercises, enlarging the simulated dataset, improving the classifier, and validating the model in a larger set of real-life situations.

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The effect of subtalar arthrodesis for the correction of adult acquired flat foot deformity on in-shoe plantar pressure

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Introduction

The Adult Acquired Flatfoot Deformity (AAFD) is characterized by the collapse of the medial longitudinal arch and by functional alterations of the foot. Primarily, this arch flattening results in a significant increase of the plantar surface contact area and modifications in plantar pressure distribution [1]. When conservative options are not sufficient to relieve pain, corrective surgery may be necessary. The aim of this study was to analyse the effects of subtalar arthrodesis in patients with AAFD on in-shoe plantar pressure parameters during walking.

Methods

Capacitive-sensor insoles were used to measure in-shoe pressure data in 10 AAFD patients before and after surgical correction (Figure 1, a) via a modified Grice technique [2]. Four walking steps at self-selected speed were collected for each patient in both the affected and non-affected foot. All patients wore the same minimalist shoes. Peak pressure, mean pressure and contact area were determined at the hindfoot, midfoot and forefoot regions and in the whole foot. Spatial- and time-normalization was performed on the trajectory of the centre of pressure to allow averaging across trials and patients. Paired non-parametric Wilcoxon's test was used to assess the effect of surgery on pressure parameters. Post-surgery data were compared to those from a healthy control population.

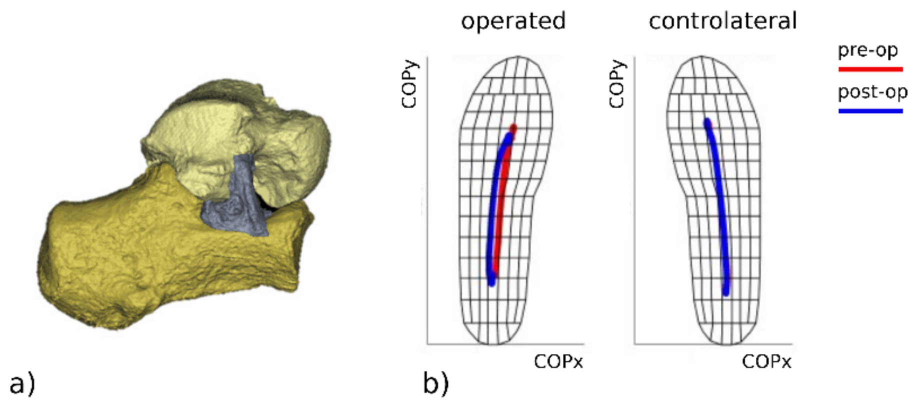

Figure 1. a) 3D reconstruction of the bones of the hindfoot from weight-bearing CT images in a typical patient after surgery; the bone graft used for the arthrodesis is depicted in gray. b) average trajectory of the in-shoe centre of pressure at pre-op (red) and post-op (blue) across all patients in the operated (left) and controlateral foot (right).

Results

While individual differences were observed, a "lateralization" of the plantar pressure distribution and a reduction of the mean contact area at the medial midfoot (pre-op = 6 ± 1%; post-op = 3 ± 1%; $p<0.01$) were detected after surgery across all patients. In addition, a more physiological trajectory of the centre of pressure was observed at post-op (Figure 1, b).

Discussion

This study provides experimental evidence on the effectiveness of subtalar arthrodesis in improving foot function and plantar pressure distribution in AAFD patients. These findings, which are consistent with the clinical outcome and the kinematic assessment conducted on the same population [3], suggest that this surgery helps reducing hindfoot and forefoot pronation.

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Age-related differences in mechanical fatigue and spatial EMG distribution of vastus lateralis muscle during dynamic contractions in old trained, old untrained, and middle-aged people

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Introduction

Physical activity plays a crucial role to limit the age-related decline in motor performance, including fatigue [1]. Muscle fatigue can be evaluated either at a mechanical/functional level or at myoelectric/neural level [2]. Mechanical fatigue is usually assessed through the decline in mechanical output (force or power) during isometric or dynamic contractions. Regarding myoelectric activation, previous studies using high-density electromyography (HDEMG) have reported age-related changes of the EMG spatial homogeneity over the muscle [3]. In this study, we investigated the effect of age and physical training on myoelectric and mechanical fatigue in old people during a dynamic, fatiguing exercise.

Methods

Twenty-six trained old subjects (70.19 ± 3.42 y.o., 17 males) were compared to 40 old untrained subjects (76.80 ± 4.45 y.o., 24 males) and 55 middle-aged subjects (59.38 ± 9.01 y.o., 19 males). The fatiguing exercise consisted of two consecutive sets of 40 isotonic (20% MVC), knee extensions (1 every 3 seconds). HDEMG signals were detected from the vastus lateralis with a grid of 64 electrodes. Differences between groups were assessed in terms of power output (torque · angular velocity) and homogeneity of the EMG amplitude distribution (coefficient of variation of the RMS across the 64 EMG channels, RMS_CoV) during the dynamic contractions.

Results

We observed that old untrained (UO) people had lower muscle power (66.0±10.9 W) than trained old (TO) individuals (114.5±12.6 W, $p<0.05$), but similar to middle-age (MA) healthy participants (89.55±9.5 W, $p=0.13$). Despite similar power reductions across groups (~30%) (Figure 1a), TO individuals recovered significantly faster between the two sets of contractions (21.3±3.8%) than UO (13.0±3.4%, $p<0.05$) and similarly to MA (19.0±3.2%, $p=0.54$). Differences in the activation map homogeneity were observed between the different groups (Figure 1b): the RMS_CoV was lower in UO subjects (13±6%) than in MA (18±7%, $p<0.05$), while TO subjects (18±5%) showed similar results to the MA subjects (Figure 1c).

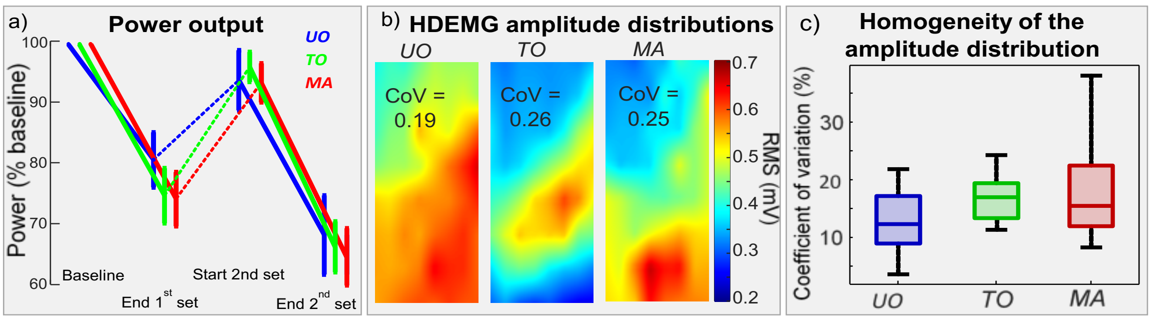

Figure 1. a) Power output changes during the test. b) Representative examples of the EMG amplitude distribution. c) Differences in the homogeneity of the amplitude distribution.

Discussion

The effect of exercise training on older subjects was evident in the absolute power production and the mechanical recovery from fatigue between the two sets of contractions. The differences in the EMG amplitude distribution of the old untrained subjects suggest a more homogeneous spatial motor unit recruitment, consistent with the known changes in fiber type content in elderly people. These changes appear to be delayed in trained older subjects, who showed a CoV of the EMG amplitude distribution comparable to that of 10-year-old younger, middle-aged subject.

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Dual-task disrupts gait smoothness in Parkinson's disease: a Timed Up and Go test study

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Introduction

The Timed Up and Go (TUG) test is often completed in a dual-task modality for assessing gait and balance and as an outcome measure in Parkinson's disease (PD). Sound movement is smooth, with movement decomposition the hallmark of ataxia. Dual-tasking reduces gait speed. However, its effects on movement smoothness have been less investigated. This study assesses whether dual-tasking reduces walking smoothness in PD besides reducing speed.

Methods

Twenty PD patients (11 females; age, years, median = 73.5; IQR = 11.75) completed the three-meter TUG test (single task modality), the TUG test while doing serial subtractions (i.e. with cognitive dual task) and carrying a glass of water (motor dual task). Two types of walking were assessed from the TUG test recorded with an inertial sensor on the lower back: walking straight and while turning. The root mean square of the trunk angular velocity and smoothness measures reflecting the number of "peaks and dips" in the speed profile (i.e. the Log-Spectral Arc length, LSpArc and the Log-DimensionLess Jerk, LDLJ) were obtained from the sensor. Linear mixed-effects models and ANOVA were calculated for hypothesis testing. Estimated marginal means were used for post-hoc tests and effect sizes (ES).

Results

Compared to single-task, in the walking phase, angular velocity was similarly reduced in cognitive (ES = 0.95; $p < 0.001$) and motor (ES = 0.77; $p < 0.001$) dual tasks. An analogous result was found for the turning phase. Dual-task also increased the number of foot strikes. Smoothness was reduced in both dual-task modalities compared to single task. In walking, LSpArc was lower in cognitive (ES = 0.67; $p < 0.001$) and motor (ES = 0.36; $p = 0.006$) dual tasks. Again, a similar pattern was found for turning. However, when the differences between tasks in velocity and step number are considered, the decreased LSpArc in cognitive (ES = 0.39; $p < 0.001$) and motor (ES = 0.18; $p = 0.024$) dual-task is confirmed only for the turning phase. LDLJ substantially replicated the LSpArc findings.

Discussion

In PD, dual-task decreases speed and increases the step number in the TUG test walking and turning phases. Dual-task also decreases gait smoothness; at least for turning, this smoothness impairment is independent of the dual-task-induced changes in gait speed and step number. As an independent feature of movement, when the dual-task TUG test is the outcome measure, improving smoothness in dual-task represents a novel outcome index in PD.

Effects of fatigability induced by prolonged walking in people with Multiple Sclerosis: preliminary results on static and dynamic balance

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Introduction

Motor fatigability, i.e. worsening of a motor task performance over time, is one of the most disabling symptoms in people with Multiple Sclerosis (PwMS) [1]. However, the causal associations between fatigability and motor functions is not yet clear. The present abstract reports preliminary results about the effect of experimentally induced motor fatigability on static and dynamic balance in PwMS.

Methods

Twenty-one PwMS (age:52±8 years, Expanded Disability Status Scale:3.6±1.0) and 10 healthy subjects (HS) (50±10 years) performed a Walking Fatiguing Task (WFT) requiring walking at sustained speed for 30 minutes or until complete exhaustion, corresponding to a Rate of Perceived Exertion (RPE)>18 (Borg scale). Participants underwent also posturographic tests (maintenance of upright posture on firm/foam surface, with eyes open/closed) before (Pre), immediately after (Post) and 30 minutes after (Rest) the WFT. All tests were executed wearing three inertial sensors (MTw, XSens, NL) on lower back and ankles. The time walked during WFT and the final RPE were provided. Moreover, three sensor-derived metrics were computed to describe dynamic balance during the WFT (mediolateral short-term Lyapunov Exponent (ML_sLyE) [2]) and static balance during the posturographic tests (ML Sway Amplitude (ML_SwayAmpl) and ML Sample Entropy (ML_SaEn) [3]). T-test was used to compare the percentage change in ML_sLyE from the first to the last minute of the WFT between PwMS and HS. Mixed-effect repeated-measure ANOVA was applied to analyze possible different trend among Pre/Post/Rest balance metrics in the two groups.

Results

All HS completed the 30-minute FWT with a RPE score of 12±3 points. PwMS walked for 23±8 minutes with a RPE score of 17±3 points. ML_sLyE increased more during the WFT (p<0.01) in PwMS (15.9%±7.9%) than in HS (-11.0%±15.1%). Regarding posturographic tests, a significant TimeXGroup interaction was found in ML_SwayAmpl and ML_SaEn (Fig.1).

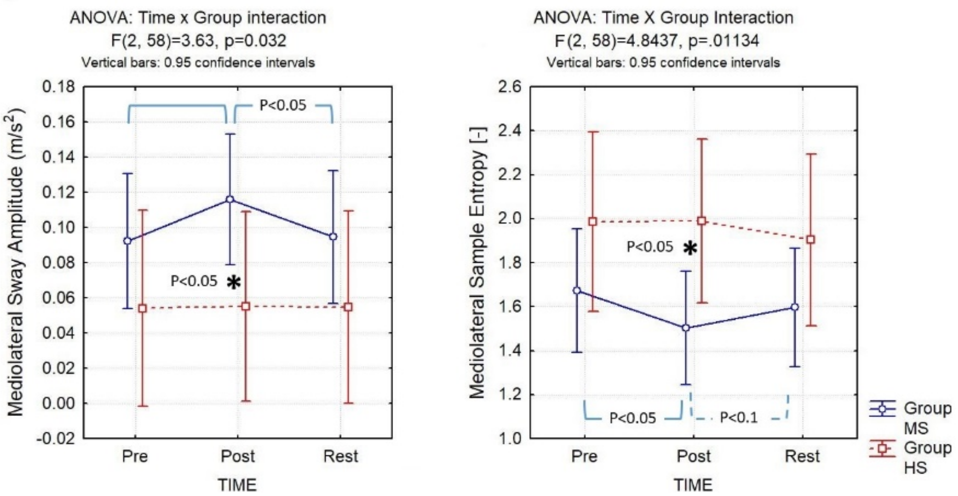

Figure 1. ML_SwayAmpl and ML_SaEn at Pre-Post-Rest balance assessment in HS and PwMS. Asterisk and blue bars: Bonferroni-Holm post-hoc comparisons.

Discussion

These preliminary results suggest an acute effect of experimentally induced motor fatigability on balance in PwMS. Dynamic balance worsened (increased ML_sLyE) during the WFT in PwMS only. Regarding standing balance, ML_SwayAmpl and ML_SaEn remained stable among Pre/Post/Rest in HS. PwMS showed a different trend: static balance worsened (increased sway amplitude and decreased entropy, meaning decreased balance control automaticity) immediately after the WFT and returned to baseline values after 30-min rest. A larger sample should confirm these preliminary findings.

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MOVEWISE (mobility observation via wearable integrated sensor evaluation): a multicentric, prospective, observational, and longitudinal study

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Introduction

Falls are a major public health concern, causing an estimated 684,000 deaths annually [1]. Neurodegenerative diseases, e.g., Parkinson's disease (PD) and multiple sclerosis (MS) and chronic vestibular disorders (i.e., elderly with dizziness, DE), significantly increase fall risk due to motor impairments. Wearable inertial sensors play a crucial role in preventing falls by providing continuous and ecological monitoring of people's mobility [2]. In this context, the MOVEWISE project is a multicentric, prospective, observational, and longitudinal study aimed at developing innovative methods for identifying and quantifying key indicators of stability to predict risk of falls using a wearable multi-sensor inertial system.

Methods

Participants will be equipped with the INDIP system, combining inertial measurement units, pressure insoles, and distance sensors, on their feet and pelvis to provide spatiotemporal gait parameters [2] and dynamic base of support (BoS) [3], and the TED, a smart badge with accelerometers and gyroscopes, for long-term monitoring. Eighty participants, including 20 healthy controls and 20 patients for each cohort (PD, MS, and DE), will be recruited from five Italian centers. Each participant will undergo four phases: preliminary evaluation to collect demographic and clinical data, including the Falls Efficacy Scale International [4]; in-lab for validation of developed methods using structured exercises with the INDIP against a stereophotogrammetric system; out-of-lab for testing of methods during 2.5 hours of real-world activities using the INDIP; and long-term monitoring with seven days of continuous tracking using the TED system. After a 12-month period, during which patients will receive standard rehabilitation treatments, these phases will be repeated to assess long-term rehabilitation effects in mobility and stability. Patients will also maintain a fall diary in case of falls. All data will be stored using REDCap, a secure web application for managing databases. Data processing will validate key metrics from the wearable systems, such as dynamic BoS and fall detection, and identify correlations between mobility parameters and fall risk markers. Additionally, it will observe changes in kinematic parameters post-rehabilitation, correlating them with subjective improvements and reduced fall risk.

Results

The study obtained ethics committee approval 474/CE 2024. Figure 1 shows an example of experimental setup.

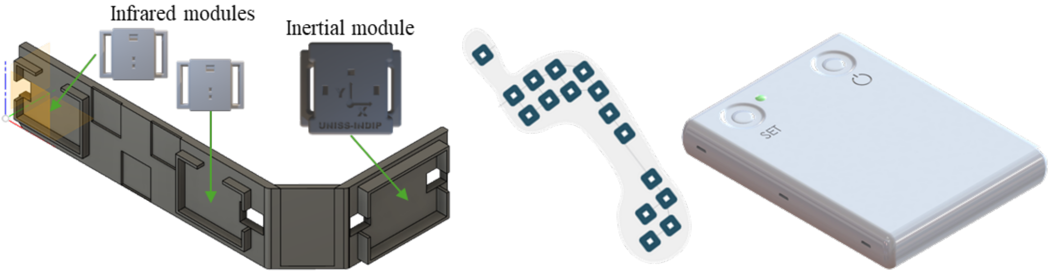

Figure 2: (left) the setup for the right foot including an ad-hoc support for the inertial and infrared modules to estimate the dynamic BoS; (centre) a pressure insole to estimate the temporal parameters; (right) TED smartbadge.

Discussion

Experiments are planned for July 2024. MOVEWISE's findings will improve fall risk prediction, significantly impacting clinical practice by offering more accurate and individualized fall prevention strategies. This abstract is part of the project NODES which has received funding from the MUR – M4C2 1.5 of PNRR with grant agreement no. ECS00000036.

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Responsiveness to rehabilitation of local dynamic stability of the trunk in subjects with primary degenerative cerebellar ataxia

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Introduction

This study aimed to assess the responsiveness to the rehabilitation of three trunk acceleration-derived gait indexes [1], namely the harmonic ratio (HR), the short-term longest Lyapunov's exponent (sLLE) [1,2], and the step-to-step coefficient of variation (CV)[1], in a sample of subjects with primary degenerative cerebellar ataxia (swCA), and investigate the correlations between their improvements (Δ), clinical characteristics, and spatio-temporal and kinematic gait features.

Methods

The trunk acceleration patterns in the antero-posterior (AP), medio-lateral (ML), and vertical (V) directions during gait of 21 swCA were recorded using a magneto-inertial measurement unit placed at the lower back before (T0) and after (T1) a period of inpatient rehabilitation. For comparison, a sample of 21 age- and gait speed-matched healthy subjects (HSmatched) was also included. Cohen's d with Hedge's correction was used to calculate internal responsiveness. To identify significant differences between swCA and HS at T0 and T1, the unpaired t-test or Mann–Whitney test was used. The external responsiveness was assessed using an anchor-based method using the smallest detectable change of the SARA scale (3.5 points) criterion for clinical improvement [3].

Results

At T1, sLLE in the AP (sLLEAP) and ML (sLLEML) directions significantly improved with moderate to large effect sizes (sLLEAP: $p = 0.03$; $d= 0.75$; sLLEML: $p=0.00$; $d = 0.86$), as well as SARA scores ($p = 0.00$; $d = 0.73$), stride length ($p = 0.04$; $d = 0.46$), and pelvic rotation ($p = 0.03$; $d = 0.49$). sLLEML and pelvic rotation also approached the HSmatched values at T1 (Fig. 1), suggesting a normalization of the parameter. HRs and CV did not significantly modify after rehabilitation. ΔsLLEML correlated with Δ of the gait subscore of the SARA scale (ΔSARAGAIT) ($\rho = 0.41$; $p = 0.03$) and Δstride length ($\rho = 0.51$; $p = 0.01$). ΔsLLEAP correlated with Δpelvic rotation ($\rho = 0.41$; $p = 0.03$) and ΔSARAGAIT ($\rho = 0.43$; $p = 0.03$). The minimal clinically important differences (MCID) for sLLEML and sLLEAP were ≥ 36.16% and ≥ 28.19%, respectively, as the minimal score reflecting a clinical improvement in SARA scores (Fig. 1).

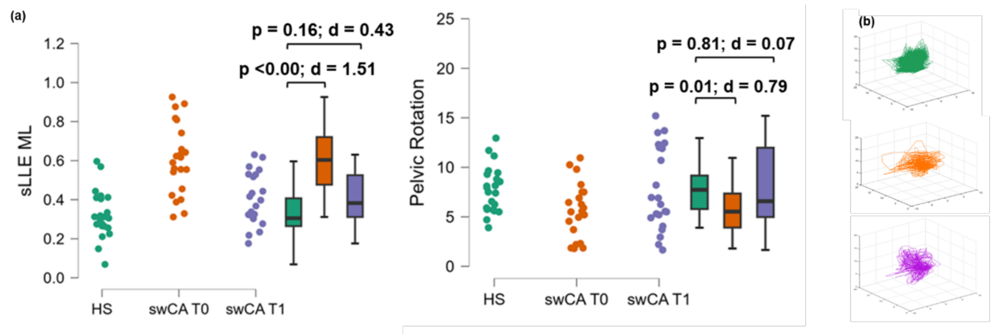

Figure 1. External Responsiveness Findings

(c)

	AUC	MCID	Se	Sp	LR+	LR-	PTP+	PTP-
Δ $sLLE_{ML}$	0.75 (0.41 - 0.91)	≥ 36,16 %	0.78	0.77	3.37	0.28	70%	16%
Δ $sLLE_{AP}$	0.70 (0.36 - 0.88)	≥ 28,19 %	0.66	0.77	2.89	0.43	67%	23%

Discussion

When using inertial measurement units, sLLEAP and sLLEML can be considered responsive outcome measures for assessing the effectiveness of rehabilitation on trunk stability during walking in swCA [4].

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Instrumental static balance assessment of patients with Parkinson's disease and Parkinsonism for clinical applications: a systematic review

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Introduction

Patients with Parkinson's disease (pwPD) and Parkinsonism usually complain of impaired balance and fall more frequently than healthy adults [1]. Instrumental posturography has been suggested to quantitatively assess static balance in pwPD [2]. This systematic review aims to critically appraise the use of static posturography in pwPD and identify gaps hindering its translation into the clinical routine.

Methods

Four databases were investigated. Primary studies on pwPD or Parkinsonism assessing the "baseline" condition (i.e., static posturography performed barefoot, in a bipedal upright stance, acquired with eyes open, on a firm surface) were included. A tailored set of 19 quality questions for the critical appraisal process was designed de novo, encompassing five different domains: study methodology, clinical aspects, assessment protocol, technical aspects, and transferability to clinical practice. Each question was scored on a three-level basis (i.e., 1 for "yes", 0.5 for "limited details", and 0 for "no"), plus "not applicable" score. This allowed computing the domain-related and total percentual score and classifying studies as high-, medium-, and low-quality [3].

Results

132 studies were included. The majority of the papers (105/132) was rated medium-quality (see Figure 1a). The two categories with the lowest scores were "transferability to clinical practice" and "assessment protocol" (see Figure 1b). The main flaw hindering translation into clinical application was the lack of a stated rationale behind the choice of a specific protocol and the selection of the posturographic parameters (32/132 high-quality studies).

From a clinical point of view, study samples lacked descriptive details or included patients with heterogeneous disease severity. On the other hand, treatment techniques and dosages, when applicable, were overall properly detailed.

From a methodological point of view, the lack of: 1) a-priori sample size design, 2) description of both set-up and instructions given to patients (e.g., foot and arm positioning, visual targets), 3) relevant technical information (i.e., sampling frequency and filters), and 4) clarity on the formulas used to obtain parameters further limit the power of study results and protocol replicability.

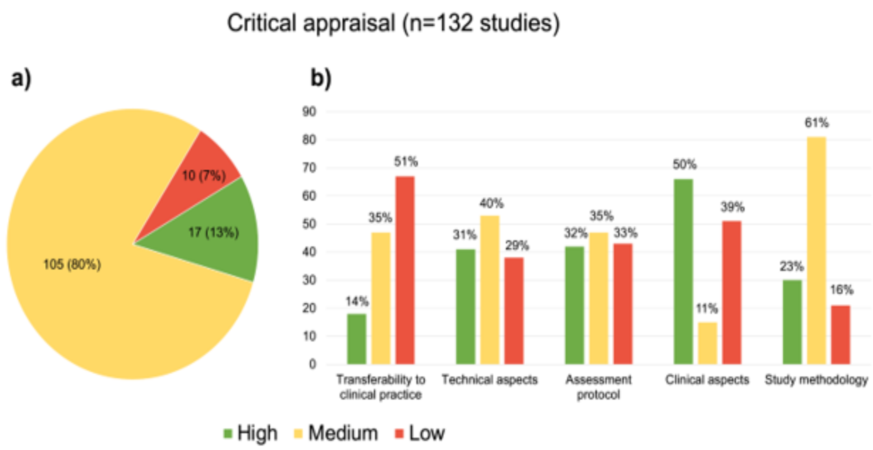

Figure 1.

Discussion

Our customized critical appraisal highlighted several opportunities for enhancing the quality of studies on static posturography in the assessment of pwPD. Addressing these areas can improve the external validity and clinical transferability of scientific literature to daily practice, which is key in biomedical research. This review provides useful references for each of the domains considered, supporting the rapid portability of findings to clinical settings.

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Monitoring the insurgence of involuntary muscle activity and the development of spasticity after an ischemic stroke over a six-month period: a case study

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Introduction

The onset of involuntary muscle activity (IMA) at rest is one of the consequences of stroke, occurring within a vicious cycle of paresis and rearrangement of soft tissues and central control [1]. The early identification of IMA in acute patients supports clinicians in designing timely tailored interventions [2]. Recent studies have demonstrated the feasibility of long-lasting electromyographic (sEMG) recordings to monitor IMA [3,4]. This study aims to monitor the insurgence and development of IMA.

Methods

This is a single case study on a 51-year-old woman with an ischemic stroke resulting in complete upper limb paresis. She underwent rehabilitation as an inpatient for the first four months, then continued it as an outpatient. Clinical evaluation involved: elbow range of motion (ROM), muscle strength (MRC), spasticity (MAS, Tardieu Angle), and other functional scales for ADLs. Instrumental evaluation was performed with the patient lying in bed and at rest using a wearable probe to acquire bipolar sEMG data and 3D acceleration (Cometa, Milan, Italy), placed on the biceps brachii (BB). The assessments took place over six months as follows: five days (T1, stroke unit, sEMG recording duration: 6h), ten days (T2, stroke unit, 6h), one month (T3, rehabilitation ward, 10 minutes), three months (T4, ward, 10 minutes), and six months (T5, home, 10 minutes) after the event. sEMG data were analyzed as in [3] and visually verified. IMA duration and peak-to-peak amplitude (p2pA) are reported.

Results

Elbow passive ROM progressively decreased from 140 to 120 degrees from T0 to T5, with muscle force slightly increasing from MRC=0 to 1. Spasticity was clinically detected at T2 (MAS=1), progressively increasing, especially for the elbow extensor muscles. At T5, the patient remained highly dependent during ADLs, with almost absent upper limb function. The results of instrumental assessment are shown in Figure 1. IMA was first detected at T1 and its percent duration increased progressively until 100% at T5.

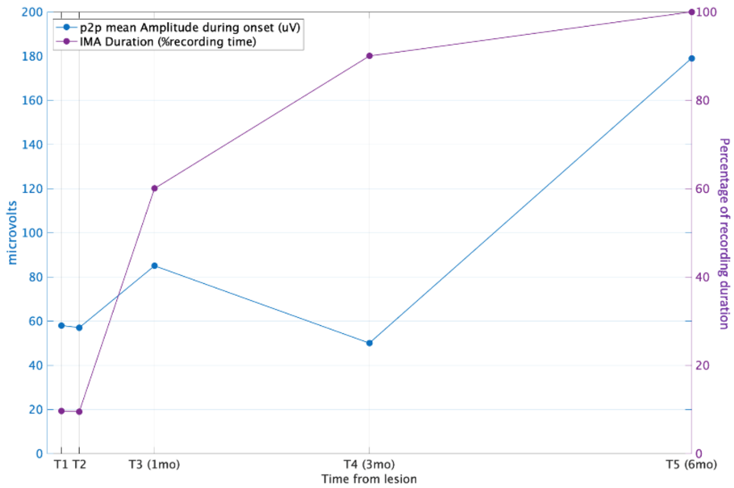

Figure 1.

Discussion

This single case study confirms the feasibility of assessing IMA in a flaccid arm in the first days after a stroke and monitoring its evolution from the stroke unit setting to the patient's home. IMA percent duration appears to be an informative indicator of the patient's evolution toward spasticity. The possibility of easily assessing IMA in acute inpatients can have a huge impact on the management of their postures, physiotherapy, and treatments.

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Whole-body cryostimulation (WBC) to improve trunk mobility in individuals with fibromyalgia and comorbid obesity: preliminary results

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Introduction

Pain, fatigue, stiffness and reduced range of motion are among the key targets for fibromyalgia (FM) rehabilitation. WBC is a physical treatment which consists in exposing the entire body to cryogenic temperatures. Emerging evidence has shown it could represent a promising complementary treatment to manage FM symptoms due to its anti-inflammatory, analgesic, and exercise-mimicking benefits [1,2]. The purpose of this study was to evaluate the effects of an add-on WBC intervention to a multidisciplinary rehabilitation program on trunk range of motion (ROM) at different treatment stages in a sample of FM patients with obesity.

Methods

Four individuals with FM and comorbid obesity were enrolled. Patients were admitted to the Istituto Auxologico Italiano (Piancavallo, Italy) for a 4-week multidisciplinary rehabilitation program, including nutritional intervention, psychological support, supervised physical activity, and a cycle of 10 WBC sessions. Each WBC session involved exposure to cold dry air at -110°C for 2 minutes in a cryochamber (Artic, CryoScience, Rome, Italy). To assess changes in ROM, participants underwent instrumented motion analysis at three time points: before the first WBC session (T0), after the first session (T1), and at the end of the WBC cycle (T2). Participants were equipped with a set of 10 reflective markers attached to specific anatomical landmarks on trunk [3], and acquired with a 6-cameras motion capture system (VICON, Oxford Metrics Ltd., Oxford, UK) across the execution of three basic exercises for trunk mobility (i.e., anterior trunk flexion, lateral bending, and twist). Data were collected for each task and compared across sessions.

Results

The overall results of the assessment showed an improving trend in the ROM associated with the performed motor tasks, in particular for anterior flexion and twist. While the ROM did not seem to significantly vary between T0 and T1, evident improvements were reported between T0 and T2. Specifically, there was an 8.86% increase in sagittal ROM during anterior flexion and a 30.13% increase in coronal ROM during the twist task.

Discussion

The overall results suggest that WBC positively impacts trunk mobility in patients with FM. These positive outcomes could be potentially due to the analgesic effects and inflammation reduction facilitated by WBC. Although the small sample limits the generalizability of the results, WBC seems to enhance physical rehabilitation in FM [4]. Further research is needed in this direction.

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Investigating Muscle Coordination during Dynamic Functional Reach Assessment

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Introduction

The Functional Reach (FR) is used to evaluate dynamic balance by measuring how far one can reach forward beyond arm's length while standing, beginning with the arm at 90° of shoulder flexion [1]. In everyday activities, however, reaching may also involve lifting the arm from a resting position to reach an object, requiring higher coordination and motor control. The understanding of muscle coordination mechanisms underlying FR with arm elevation and lowering is missing. This study aims at providing a baseline understanding of muscle coordination patterns by investigating muscle synergies in healthy young individuals, which lays the groundwork for future research on elderly population and on age-related changes in muscle synergies.

Methods

Seventeen healthy volunteers (7F, 27.53 ± 3 y.o.) completed 10 repetitions of standardised bilateral (BiFR) and unilateral (UniFR) FR, using both arms for BiFR and their dominant arm for UniFR. Bilateral activity was recorded from 16 muscles by surface electromyography (EMG): Anterior Deltoid (AD), Erector Spinae (ES), Latissimus Dorsi (LD), Vastus Lateralis (VL), Tibialis Anterior (TA), Biceps Femoris (BF), Gastrocnemius Medialis (GastM), and Soleus (Sol). Kinematic data enabled segmentation of each repetition, which was then applied to pre-processed EMG data. Segmented, time normalised EMG data from all repetitions were concatenated and averaged to emphasize consistent activation patterns and reduce noise. Muscle synergies were extracted for each subject from the mean EMG dataset using a non-negative matrix factorization. The number of synergies was identified by [2,3]. Similarity of weight coefficients within subject groups and between UniFR and BiFR was evaluated using the scalar product (DOT) [4]. Similarity of synergies' activation profiles was assessed with a non-parametric two-sample t-test using statistical parametric mapping.

Results

Three muscle synergies were necessary to reconstruct the EMG data for both tasks (Figure 1): Syn1 pertains to FR execution, involving ankle stabilizer muscles alongside AD and LD; Syn2 relates to braking during movement control and returning to upright posture, featuring ES and BF; Syn3 acts as a stabilizing synergy during arm elevation and lowering. No significant differences in synergies' activation profiles were found.

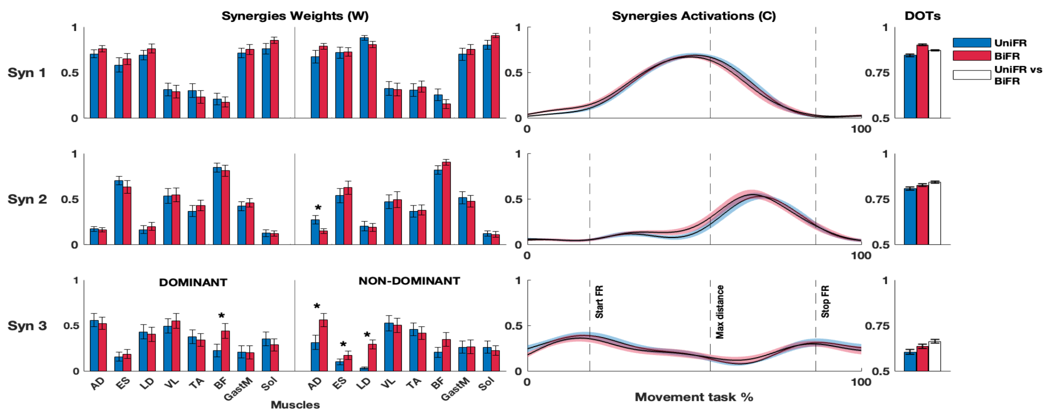

Figure 1. Comparison of muscle synergies extracted during UniFR and BiFR. The asterisk (*) indicates a statistically significant difference ($p < 0.05$).

Discussion

This study demonstrated that FR exhibits a typical muscle coordination pattern regardless of whether it is performed with one or both arms. Moreover, young individuals exhibited a preference for an ankle strategy in transitioning from a static to an unbalanced forward position. Future research is needed to elucidate if age-related decline in balance ability changes these patterns in elderly.

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A novel image processing pipeline to enhance muscle fascicle tracking during gait

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Introduction

Ultrasound-based tracking of muscle fascicles enables the quantification of architectural parameters of the muscle-tendon unit and their changes during a contraction. This information is crucial, as muscle architecture significantly influence how neural excitation is converted into force and movement. Currently available tracking algorithms were designed for isometric or highly-controlled dynamic contractions and perform poorly in unconstraint movements, where complex muscle shape changes may hinder fascicle visibility and tracking. In this work, we propose a novel algorithm (DynTrack) to enhance the visibility of muscle fascicles in order to improve the tracking accuracy during gait.

Methods

We developed a semi-automatic algorithm based on the sequential feature-point tracking combining spatial and frequency-domain filters (1) to enhance fascicles' visibility. Ultrasound (US) videos (50 fps) of the medial gastrocnemius were recorded in two participants during heel rise and walking at three different velocities (60, 90, 120 bpm and 0.5, 1.1, 1.4 m/s). We compared the estimated fiber lengths (FL) and pennation angles (PA) obtained by our algorithm with those derived from manual tracking (reference measure). Root mean square error (RMSE) and correlation coefficient (CC) of the FL and PA profiles were used for quantifying differences. These results were then compared with those obtained using an existing tracking algorithm (UltraTrack, 2).

Results

The two methods showed comparable CC values for the heel rise task (0.78 ± 0.15 for DynTrack vs 0.78 ± 0.11 for UltraTrack). However, lower RMSEs were obtained with our method for both FL and PA estimates (FL: 7.37 ± 3.28 mm vs 13.90 ± 2.18 mm and PA: 2.65 ± 1.29° vs 4.81 ± 1.27°). Similar results were obtained during walking (FL: 8.72 ± 2.52 mm vs 13.07 ± 2.39 mm and PA: 2.44 ± 0.61° vs 5.36 ± 2.95°). During walking CC values differed substantially: 0.64 ± 0.15 for DynTrack vs 0.22 ± 0.17 for UltraTrack (Figure 1).

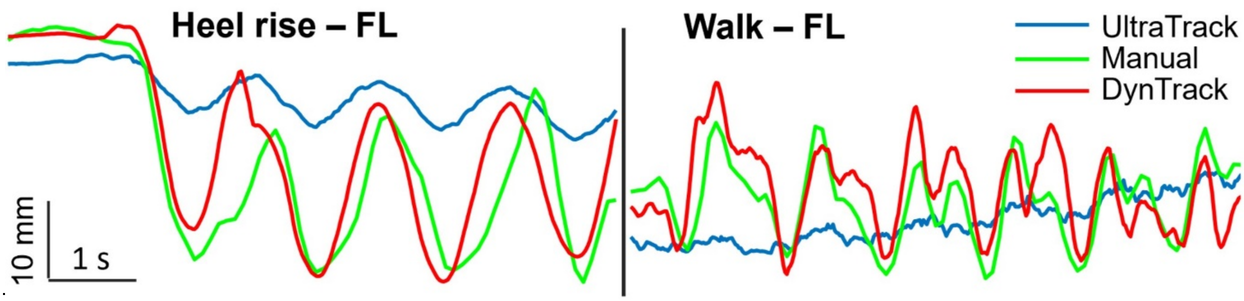

Figure 1. Fascicle length (FL) estimates during two dynamic tasks. Similar results were obtained for PA.

Discussion

The proposed method enhances tracking accuracy compared to currently available tracking algorithms. Dynamic fascicle tracking, coupled with the increasing miniaturization and wearability of ultrasound devices (3), opens new opportunities for quantifying muscle structure during gait.

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The impact of sports training on the Spinal Cord Injury individual's balance: the PITS project

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Introduction

Spinal Cord Injury (SCI) causes major challenges to mobility and daily life activities. Maintaining balance in dynamic and static contexts becomes a crucial issue with the need to adopt new strategies. Sports and physical activities are rehabilitation methods for patients with SCI [1]. The assessment of balance currently relies on subjective evaluation scales, highlighting the need for objective measurement methods, such as optoelectronic systems. We hypothesize that SCI patient's balance would increase after the sports. This study aims to assess the efficacy of different sports on the balance strategies of patients with SCI.

Methods

The study was conducted by the activities of the "Piano Individuale Terapeutico Sportivo (PITS)" project. Patients with SCI practiced sports including archery, bowls, swimming, tennis, fencing and athletics, designed for them for 3 months. Twenty-two patients (17 male and 5 female, 45.39(±14.33) years, BMI: 24.60(±4.04) kg/m2) kept a 30-second open-eye and closed-eye seated stand to assess the static postural balance in their wheelchair before(T0) and after(T1) the sports. Kinematics was acquired by placing 14 retro-reflective markers in relevant body landmarks, with an 8 infrared cameras optoelectronic system. We computed the Centre of the Upper Body (CUB) and evaluated two posturology parameters [2,3]: Total Sway Length and Mean Sway Density Peak (MSDP), a parameter extracted from the Sway Density Curve. The non-parametric Wilcoxon signed rank was used to compare the T0 and T1 conditions. A p-value lower than 0.05 was considered statistically significant.

Results

The statistical analysis showed a statistically significant difference between T0 and T1 in the Total Sway Length, both in the eyes-opened and closed ($p=0.033$, and $p=0.039$, respectively), while no statistical differences between T0 and T1 were found for the MSDP in both conditions ($p=0.592$, and $p=0.263$, respectively). Figure 1 shows the mean and standard deviation values.

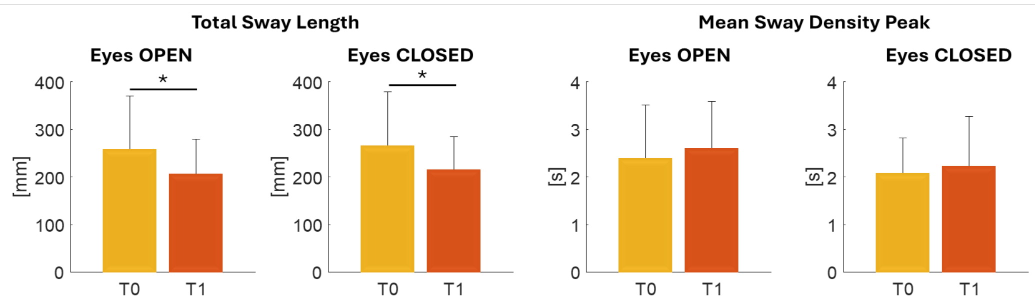

Figure 1. Mean and standard deviation of the Total Sway Length indices for the open-eye (a), closed-eye (b) and Sway Density Curve indices for the open-eye (c), closed-eye (d) both before (T0) and after (T1) sporting activities.

Discussion

The results reveal a reduced overall displacement of the CUB in plane demonstrating an improvement in the subjects' postural balance management [4]. In details, the statistically significant decrease in the Total Sway Length and the increase trend in MSDP parameter in the subjects at T1, both in the eyes-opened and closed conditions, confirm an improvement in balance stability. The absence of statistical significance in MSDP could be due to the considerable variability through the various spinal lesion levels [5]. Overall, our findings demonstrate the benefits of sports activity in the rehabilitation of SCI patients, as well as the parameters' usefulness in quantitatively assessing their balance.

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Using textile sensors to assess electromyographic activation patterns during gait

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Introduction

Wearable textile sensors have the potential to be a valuable and innovative tool for monitoring muscle function in ways that are more comfortable and less invasive compared to traditional methods. The objective of this work is to identify electromyographic (EMG) patterns for the lateral gastrocnemius (GL) muscle by wearing a sEMG wearable device, that consisted of an e-textile leg sleeve with embedded sensors positioned below the knee and an insole with three textile pressure sensors for pressure signal acquisition. The sEMG band was presented and validated in a previous work [1].

Methods

This work enrolled six healthy subjects (age: 26.3 ± 1.6, 4 women) for the acquisition of EMG data from the GL muscle. The acquisition protocol entailed five consecutive direct walks along a 10-metre walkway. The acquired pressure signals were processed by an algorithm developed in Python to segment the steps. This allowed the extraction of parameters relating to the activation of the anatomical districts of interest during walking, as proposed in a previous work [2]. EMG envelopes were normalised in time and amplitude and averaged over the steps of a single walking trial. Activations were detected using a double threshold algorithm.

Results

The results indicate that during the gait cycle, the GL exhibits three distinct activation patterns. The first characterized by one activation, the second characterized by two activations and the third characterized by three activations. Figure 1 represents the three activations patterns with horizontal bars coded in grayscale. Different levels of grey represent the number of subjects in whom an activation was observed during the corresponding instant of the gait cycle, expressed as a percentage on the x-axis. Black corresponds to a condition observed for all subjects.

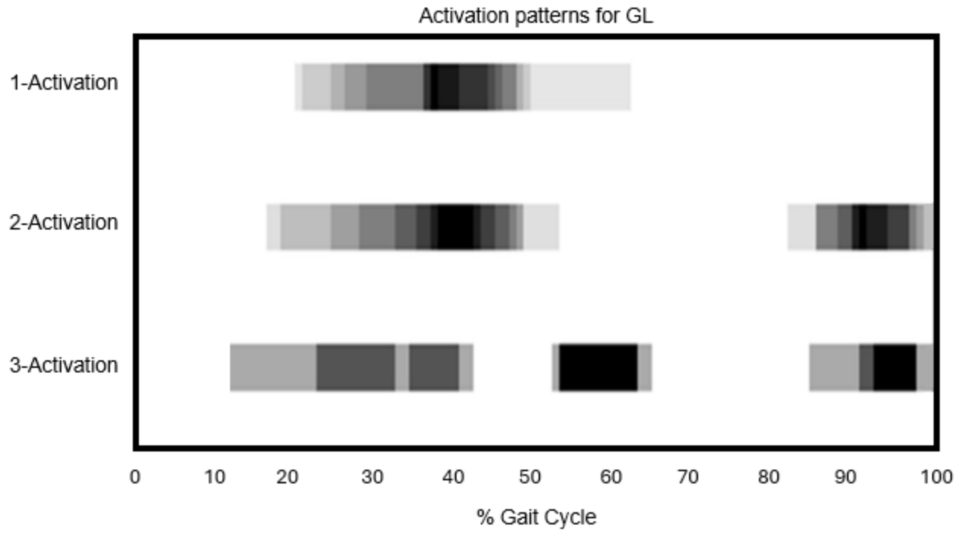

Figure 3. GL Activation modes according to gait cycle.

Discussion

The analysis indicates that the activity of the GL is concentrated in two regions of the gait cycle: flat foot contact to push-off (found in 100% of the trials) and the terminal-swing phase (54.4% of the trials). The first region is detected in all activation patterns. The second region is detected in the two- and three-activations patterns, in agreement with a previous work [2]. The third region is detected in the pre-swing phase (14.2% of the trials). This work verified the feasibility of this analysis using non-invasive textile sensors. In the future, the population under investigation will be expanded, to confirm the identification of activation modes.

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Gait analysis in the evaluation of cancer-related fatigue. A literature review

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Introduction

Gait analysis (GA) is a valuable tool in evaluating and rehabilitating patients suffering from different diseases and related disabilities [1]. Among the possible roles of GA, the evaluation of the impairment of ambulation due to fatigue may be considered. Fatigue represents one of the most debilitating consequences of cancer. It can be caused by different factors: direct damage to the cancer, side effects of treatments, psychological status, and so on [2]. The aim of this study is to define the current status of the scientific knowledge about GA and cancer-related fatigue.

Methods

A search on PubMed was performed, using the criteria: ("gait analysis" OR "motion analysis") AND cancer AND (breast OR prostate). No specific filters were used. We performed a similar search using the MeSH Terms, which found a lower number of papers. For this reason, we used the first search without the MeSH Terms. The search was focused on breast and prostate cancers, due to the highest incidence of these forms of tumors in women and men respectively.

Results

We identified 33 articles, of which 8 were selected for pertinence. Seven were concerned with breast cancer and one with prostate cancer. Furthermore, only a scoping review included in the selection directly mentioned the topic of fatigue. The papers showed the importance of gait evaluation and balance assessment. The articles suggested that GA could provide useful information to personalize rehabilitation programs, helping to improve patients' quality of life through targeted interventions.

Discussion

Despite the limited number of studies, the evidence collected indicates that GA has great potential in the context of oncologic rehabilitation. These studies highlight the need for further research to deepen the application of this methodology, develop standardized protocols, and evaluate the effectiveness of rehabilitation interventions based on GA. Ultimately, the integration of this technology into treatment pathways could significantly improve the functional recovery and quality of life of patients suffering from breast and prostate cancer. The selected studies highlighted how GA could be used to evaluate and monitor functional and biomechanical changes in patients diagnosed with this form of cancer [3]. In conclusion, even the evaluation of cancer-related fatigue may be supported by GA and further research should shed light on this topic.

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The effects of hyaluronic acid on kinematic gait parameters in patients with knee osteoarthritis: a systematic literature review

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Introduction

Gonarthritis is a condition affecting about 10% of the population over the age of 50, due to a progressive alteration of the joint microenvironment and characterized by pain and functional limitation. Hyaluronic acid (HA) is a key component of synovial fluid and plays an important role in regulating the biochemical balance of the osteo-cartilaginous matrix. Affected patients are usually assessed using clinical scores and self-administered scales to evaluate symptoms. In this context, gait analysis provides an objective and detailed evaluation of the patient's walking to assess any deficit, set up a personalized rehabilitation treatment and verify improvements.

The effect of HA injections on the kinematic parameters of the knee during walking is present in a limited number of studies. The primary purpose of this systematic review is to examine the short and long-term effects of intra-articular HA injections on gait kinematic parameters, secondary aims include the evaluation of pain and improvement of autonomy during daily living activities (ADL).

Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed for screening the following databases: PubMed, Web of Science, Scopus. The following PICO model was used: patients with radiographic diagnosis of knee osteoarthritis (grade I-III according to Kellgren Lawrence); patients received intra-articular hyaluronic acid infiltrations; healthy controls or patients treated with corticosteroid or placebo infiltrations. Outcomes evaluated included gait kinetics measurements and functional assessment scales before infiltration and after follow-up.

Results

Out of a total of 342 articles identified, 13 articles were included. The data obtained reported a statistically significant improvement in speed ($p=0.001$) and step cadence ($p<0.005$) at 30 days after the end of treatment, knee adduction moment ($p<0.001$), sagittal ground reaction force vectors (GRF) ($p<0.01$) up to 6 months post-treatment, a confirmed reduction in pain and an improvement in clinical scores of VAS ($p < 0.001$), Lequesne score ($p < 0.001$), and KOOS ($p < 0.001$) in short-term follow-ups. Treatment with only HA did not result in a significant improvement in other gait parameters and muscle activity on electromyography.

Discussion

This review confirmed the role of hyaluronic acid treatment on knee pain and functionality. It's important to use gait analysis to objectively assess patient deficits and develop a personalized rehabilitation plan. The synergy between infiltrative treatment and rehabilitation treatment is essential to prolong the effects of hyaluronic acid, improve patient walking, and prevent the progression of gonarthritis.

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Assessment of erector spinal muscles activation in pre and post training with surface electromyography in an equestrian athlete with recurring non-specific low back pain

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Introduction

Several studies have highlighted the association between low back pain (LBP) and horse riding without specifically analyzing the causes. Moreover, there is a lack of literature on evaluating LBP (low back pain) in equestrian athletes, often overshadowed by the horse's health [1,2]. The study aims to determine if surface electromyography can identify changes in spinal erector activation pre- and post-training in an equestrian athlete with recurring non-specific LBP by measuring the flexion relaxation phenomenon (FRP).

Method

The clinical case study was carried out following the guidelines "CARE" for reporting clinical cases [3]. The patient is an equestrian athlete, who experienced low back pain after training. To analyze this, surface electromyography of the spinal erector muscle was conducted pre- and post-training using the BTS FREEMG 1000 surface electromyography and the G-SENSOR with the Flex-relax protocol following the guidelines [4,5], along with the NPRS (numeric pain rating scale) [6] pain scale assessment.

Results

Both FRP and FRR (flexion relaxation ratio) occurred correctly pre- and post-training on both first and second day (Table1), NPRS values were 4 both days during pre-traing and 8 and 7.5 during post-traing on th first and second days of measurements, respectively.

Table 1. Average values on November 24th and 30th.

		November 24th	November 30th
Pre-training	FRP	3.40	7.32
	RMS standing phase	12.43	12.14
	FRR	13.26	11.98
Post-training	FRP	3.33	4.92
	RMS standing phase	6.37	6.81
	FRR	12.59	6.91

Discussion

Although the FRP values were found to be within normal limits both pre and post- training it was observed that the FRP values obtained post-training were very close to the RMS values of the standing phase, which indicates that there was less activation energy in the extensors during the standing phase witch could be related to the pain felt by the patient after training as indicated by an NPRS of 8 on the first day and 7.5 on the second day. Conclusion: The findings suggest that surface electromyography can detect differences in spinal erector muscle activation between pre- and post-training. Additional measurements and a larger study population would enhance certainty.

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AI-Enhanced Wearables: Transforming Parkinson's and Atypical Parkinsonism Diagnosis

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Introduction

Parkinson's Disease (PD) and Atypical Parkinsonism (AP) exhibit overlapping signs and symptoms, making it challenging to distinguish, especially at their onset. They may present a similar clinical picture initially, but the evolution, treatment, and prognosis are significantly different. People with AP typically exhibit a poor response to levodopa (LD) treatment [1]. Integrating instrumented motor tasks (e.g., Instrumented Timed Up and Go, iTUG [2]) with clinical assessments enables comprehensive evaluation of motor impairment. This study aims to evaluate gait impairment in people with PD and AP using wearables, investigate the discriminative power of iTUG outcomes, and develop machine learning (ML) algorithms to differentiate PD and AP.

Methods

The study included 71 (75.5 %) and 23 (24.5 %) persons affected by PD and AP, respectively. Motor response to LD-based treatment was assessed by iTUG, performed before (med-OFF) and 60 minutes after drug administration (med-ON). Blood samples for measuring LD plasma concentration were collected before the LD dose, at 15-minute intervals for the first 90 minutes, and at half-hourly intervals up to 3 hours after dosing [3]. The wearable system (mTest, mHealth Technologies srl) automatically computed spatiotemporal parameters using a single inertial sensor worn on the lower back. Area Under the Curve of the Receiver Operating Characteristics (AUC-ROC) analysis was used to assess the discriminative power of sensor-based gait parameters and clinical scores in differentiating PD and AP. The dataset was randomly divided into 70% for training and 30% for testing ML models. Undersampling and oversampling techniques were applied to account for imbalanced data issues.

Results

Most clinical variables did not differ between the two populations, except for MDS-UPDRS III score, which was significantly higher in AP. Motor performance was significantly worse in people with AP than with PD (Figure 1). The iTUG duration in the med-ON condition exhibited the highest AUC-ROC (0.82). The sensor-based motor outcomes in the med-ON condition were more discriminative than those in the med-OFF condition. The Support Vector Machine model trained using iTUG outcomes exhibited a higher F1-score in the testing dataset (0.88) than the model trained with only clinical scores (0.80).

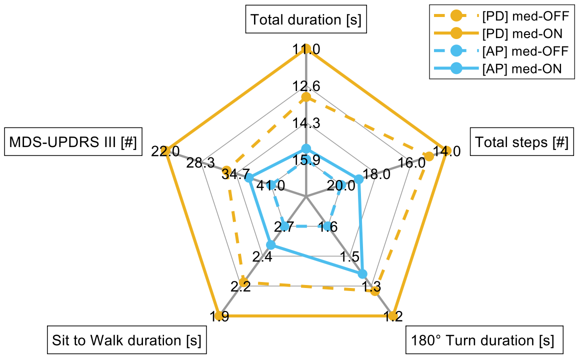

Figure 4. Radar plot of the median value of spatiotemporal gait parameters and MDS UPDRS III score in PD (yellow) and AP (blue). The med-OFF and med-ON conditions are represented by dashed and continuous lines, respectively. Internal values of the radar plot correspond to worse motor performance.

Discussion

Consistent with [4], the sensor-based iTUG gait parameters demonstrated promising results in discriminating between AP and PD. Results were better when they incorporated the responsiveness to LD. Applying ML and deep learning algorithms on larger cohorts of subjects may result in an accurate classification algorithm in the future, providing valuable insights for early disease diagnosis.

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Gait, posture, and upper limb bradykinesia responsiveness to subthalamic deep brain stimulation and levodopa in patients with Parkinson's disease using digital technology

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Introduction

Deep brain stimulation of the subthalamic nucleus (STN-DBS) is a well-established therapeutic treatment for Parkinson's disease (PD), providing improvement of symptoms such as tremor, rigidity, and bradykinesia [1]. Understanding the distinct impact of stimulation and levodopa on gait and postural features is crucial to optimize personalized therapeutic approaches. In addition to clinical rating scales, cutting-edge wearable sensors can be used to assess the effectiveness of pharmacological and surgical treatments, both in clinical settings and real-life environments [2-4]. This study uses wearable sensors and digital technology to evaluate gait, posture, and upper limb bradykinesia responsiveness to STN-DBS and levodopa.

Methods

Thirty-three persons with PD were evaluated before (pre-DBS) and six months after (post-DBS) bilateral STN-DBS. They performed a comprehensive motor protocol (including Timed Up and Go, 18-m walk test, full 360° turn in place, and postural sway) monitored by wearable inertial sensors placed on the lower back and the feet (mTest, mHealth Technologies srl), automatically measuring spatiotemporal gait parameters. A finger tapping test was performed using a tablet, tracking the number of times the person could alternately tap two buttons 20cm apart in 60 s with the most affected hand. In the pre-DBS, tasks were performed before (med-OFF) and 60 minutes after levodopa intake (med-ON). Post-DBS patients were evaluated in different stimulation and medication conditions (med-OFF/stim-ON, med-OFF/stim-OFF, med-ON/stim-OFF, med-ON/stim-ON). Tasks were performed in both single- and dual-task modes. The study evaluated clinical and instrumental motor outcomes before and after STN-DBS, comparing each medication condition before DBS to the corresponding condition after DBS with stimulation ON. The responsiveness of gait and posture to treatments was evaluated post-DBS by computing standardized response mean values, with the med-OFF/stim-OFF condition as the baseline.

Results

The comparison of the sensor-based motor parameters before the levodopa intake (med-OFF in pre-DBS and med-OFF/stim-ON in post-DBS) revealed a significant improvement in gait parameters (e.g., gait speed, stride length, and turning velocity) following STN-DBS surgery. In contrast, postural parameters exhibited minimal change. The alternate finger tapping test demonstrated a significant improvement post-DBS ($p<0.001$). Six months after the surgical procedure, gait speed was significantly enhanced in stim-ON conditions ($p<0.001$).

Discussion

STN-DBS significantly improved upper limb bradykinesia and spatiotemporal gait parameters, thereby supporting the efficacy of STN-DBS surgery on motor outcomes, gait, and axial features. Further research is needed to explore the long-term effects of STN-DBS, especially in real-world conditions using wearable sensors.

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How non-specific low back pain affects gait kinematics: a systematic review and meta-analysis

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Introduction

Non-specific low back pain (NS-LBP) is a frequent musculoskeletal condition affecting up to 80% of the population in their lifetime. Alterations in spinal and lower limb dynamics have been considered as potential factors directly involved in NS-LBP, including muscle weakness and poor neuromuscular function.

Since walking represents an activity routinely repeated throughout the whole day, it can be affected and contribute to pain and disability in subjects presenting NS-LBP. Despite the large number of studies carried out over the years, no systematic review exists on this topic.

Therefore, we carried out a systematic providing a synthesis of the evidence concerning gait kinematics in NS-LBP.

Methods

The conceptualization of this review followed the PRISMA 2020 checklist and the protocol was preliminary registered in PROSPERO (ID: CRD42023431380). A search strategy was implemented in Medline, Embase, Scopus, Web of Science, and IEEE Xplore databases, up to March 2024.

Inclusion criteria were: any analytical observational research instrumentally assessing the trunk and lower limbs kinematics of spontaneous walking in NS-LBP, compared to healthy people. Studies where walking was assessed on the treadmill were excluded.

Study selection and data extraction were performed by two blinded reviewers, the methodological quality was evaluated by the JBI Critical Appraisal Checklist, and the quality of the evidence was rated through GRADE framework.

Results

Overall, a total of 19 cross-sectional studies were included and none of those was found without any methodological issues. A meta-analysis was only possible for some of the examined spatial-temporal parameters.

The meta-analysis showed a lower gait velocity [-15.42 (-22.78, -8.06) cm/s; $p \leq 0.0001$], a lower cadence [-9.85 (-18.72, -0.99) steps/min; $p = 0.03$] and a lower step length [-6.30 (-11.83; -0.77) cm; $p = 0.03$] in NS-LBP compared to healthy people. A few authors observed a less and asymmetrical motion of the lower spine in the frontal and in the transverse plane. The quality of the evidence was rated as very-low.

Discussion

There is very-low quality evidence that gait speed, cadence and step length are reduced in patients with NS-LBP. There is proof of a movement reduction in the lower lumbar spine and in the pelvis, both in the transverse and in the frontal plane.

High-quality observational studies are needed to improve the quality of the evidence and to determine if the kinematic modifications in NS-LBP are related to physical or psycho-behavioral factors, and if they are caused by the presence of pain or by physical re-adaptations.

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Neuromuscular control patterns in Parkinson's disease: comparison of different EMG-driven neuromusculoskeletal modelling approaches

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Introduction

Parkinson's Disease (PD) has become the second most prevalent neurodegenerative disorder, affecting mostly the motor system. In recent decades, musculoskeletal modeling (MSM) approaches have proven to provide specific metrics (i.e. muscle forces) to quantitatively assess disease progression and plan rehabilitative interventions. Indeed knowing how muscle forces are distributed among the muscles offer the possibility to identify specific muscle deficiencies associated with a pathology and the impact of rehabilitation programs in restoring muscle function. When dealing with neurological pathologies, the adoption of elettromiography (EMG)-driven MSMs could be more appropriate [1]. The goal of the study is to compare two different EMG-driven MSM approaches on the assessment of muscle forces in PD.

Methods

The gait of 11 PD individuals (age=68.6±7.9 years, BMI=25.5±3.0 kg/m2) was assessed (Fresco center, Villa Margherita, Vicenza, Italy, ClinicalTrials.gov Identifier: NCT04778852), through an 8-camera optoelectronic system (120Hz, Vicon), synchronized with two force plates (960Hz, AMTI) and an 8-channel EMG system (2000Hz, Cometa). The IORGait protocol was adopted [2] and the electrical activity of 4 lower-limb muscles (Biceps Femoris, Rectus Femoris, Gastrocnemius Lateralis, and Tibialis Anterior) was recorded. Three methods were applied to compute the muscle forces: 1. OpenSim (v4.4) Static Optimization (SO); 2. CEINMS [3]; 3. Moco [4].

Muscle-optimizer tool was used to recursively scale the model; afterwards, inverse kinematics, joint torques and muscle-tendon unit moment arms were computed. In order to verify the validity of each approach, the MSM derived muscle activation profiles were compared with the experimental envelopes normalized on the peak value within the gait cycle through 1-D Statistical Parametrical Mapping [5]. Moreover, Root Mean Square Error (RMSE) and the Coefficient of Multiple Correlation (CMC) [6] were computed.

Results

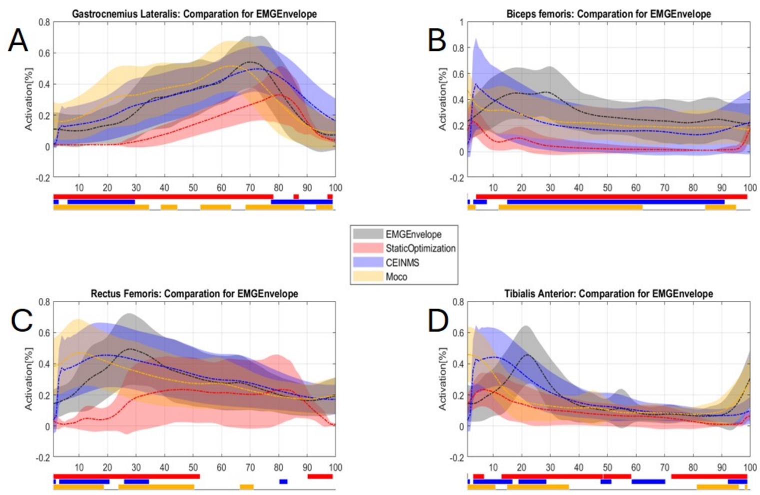

Figure 1. Gastrocnemius Lateralis (A), biceps femoris (B), rectus femoris (C) and tibialis anterior (D) estimated activation profile. Experimental envelope (grey), SO (red), CEINMS (blue), Moco (yellow): mean ± standard deviation. Statistical significance ($p<0.05$) in the lower part of the graphs: Experimental vs SO = red, Experimental vs CEINMS = blue, Experimental vs Moco = yellow.

Discussion

Results showed (Figure 1) closer agreement between muscle activity estimated through CEINMS and the experimental one both in terms of CMC (>0.67) and RMSE (<0.14), except for the Biceps Femoris where Moco was more accurate. Following these promising results, a deeper investigation on a larger cohort of individuals is necessary for a better generalization.

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Reliability assessment of IMU-driven inverse kinematics in Opensim: a proof of concept

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Introduction

In recent decades, Musculoskeletal Modelling (MSM) approaches have gained increasing interest due to the chance of estimating biomarkers not measurable in vivo (i.e. muscle forces). The main limitation of standard MSMs is the need to provide variables obtainable only through standard laboratory environments, thus limiting its application in free living environments. With the advent of OpenSense [1] the possibility to develop inertial measurement units (IMU)-driven MSMs have been provided for Xsense IMU devices.

The aim of this study is to assess the reliability of IMU-driven MSMs with respect to stereophotogrammetry based ones.

Methods

Several walking trials were acquired at the BioMovLab (University of Padova) from an individual (30 years, 22.86 kg/m^2) synchronously through an 8-camera optoelectronic system (Vicon, 200 Hz), and two different IMU systems: Cometa WaveTrack (142 Hz); Xsens (100 Hz); IORgait protocol was adopted [2].

OpenSense and a self developed adapted version, suitable for managing Cometa IMUs data, were applied to provide data compatible with OpenSim. Stereophotogrammetric data were preprocessed in MotoNMS [3].

A 13-degrees of freedom (DOF) lower limb model [4], optimally scaled from markers data, and IMU Placer tool for inertial data [4] were adopted to run the Inverse Kinematics (IK).

Two different comparisons were performed:

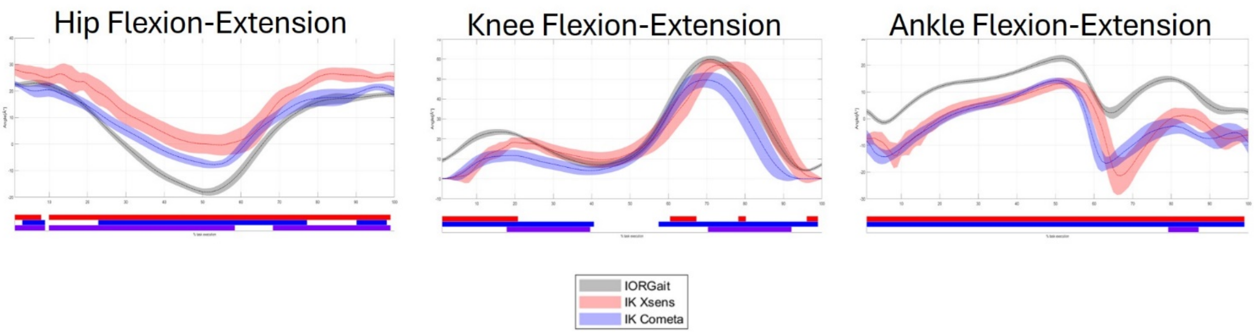
stereophotogrammetry-based joint angles estimation and IMU-based one;

stereophotogrammetry based IK in OpenSim and IMU driven Opensense obtained with both IMU systems.

1D Statistical Parametric Mapping [5], Root Mean Square Error (RMSE) and the Coefficient of Multiple Correlation (CMC) [6] were applied to test for statistical differences among the methods.

Results

Figure 1. Hip (left) knee (mid) and ankle (right) estimated Flexion-Extension. Markerbased (grey), XSens IMU-driven (red) and Cometa IMU-driven (blue) IK: mean ± standard deviation. Statistical significance in the lower part ($p<0.05$): Markers vs Xsens = red, Markers vs Cometa = blue, Xsens vs Cometa = Violet.



Discussion

Results showed higher agreement between XSens IMU-driven IK and the stereophotogrammetric based one, both in terms of offsets (RMSE<10°) and correlation (CMC>0.7, exception made for ankle).

Despite the lower agreement, Cometa system exhibited results similar to Xsens if compared with the markerbased IK.

Nevertheless, results should be considered in light of the presence of differences in the body pose estimation, scaling tools and the reduced complexity of the OpenSim model adopted in the present study.

Future research will involve a larger cohort and a more complex OpenSim model to gain deeper insights.

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Outpatient rehabilitation in a chronic stroke patient focused on motor control: the significant support of motion analysis

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Introduction

Stroke is a cerebrovascular disease related to the damage of brain tissue with consequent function disruption of different severity. It is an important worldwide cause of disability [1]. Walking may be involved among the possible function alterations with a significant reduction in daily abilities and quality of life. For these reasons, specific rehabilitation programs should be applied to get a proper functional recovery. We present a case of 58-year-old stoke patient in which computed motion analysis allowed to reveal the peculiar gait impairments to design a tailored rehabilitation and to show the evolution.

Methods

The patient reported a left hemiparetic syndrome following right ischemic stroke in 2018. He came to our attention for severe gait impairment and important asymmetry with reduction in gait speed. The bedside examination highlighted: plegia of the left lower limb, spasticity of the triceps surae with clear catch (Modified Ashworth Scale 2), few degrees of motion in dorsiflexion at the ankle.

After the clinical examination, we performed a 3D gait analysis (barefoot, with footwear, and with footwear plus crane) with an eight-camera stereophotogrammetry system (Vicon Nexus) and stabilometry. He followed a rehabilitation program based purely on motor control and balance training (20 sessions lasting 40 minutes), and instrumental follow up 2 months after the first evaluation.

Results

The asymmetry in the space-time parameters reduced and the gait became more reproducibile in the three different modalities. While barefoot walking, kinematics improved at the pelvis, left hip (recovered the flexion-extension pattern) and knee bilaterally (improved flexion peek in the swing phase); left limb space-time parameters and gait speed improved, the latter still reduced (27 m/s pre vs 33 m/s post).

Stabilometry revealed a reduction of the area of the stabilogram in the open-eyes (35,8 mm^2/s pre vs 25,4 mm^2/s) and in the closed-eyes trials (73,9 mm^2/s pre vs 63,3 mm^2/s post).

Discussion

Results are noteworthy given the date of the impairment, no high technology machine involved, lower treatment intensity and exposure in comparison to an inpatient setting. The therapist worked on semi-tandem gait, changes of direction, blind-walking with vocal feedback, single-leg standing.

The gait analysis allowed to focus the goal of the rehabilitation and to check the achievements: a better symmetry and stability had been gained and these may be the grounds on which the further training can rely on to work on improving the gait speed, a known independent factor of mortality [2].

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Do feet position and visual target distance affect postural stability and body weight distribution in healthy subjects?

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Introduction

Foot placement [1] and visual target distance [2] are often considered factors affecting postural stability during stabilometric exam. Previous studies highlighted the need of a standardized feet position [3], while other ones showed no influence on postural stability, suggesting a comfortable feet position [4]. These conflicting results did not lead to a final recommendation [5]. Moreover, a standardized visual target distance should be defined to avoid a further variability of stabilometric parameters [6]. To the best of our knowledge, no study simultaneously evaluates changes and variability of stabilometric and plantar pressure parameters due to different feet placements and visual target distances. The aim of the present study is to investigate the effects of different feet positions (comfortable vs standardized) and visual target distances (near vs distant) on postural stability and body-weight distribution.

Methods

Twenty healthy subjects were evaluated in upright bipedal posture using baropodometry. Firstly, they executed the exam in a self-selected comfortable feet position (CFP) and then, with a standardized feet placement (SFP) forming an angle of 30° degrees between feet and heels slightly apart 5cm. This procedure was performed with different visual target distances: viewing nearby (VNT) and distant (VDT) target at 0.70m and 3m from heels, respectively. Intra-subject Coefficient of Variation (CV) and median values were calculated for plantar pressure and stabilometric parameters. Moreover, significant differences between each condition were test using Wilcoxon Signed Rank test.

Results

In CFP, variability (CV) of the most parameters was significantly increased in VDT compared to VNT. Focusing on VNT condition, variability of plantar pressure parameters was significantly higher in SFP than CFP, with no significant difference for stabilometric parameters (Figure 1). Moreover, a significant increase of left total foot mean pressure and midfoot mean and maximum pressures, and a significant decrease of right foot contact area and CP-speed, were found in SFP with respect to CFP.

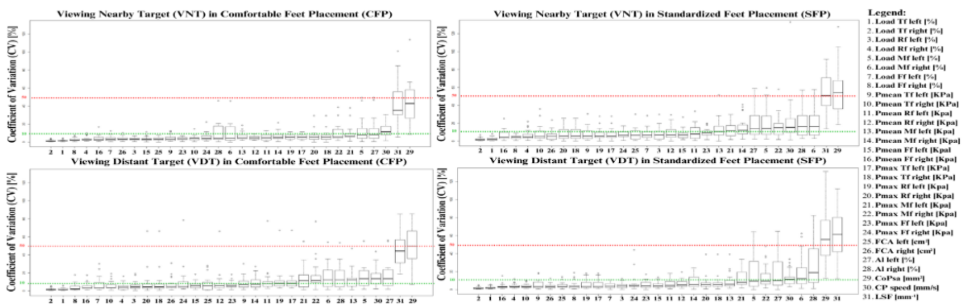

Figure 1. Boxplot of intra-subject Coefficient of Variation (CV) in percentage for all stabilometric and plantar pressure parameters, sorted in ascending order according to the median values in each condition of feet placement (CFP and SFP) and target distance (VNT and VDT).

Discussion

Results of our study confirmed the need of using a near visual target in order to avoid a greater variability of stabilometric parameters. Moreover, during viewing nearby target the standardized feet position increased variability of the most parameters and decreased foot contact area, generating as adaptation an increase of plantar pressures, particularly in midfoot. Evidence of the present study highlighted the importance to choose a comfortable feet position associated to viewing nearby target in order to improve the reliability of baropodometric results and avoid their wrong interpretation.

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Effects of acoustic and visual stimuli on Countermovement jump performance in volleyball players evaluated by Inertial Measurement Unit

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Introduction

The ability to execute maximal vertical jumps significantly affects athletic performance in several sports, such as basketball, handball, and volleyball [1]. Vertical jump (VJ) is a multi-joint movement, that requires complex motor coordination, and it has been identified as one of the fundamental movement skills in various sports [2]. One of most used and standardized protocols of VJ test is the Countermovement Jump (CMJ). In the CMJ the starting position is in upright standing and the subject must bend on the knees until about to 90° and then jump, performing a Countermovement (CM). A few studies analyzed the effects of different sensory stimuli on VJ performance [3, 4].

To the best of our knowledge, no study quantitatively assessed the variations of spatial-temporal and kinetic parameters during Countermovement Jump-Free Arms (CMJ-FA) execution in different acoustic and visual conditions. The aim of the present study is to explore the effects of the visual and acoustic stimuli, in conditions considered incentive and disincentive, on CMJ-FA performance via an Inertial Measurements Unit (IMU).

Methods

Twenty male volleyball athletes were assessed. Five sessions of three CMJ-FA were assessed in the following conditions: without sensory stimulus (NS), with incentive (IAS) and disincentive (DAS) acoustic stimulus, and with incentive (IVS) and disincentive (DVS) visual stimulus. In particular, during trials in IAS and DAS conditions, an audio playing "GO - GO - GO - COME ON" associated with the sound of a crowd cheering and another one playing "NO - NO – NO" associated with a crowd booing were used, respectively. Instead, for trials in DVS and IVS conditions, a ball was used as visual stimulus placing it at a lower and higher height.

Results

The results showed significant decrease in disincentive conditions (DVS and DAS) with respect to NS in Mean Time of Flight Phase, Mean and Peak Jump Height. Moreover, in DVS an increase of Impact Index compared to NS was found (Table 1). Eventually, a greater Mean Time of Eccentric Phase was found in DAS compared to DVS.

Parameters	Comparison between each stimulus (visual or acoustic) and NS Wilcoxon Signed Rank Test (P-value)			
	IVS vs NS	DVS vs NS	IAS vs NS	DAS vs NS
Mean Time of Flight Phase [s]	0.174	**0.027*** ↓	0.360	**0.018*** ↓
Mean Jump Height [cm]	0.125	**0.016*** ↓	0.476	**0.011*** ↓
Peak Jump Height [cm]	0.137	**0.008*** ↓	0.466	**0.011*** ↓
Impact Index	0.372	**0.035*** ↑	0.500	0.405

Table 1. Inter-subject comparison between each visual or acoustic stimulus (in both incentive and disincentive conditions) and no sensory stimulus. Decrease ↓ and increase ↑ in DVS or DAS with respect to NS.

Discussion

These findings highlighted the interference of disincentive conditions on jump performance; moreover, an increase of ground impact force during landing phase in DVS may predispose to muscle-skeletal lower limb injuries. These knowledges could be useful to the sports trainers for improving athletes' control, in order to desensitize them from disincentive conditions, keeping a good performance and decreasing the risk of injuries during the competition.

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Deep learning algorithms for the recognition of human movements in work activities

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Introduction

The field of Human Activity Recognition (HAR) concerns the automatic detection of people's daily physical activities. HAR employs inexpensive and low-energy sensors, in conjunction with advancements in machine learning and artificial intelligence, to identify activities and provide feedback. This study uses advanced deep learning techniques to recognize complex, strenuous work activities typical of intensive jobs. The objective is to accurately identify high physical exertion activities, developing systems for assisting workers.

Methods

Ten healthy subjects were selected by personnel from INAIL in Monte Porzio Catone, Italy. The subjects were equipped with three wireless inertial measurement units (WaveTrac Inertial System of Cometa, Italy), recording triaxial accelerations at 2000 Hz. The IMUs were positioned on the upper back (N), lower back (L), and right arm (D). The tasks simulated were: pushing a wheelchair (C), climbing stairs (S), carrying boxes (T), hammering (M), rolling a paint roller (P), and lifting boxes from the ground (SL). Each task was performed by six subjects and repeated for a duration of ten minutes [1]. The data were resampled at 10 Hz, normalized, and divided into windows of 100 samples. The deep learning operations performed include the application of Long Short-Term Memory (LSTM), with a layer for batch normalization.

Results and Discussion

The results of the study (Table 1) demonstrate that the HAR algorithm is highly effective in recognizing simulated work activities. The best performance is achieved with the sensor placed at the right arm. Data analysis indicates the optimal combination for accurately identifying activities is using accelerometers on the upper back and right arm simultaneously. This configuration is able to capture changes in trunk and upper limb movements. Moreover, the Confusion Matrix reveals that most simulated activities are identified with a high degree of precision. However, a notable exception is observed for SL activities, which are prone to being confused with the S activities. This can be attributed to the morphological similarity of the accelerometer signals recorded for these activities, which makes the distinction more complex for the algorithm. This phenomenon indicates the existence of an area of potential improvement for the activity recognition system, which could benefit from further optimization to improve the distinction between similar activities. This could be attributed to the relative narrowness of the accelerometer database used. Expanding the accelerometer database could be a first step to provide a broader basis for deep learning algorithm training.

Table 2. Results of Deep Learning in terms of Classification's performance.

Combination	Accuracy [%]	Precision [%]	Recall [%]	F1-score [%]
N	79.63	80.71	80.07	78.10
L	75.60	77.12	74.53	73.89
S	88.03	88.81	88.03	87.81
N + L	72.76	74.76	72.61	71.65
N + S	85.64	87.54	84.79	85.22
L + S	87.22	88.10	87.22	86.99
N + L + S	82.67	83.45	82.32	81.80

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Anticipatory postural adjustments for reaching and lifting an object from the floor

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Introduction

Anticipatory postural adjustments (APAs) are needed to stabilize the body prior to voluntary movements [1]. Though they reflect everyday real-world activities, whole-body reaching tasks with targets on the floor are underrepresented in published literature. We aimed to perform a preliminary characterization of APAs for reaching and lifting an object from the floor.

Methods

The LG-MIAR dataset was used, where twelve healthy participants (26-43 years) were instrumented with five inertial measurement units (AX6, Axivity) attached to the ankles, wrists, and lower back. Data from eight cameras (Smart-D, BTS Bioengineering) and one force plate (FP4060, Bertec) were simultaneously recorded. The task started in the standing position. Subjects were asked to pick a box (14.5x20.5x25cm, 600g) from the floor with both hands, and deliver it to an operator standing before them. An automatic event detection algorithm segmented the task based on the center of mass (COM) vertical velocity. The APAs and the descending phase were characterized through the excursion of the centre of pressure (COP) in the antero-posterior and medio-lateral directions, the COM shift in the vertical, antero-posterior, and medio-lateral directions, and the angular velocity of the lower back around the medio-lateral axis.

Results

Four subjects were discarded due to the occlusion of markers during the task. The APAs were characterized by an upward COM shift. Forward COM shift and lower back tilt were observed in 7 subjects. The COP shifted forward in 6 subjects. COM and COP both shifted to the right in 4 subjects. The APAs duration was 0.4 ± 0.1s (mean ± SD). Table 1 reports kinetic and kinematic parameters during the APAs and descent phase of the task.

Table 1. Data are mean ± SD on 8 subjects. Positive velocity values refer to backward, upward, and rightward directions. Antero-posterior (AP), medio-lateral (ML), vertical (V).

	Duration [s]	COM excursion [mm]			COP excursion [mm]		COM peak velocity [m/s]		Lower back angular velocity peak [°/s]
		AP	ML	V	AP	ML	AP	V	ML
APA	0.4 ± 0.1	12.6 ± 7.2	5.3 ± 4.3	5.8 ± 1.8	21.6 ±19	7.2 ± 5.3	-0.08 ± 0.04	0.03 ± 0.01	- 29.11 ± 9.51
Descent phase	1.3 ± 0.2	100.4 ± 40.5	19.5 ± 12.1	502.6 ± 117.8	80.3 ± 37.7	41.6 ± 32	-0.12 ± 0.10	-0.74 ± 0.12	-68.70 ± 46.64

Discussions

We showed that APAs are present in preparation to this whole-body reaching task; we characterized these preparatory movements as un upward shift of COM and a forward shift of COP and COM, together with a forward tilt of the lower back, which was detected with a wearable sensor. Characterizing these patterns in healthy adults may serve to highlight (and train) pathological patterns in people with movement disorders.

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COM velocity estimation with wearable sensors during reaching and lifting an object from the floor

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Introduction

The center of mass (COM) velocity is used to assess balance in postural transitions [1]. It is usually measured from laboratory instrumentation. Obtaining it from wearable sensors may allow us to estimate COM kinematics outside the laboratory in a real-world environment. We aimed to identify a method for accurately estimating COM linear velocity based on wearable inertial measurement units (IMU) comparing a single-sensor and a multi-sensor setup.

Methods

The LG-MIAR dataset was used, where twelve healthy participants (26-43 years) were instrumented with five IMUs (AX6, Axivity) attached to the ankles, wrists, and lower back. Data from eight cameras (Smart-D, BTS Bioengineering) were simultaneously recorded. The subjects were asked to pick a box (600 g) from the floor with both hands and deliver it to an operator standing before them. The gold-standard COM velocity was computed as the first derivative of the COM displacement, obtained from the position of all body segments and the subjects' mass [2]. IMU-based COM velocity was estimated by integrating only the lower back sensor acceleration and a weighted average of the five IMUs accelerations. A constrained grid search mapped all the values and combinations of the weights.

Results

Four subjects were discarded due to the occlusion of the markers while reaching the floor. Out of 36 combinations, the weights resulting in the minimum average root mean square error normalized to the COM velocity range (NRMSE) were 70% for the lower back, 5% for the ankles, and 10% for the wrists. The NRMSE of the single-sensor and multi-sensor COM velocity estimates were 15 ± 6 % and 12 ± 2 %, respectively. Figure 1 shows the velocity comparison of one representative subject.

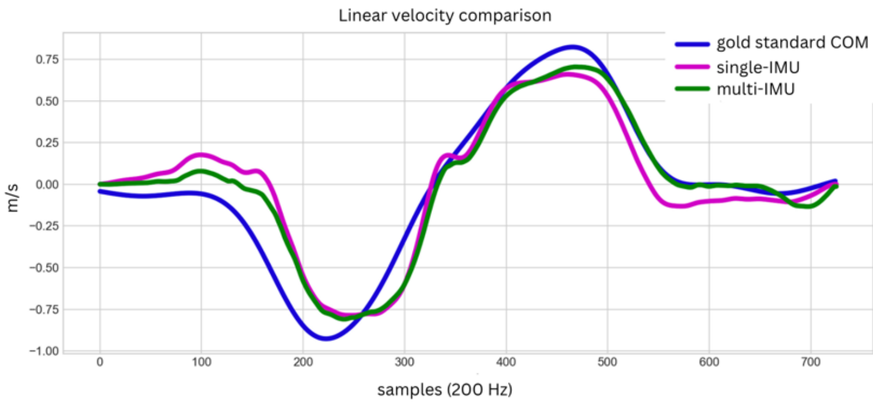

Figure 1. Example of comparison among the stereo-based COM velocity, wearable-based COM velocity and Lower back IMU velocity in 1 subject.

Discussion

We demonstrated that the COM velocity can be estimated from wearable sensors in a single and multi-sensor setup, with a moderate gain in error using five IMUs instead of one. The wearable-based COM velocity could be used for the balance assessment in postural transitions out of the lab, such as in telerehabilitation.

This research was co-funded by the Italian Complementary National Plan PNC-1.1 "Research initiatives for innovative technologies and pathways in the health and welfare sector" D.D. 931 of 06/06/2022, "DARE - DigitAl lifelong pREvention" initiative, code PNC0000002, CUP: B53C22006450001. This research was co-funded by Fondazione del Monte di Bologna e Ravenna and by the Fondazione Cassa di Risparmio di Bologna.

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A markerless platform for automatic assessment of gait

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Introduction

Instrumental gait analysis (iGA) is time-consuming and needs dedicated spaces and personnel. Observational gait analysis (oGA) offers an alternative, relying on clinicians assessing video recordings of walking to identify normal and abnormal patterns. Despite the development of structured instruments, oGA remains strongly operator dependant, with low test-retest and inter-rater reliability, calls for visual gait phases segmentation, introducing more evaluation bias [1]. Markerless presents a promising solution to iGA and oGA limitations, and its efficacy in clinical settings has already been tested [2]. This article presents a Markerless Automatic video-based platform for Gait Analysis (MaGA) as a rightful trade-off between iGA and oGA.

Methods

MaGA, adapted to the Rancho Los Amigos (RLA) [4], consisted of: (i) a video camera and OpenPose [3]; (ii) a joint kinematics estimator; (iii) a gait phases identification algorithm; and (iv) a Support Vector Machine (SVM), with a linear and a non-linear Gaussian kernel, for altered/normal pattern classification for each RLA cell.

Kinematics from ten adults with chronic stroke (7 males, 52.4±9.5 yo) and eight healthy adults (6 males, 28.0±3.7 yo) were segmented over gait cycle sub-phases and manipulated to extract descriptive statistics (average, minimum, maximum, etc), closeness (mean absolute error (MAE) and Linear Fit Method coefficients [5]) and statistical difference (area under the Statistical Parametric Mapping *t*-curve [6]) between test and control datasets.

Three experts evaluated videos of chronic stroke patients, merging their assessments and assigning RLA cell values (0-3) based on raised concerns. These data and the extracted features were used to train and test MaGA with a k-fold cross-validation (k=10). Performances were assessed with accuracy, precision, sensitivity, specificity, F1-score and MAE.

Results

Fig. 1 shows a MaGA-filled RLA sheet against the experts-merged. MaGA generally underestimated severity. Non-linear SVM generally outperformed the linear model (MAE ≤ 0.50 vs. 0.04-0.70), leading to non-ambiguous severity levels. For instance, severity = 2 and MAE > 0.5 could indicate switching between normal/altered states (severity ≤ 1.5 or ≥ 2.5).

		MaGA evaluation								Experts' evaluation							
		IC	LR	MSt	TSt	PSw	ISw	MSw	TSw	IC	LR	MSt	TSt	PSw	ISw	MSw	TSw
Hip	Flexion limited																
	Flexion excess																
	Inadequate extension			1.37	0.98							1	2				
	Past retract																
Knee	Flexion limited		0.32			0.41	0.48				1			1	1		
	Flexion excess																
	Inadequate extension			1.01					0.81			2					1
	Wobbles																
	Hyperextended																

Figure 5. MaGA-filled RLA sheet (left side) and experts' RLA evaluation (right side) obtained for hip and knee sagittal kinematics for an individual with chronic stroke. In black the non-relevant cells, in grey those with least relevance and in white the most relevant cells [4]. Severity is reported in each cell if different from zero.

Discussion

MaGA accurately identified all expert-highlighted items, with only one instance of knee wobbles being missed (marked by one expert). This could potentially be mitigated with higher resolution and capture rate devices.

MaGA has the potential to be customized according to various oGA tools, thereby addressing their limitations. Future plans include MaGA sensitivity analysis to data collection conditions and the establishment of a broader reference dataset, encompassing individuals with diverse disorders and severity levels.

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A method for mechanical crosstalk rejection and running event detection on a 9-force plates instrumented track

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Introduction

Collecting representative data for athletic performance presents challenges. Laboratory settings reduce the sense of competition, while on-field measurements may require bulky devices [1]. The OLYMPIA SmartTrack, featuring a 10-IR camera stereophotogrammetric system (Vantage V5, Vicon Motion Systems Ltd, UK) and 9 force plates (2xBMS400600 and 7xBMS600900, AMTI Technology, Inc., USA), addresses these issues [2]. Despite installing force plates on a customized steel basin embedded in a concrete soil and using independent threaded bars, mechanical crosstalk among plates was observed while running, altering the resultant ground reaction vectors. Two algorithms were proposed to eliminate crosstalk and automatically detect foot-strike (FS) and foot-off (FO) events during running from force-plate data.

Methods

Ground reaction forces were low-pass filtered (Butterworth, 4th-order, 100 Hz) and artificially switched-off when no contact was detected. Contact was determined either looking at vertical component being larger than a 20 N (force plate-based method, PLT) or checking for the projection of the foot markers (one at the rearfoot and one on the foot tip - marker-based method, MKR) on force plates surface. Tentative on-off instants were further refined. Typically, only one contact occurred per platform, with a swing phase lasting approximately 0.10 s. Subsequent contacts within 0.05 s were merged. FS and FO events were automatically identified as instants where the vertical component of the resultant ground reaction force reached 20 N before and after a peak of at least 1200N. The algorithms were tested on three transfemoral amputee female athletes (T63 100 m medallists in 2020 Paralympic Games) wearing different Running Prosthetic Feet over trials and a 3S80 monoaxial prosthetic knee joint (Ottobock, Germany) on their residual limbs. Automatic FS and FO event detection underwent Bland-Altman testing [3] against the manual labelling by an expert operator (GOLD). Correlation analysis was also performed.

Results

Seven running trials per athlete were analysed (stance duration = 0.114±0.022 s), yielding 85 FS and 85 FO events. No residual crosstalk was observed after applying both algorithms. The MKR method returned 2 false negatives for both FS and FO, whereas the PLT had none. Both methods returned 1 false positive for both FS and FO. The operator excluded that specific stride due to unclear foot positioning over the force platform.

Event type	{data1} vs {data2}	Bias	LoA		RC	Pearson's r	slope	intercept	KS-test *p*-value		*t*-test
			Lower	Upper					{data1}	{data2}	*p*-value
FS	**MKR vs GOLD**	-5	-20	10	17	0.9998	0.9973	0.0000	0.658	0.584	< 0.001
	PLT vs GOLD	-6	-13	1	13	1.0000	1.0006	0.0000	0.648	0.575	< 0.001
	PLT vs MKR	-1	-13	12	12	0.9999	1.0026	0.0000	0.671	0.670	0.312
FO	**MKR vs GOLD**	3	-6	12	10	0.9999	0.9978	0.0000	0.748	0.769	< 0.001
	PLT vs GOLD	2	-5	9	8	1.0000	0.9981	0.0000	0.738	0.718	< 0.001
	PLT vs MKR	0	-6	6	6	1.0000	1.0001	0.0000	0.802	0.794	0.277

Table 6. Results of Bland-Altman and correlation analysis for foot-strike (FS) and foot-off (FO) events comparing marker-based (MKR) and force plate-based (PLT) with the GOLD standard and between them: bias, limit of agreement (LoA - with its lower and upper value), the repeatability coefficient (RC), the Pearson's correlation coefficient (r), the slope and the intercept of the linear interpolation between the datasets to compare, the Kolmogorov-Smirnov test p-value for both dataset to compare and the t-test p-value obtained from comparing the datasets.

Discussion

The presented algorithms effectively remove the crosstalk and allow for robust automatic FS and FO events detection while running. Marker-based and force plate-based methods are interchangeable. **Acknowledgments.** Supported by INAIL: agreement n. PR19-PAI-P4.

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A motion capture protocol for the in-vivo assessment of running and long jumping biomechanics in transfemoral and transtibial running elite para-athletes

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Introduction

Paralympic athletes compete at high levels thanks to technologies that allow individuals with amputations to engage in sports. Current studies focusing on enhancing athletic performance, device safety, comfort and production process lack standardized procedures, hindering result generalizability [1]. The OLYMPIA project aims to address this gap, improving prosthetic device quality and effectiveness, and enhancing measurement transferability from in-vivo to bench testing. We propose a novel method to evaluate running and long-jumping biomechanics using marker-based motion capture, useful to inform video analysis, bench tests, FEM and musculoskeletal models.

Methods

The protocol includes definition of segments, local coordinate (LCS) and joint coordinate systems (JCS), marker locations and labels. Definitions are similar to those given in [2] for sound segments, while each component of the prosthetic limb is associated with a segment, a marker cluster and LCSs: socket to accommodate the residual limb; socket clamp (socket and subsequent distal part interface); prosthetic knee for transfemoral (TF) amputees (with proximal and distal LCSs); foot clamp; and Running Prosthetic Foot (RPF), with its most proximal and most distal extremities. Socket clamp corresponds to foot clamp for transtibial (TT) amputees. At least three markers were placed on each segment and redundancy was sought using clusters. If the prosthesis configuration prevented from positioning markers directly on the segments, a marker-equipped wand was used to locate and reconstruct them [3]. Prosthetic joints were: (i) socket-pelvis as hip in TF; (ii) distal-proximal prosthetic knee in TF; (ii) socket-thigh as knee in TT; and (iii) distal RPF-clamp as virtual ankle in TF and TT (with virtual null angle when unloaded). The protocol was tested on a female athlete (58 kg; 1.65 m; T63 100 m medallist in 2020 Paralympic Games) wearing a 1E91 Standard Runner Cat 4.0 RPF and 3S80 monoaxial prosthetic knee joint (Ottobock, Germany) on her left residual limb. Across trials, an expert prosthetist adjusted the socket tilt relative to the great trochanter-knee joint centre line (sagittal plane) from 5° (A0) to 15° (A3) [4].

Results

Joint kinematics for sound and prosthetic lower limbs (Fig. 1) demonstrate that LCS and JCS definitions effectively track joint motion during running. They also highlighted the effects of the two prosthesis configurations on joint kinematics.

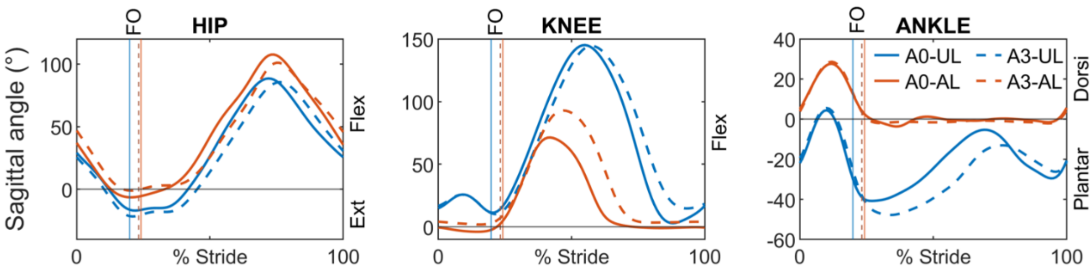

Figure 7. Sagittal kinematics of anatomical (on the unaffected limb – UL; in blue) and prosthetic (on the affected limb – AL; in orange) hip, knee and ankle angles normalized over the percentage of the stride, computed for a transfemoral amputee wearing a prosthetic limb in two different configurations (socket sagittal tilt: 5° - A0; and 15° - A3) on two running trials. Vertical lines represent foot-off (FO) events.

Discussion

The presented protocol allows collecting and analysing running biomechanics data in para-athletes with lower limb amputations, setting a new standard for future studies and applications.

Acknowledgments: Supported by INAIL: grant n. PR19-PAI-P4.

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A novel statistical approach for upper-limb movement segmentation using a single wrist-worn magneto-inertial measurement unit

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Introduction

Activities of Daily Life (ADLs) are fundamental tasks that need to be carried out for maintaining a good quality of life. For patients with motor impairments, task-oriented therapy is a reasonable approach for recovering the ability to perform basic ADLs [1]. Magneto-Inertial Measurement Units (MIMUs) are commonly used for kinematic assessments in various pathological conditions [2]. The time needed to complete a motor task is a metric often used by physical therapists to assess motor impairments. To facilitate this evaluation, accurate algorithms that can distinguish between movement and rest states are needed. This contribution aims at introducing a segmentation method for the identification of upper-limb movements based on statistical considerations.

Methods

Twenty-five healthy participants were instructed to grasp a bottle, take a sip of water, and then return the bottle while seated comfortably in front of a table. Subjects were instrumented with a MIMU fixed at the dominant wrist using double-sided adhesive tape. The proposed method segments upper-limb movements by applying a relative threshold to the norm of the angular velocities acquired through the MIMU. To compensate for segmentation errors, a post-processing step is applied based on statistical considerations of movement duration distribution [3]. The proposed approach was compared to the threshold-based segmentation methods proposed by Carpinella et al. [4] and Schwarz et al. [5]. The performance of the assessed approaches was tested against a gold standard, the stereophotogrammetric system (Vicon T20). Performance was tested through the Mean Absolute Error (MAE) of the movement onset/offset estimates. A 1-way ANOVA with Bonferroni correction for multiple comparisons was performed to test performance differences.

Results

Figure 1A and Figure 1B show the MAE distributions of the three tested segmentation approaches for movement onset and offset, respectively. The newly proposed approach significantly outperformed the other tested approaches in terms of both onset MAE (proposed method: 0.07±0.02 s (mean ± SD); Carpinella et al.: 0.10±0.04 s; Schwarz et al.: 0.22±0.05 s) and offset MAE (proposed method: 0.08±0.03 s; Carpinella et al.: 0.20±0.04 s; Schwarz et al.: 0.29±0.07 s).

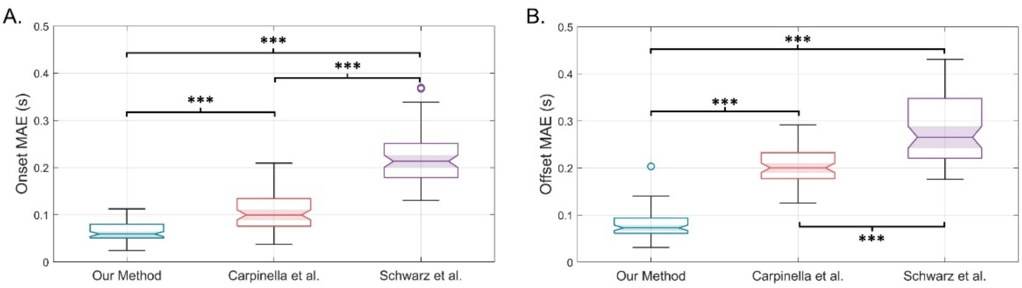

Figure 1. Boxplot showing differences in onset and offset Mean Absolute Error (MAE) between the tested segmentation algorithms and the gold standard are represented in **Figure 1A** and **Figure 1B**, respectively. Statistically significant differences are represented by asterisks (*** p<0.001).

Discussion

The newly proposed method revealed significantly better performance in movement segmentation from MIMU recordings compared to state-of-the-art approaches. This method has proven to be effective in segmenting upper-limb movements, indicating its usefulness in studies that require movement segmentation without the use of expensive stereophotogrammetric systems. Future studies will focus on validating the method on patients affected by neurological disorders and characterizing reach-to-grasp movements kinematically.

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Obesity effects on young adults' gait pattern after five years from Sleeve Gastrectomy

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Introduction

This work is a completion of the study of Summa et al. [1] that showed several gait alterations in obese adolescents 1-year (T1) after the Laparoscopic Sleeve Gastrectomy (LSG) surgery. We studied the gait pattern after five years (T5) from LSG surgery to evaluate if the gait pattern has normalized.

Methods

Thirteen patients with a Body Mass Index (BMI) < 30 (Normal Weight Group=GNW group); 4 females and 9 males; age 20.9 ± 2.4; weight 79.6 ± 10.2 kg, BMI 26 ± 2.4 kg/m2, participated in the study. Eight patients with a Body Mass Index (BMI) > 30 (Overweight Group=GOW group); 6 females and 2 males; age 21 ± 3.2; weight 94.2 ± 12 kg, and the averaged BMI was 35.5 ± 3.4 kg/m2, participated in the study. These groups were acquired 5 years after the intervention. A control group of 10 healthy subjects (GH) was introduced as a benchmark of "normal gait" (7 female and 3 males; age 18.7 ± 4.9; weight 57.3 ± 11.5 kg; BMI 21.7 ± 2.0 Kg/m2). 3D gait analysis was conducted using an optoelectronic system with twelve cameras (Vicon MX, UK) and two force plates (AMTI, Or-6, US). We evaluated kinematics and kinetics while walking. We looked at the differences between the gait pattern at T5 of GNW and GOW vs the gait pattern of GH.

Results

Five years after surgery the averaged total weight loss of GNW was 44.7 ± 12.2 kg, the averaged total change in BMI was 16.7 ± 2 kg/m2. For the GOW the averaged total weight loss was 19.5 ± 3.7 kg, the averaged total change in BMI was 9 ± 0.1 kg/m2. At T5 GNW compared to GH showed a normalization of several kinematics alterations at pelvis, hip, and knee levels. Instead, the ankle still showed an increase of maximum dorsiflexion and a reduction of maximum plantar flexion. GOW compared to GH still showed several alterations above all at knee and ankle levels. Indeed, we highlighted an increase of hip extension moment, a reduction of knee extension moment, an increase of ankle maximum dorsiflexion, a reduction of ankle dorsal moment. See figure 1.

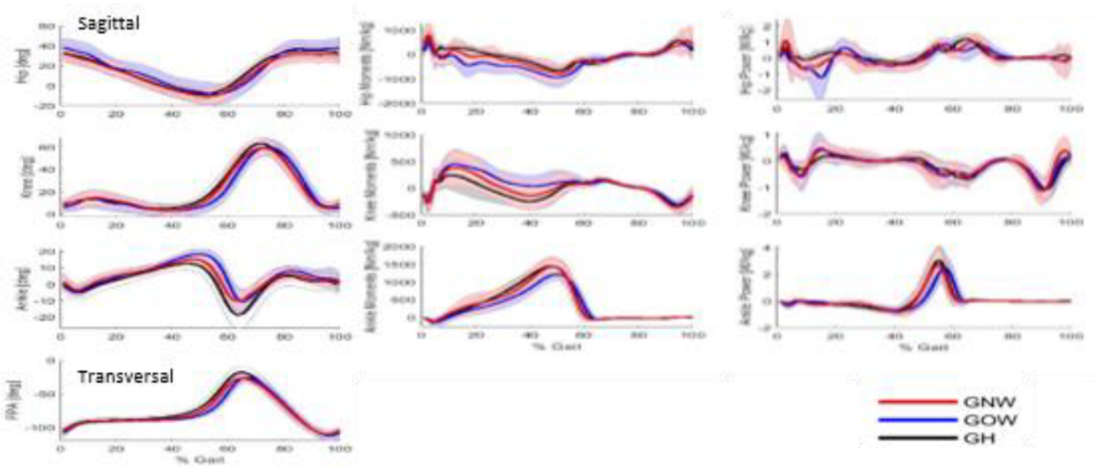

Figure 1. Left panel lower body kinematics. Central panel joints moment. Right panel joints power. Solid lines denote averaged group value. Dashed areas denote the standard deviation (STD). Red, blue and black colors stand respectively for GNW, GOW at T5 and GH. (FPA: Foot Progression Angle).

Discussion

The bulk of the masses, during the patient's growth, affects the gait pattern once they are removed. After 5 years some alterations persist in some dynamic gait components. Gait recovery also required time and experience of motor function in daily life. The results encourage an individualized rehabilitative intervention of sensory-motor re-education for restoring dynamic gait components after a patient-specific assessment.

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An automatic anthropometric model generation tool for scalable human whole-body musculoskeletal modeling

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Introduction

Biomechanics plays a crucial role in the understanding of human movement in various fields, such as health care, occupational health and safety in the workplace. Although current musculoskeletal models that support these studies approximate real human anatomy, they often lack detailed anthropometric and inertial parameters, which are essential to customize and scale these models accurately [1,2,3]. This study aims to develop an automatic anthropometric whole-body human model generation (HMG) tool, adhering to the URDF standard format, which seamlessly integrates skeletal and muscular information, ensuring scalability to individual subjects.

Methods

The proposed Python-based HMG tool integrates automatic adjustments to body links mass percentage and inertial parameters based on the anthropometric literature [1,2]. These sources provide data for estimating the mass distribution and inertia of whole-body links. Additionally, the estimation of segment dimensions is guided by the methodologies outlined by Winter (2009) [3]. The model construction algorithm combines anthropometric and inertial data to generate a customized human model. The HMG is fed with simple anthropometric inputs, e.g., subject's total mass, total height, and measurements for the link modeling (i.e., parallelepiped, cylinder, sphere).

Results

A preliminary analysis shows that the generated models accurately reflect individual anthropometric variations and provide a reliable representation of both skeletal and muscular systems. The integration of muscle data enhances the dynamic simulation capabilities of the model, allowing for more precise movement analysis. Notably, each model comprises 21 links, 18 joints with 45 degrees of freedom and 22 insertions of muscles, allowing for detailed representation of human movement.

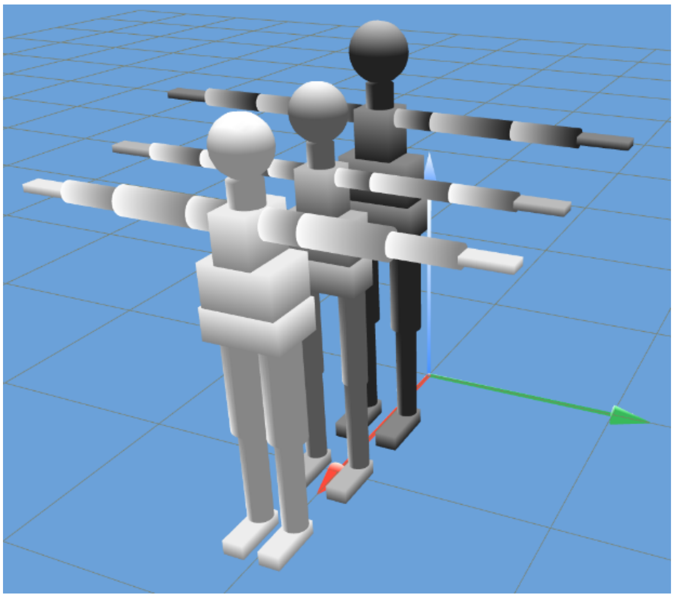

Figure 8. Three HMG-generated models representing individuals with different anthropometric profiles: light gray (170cm height, 100kg), intermediate gray (170cm height, 60kg), and dark gray (185cm height, 70kg).

Discussion

The HMG is a promising tool for improving the accuracy and personalization of human models used in biomechanical studies. Future work will focus on refining the muscle modeling algorithms and on validating the tool against a broader range of motion analysis scenarios. The potential applications of this tool span from clinical diagnostics to improving workplace safety and injury prevention. Additionally, the detailed and personalized models generated by the HMG can be used to enhance the accuracy of obtaining Key Performance Indexes (KPIs) in motion analysis, providing valuable insights for rehabilitation therapy in various pathologies affecting the motor system.

For more information, the repository is available at https://github.com/ami-iit/human-model-generator.

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The influence of executive functions on gait kinematics during dual task walking evaluated by EEG and 3D Motion analysis

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Introduction

Executive functions (EFs) are neurocognitive processes planning and regulating daily life actions [1]. The basic EFs are working memory, inhibition and cognitive flexibility [2]. The working memory is the ability to keep in mind information while performing complex tasks. The inhibition allows to control thoughts, behavior, and/or emotions by overcoming a strong internal predisposition or external pull. The cognitive flexibility is the ability to adapt to rapidly varying circumstances. The ability to carry out cognitive tasks while simultaneously walking is one of the most essential skills for daily-life activities [3]. From last years, gait has been no longer considered as an automatic activity but as an activity involving EFs. Performance of two simultaneous tasks, requiring the same cognitive resources, lead to a cognitive fatigue [4]. Several studies investigated cognitive-motor task and the interference during walking, highlighting an increasing risk of falls especially in elderly and people with neurological diseases [5]. A few studies instrumentally explored relationship between activation-no-activation of two EFs (working memory and inhibition) and spatial-temporal gait parameters [6]. Aim of our study was to detect activation of inhibition and working memory during progressive difficulty levels of cognitive tasks and spontaneous walking using, respectively, wireless electroencephalography (EEG) and 3D-Gait analysis.

Methods

Thirteen healthy subjects were recruited. Two cognitive tasks were performed at two levels of difficulty, activating inhibition (Go-NoGo_1 and Go-NoGo_2) and working memory (N-back_1 and N-back_2) during walking. EEG features (the absolute and relative powers) were extracted by Power Spectral Density (PSD) function of the signal in eight bands for eight active channels. Seven spatial-temporal and nine kinematic parameters, referred to Gait Variable Scores (GVS) for lower limbs range of movement, were computed.

Results

A significant decrease of stride length and an increase of external-rotation of foot progression were found during dual task walking with Go-NoGo. Moreover, a significant correlation was found between the relative power in the delta band at channels Fz, C4 and progressive difficulty levels of Go-NoGo (activating inhibition) during walking, whereas working memory showed no correlation (Table 1).

	Spatial-temporal parameter	Kinematic parameter
Experimental conditions	Stride length [m]	Foot progression (GVS=Gait Variability Score)
Walking vs Dual task walking with Go-NoGo_1	**0.049*** ↓	**0.045*** ↑
Walking vs Dual task walking with Go-NoGo_2	**0.046*** ↓	**0.048*** ↑

Table 1. Significant results (p-value < 0.05) of Wilcoxon Mann Whitney Test for spatial-temporal and kinematic parameters among different experimental conditions. Decrease ↓ and increase ↑ in Walking with respect to dual task walking with Go-NoGo.

Discussion

Evidence of the present study suggested a lower balance control, more instability and revealed specific kinematic adaptations during dual cognitive-motor task. These findings reinforced the hypothesis of the prevalent involvement of inhibition in motor task execution with respect to working memory, probably revealing an interference of this EF during walking. The foundations for EEG-based monitoring of cognitive processes involved in gait are laid.

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Gait Analysis in Patients Undergoing Rehabilitation after Soft Tissue Sarcoma Surgery. Preliminary results

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Introduction

Soft tissue sarcomas (STS) are a rare and heterogeneous group of tumors, comprising about 1% of all adult malignancies occurring in the trunk, retroperitoneum, or limbs [1]. Surgery is the standard treatment for primary and localized STS, often requiring extensive tissue dissection to achieve sufficient surgical margins for a good oncologic outcome [2]. Given the high heterogeneity of the clinical presentation, a quantitative and specific assessment of motor impairment should be included in the clinical evaluation, to plan an individualized rehabilitation program after surgery. A comprehensive gait assessment after surgeries for lower limb or retroperitoneal sarcoma with femoral nerve involvement can help to characterize the gait pattern in each patient, measure the effects of the intervention, and personalize rehabilitation. The aim of this study is to evaluated the impact of post-operative rehabilitation treatment on gait recovery.

Methods

We analyzed gait performance in 24 subjects (50% men, age 59.5 ± 14.4) who underwent surgery for lower extremity or retroperitoneal/pelvic STS and subsequent rehabilitation. Before (T0) and after (T1) rehabilitation assessments were performed. Subjects were asked to walk at a comfortable speed along a 10-meter path, with each patient performing at least 10 trials. The Davis protocol was followed for marker placement [3]. Kinematic (Smart D500, BTS, Italy), kinetic (P6000, BTS, Italy), and surface electromyography data (Free1000, BTS, Italy) were acquired. Spatiotemporal parameters and joint kinematics were calculated, and asymmetry, as well as spatial and temporal variability, were assessed. Muscle activity was measured using eight probes placed bilaterally on the rectus femoris, biceps femoris, tibialis anterior, and gastrocnemius lateralis.

Results

At baseline, we detected statistically significant differences in all analyzed spatiotemporal parameters and a decrease in hip and ankle range of motion, compared to normative values. After rehabilitation, we observed statistically significant improvements in spatiotemporal parameters and gait speed (Figure 1). Kinetic and electromyography data are currently under analysis.

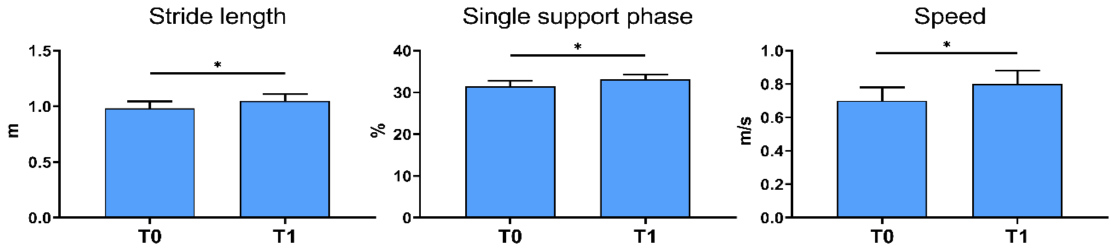

Figure 1. Changes after rehabilitation in stride length, single support phase (operated side), and gait speed (* $p<0.05$).

Discussion

Following surgery for the removal of soft tissue sarcoma in the lower extremities or retroperitoneum/pelvis, patients exhibit motor deficits that require targeted rehabilitation interventions. Instrumental assessment through motion analysis demonstrated also the beneficial effects of rehabilitation on the gait pattern, providing valuable insights for evaluating the effects of treatment and tailoring it to the specific needs of each patient, thereby supporting a personalized approach.

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Kinematic data after Latarjet procedure with or without cutting the pectoralis minor muscle in young patients: observational study at 6 month follow-up

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Introduction

The Latarjet procedure is indicated for patients with anterior shoulder instability. Its function is to primarily provide a ‘‘sling’’ effect of the conjoint tendon acting on the subscapularis muscle and on the capsule, and secondarily a ‘‘bony effect’’ through the extension of the glenoid surface. The standard surgical technique currently in use requires the detaching of the tendon of the pectoralis minor muscle, which has a role as protraction, downward rotation and depressor of the scapula [1]. Now a new surgical approach is increasingly advancing, based on sparing the pectoralis minor muscle tendon. The aim of the study is to analyze and compare shoulder performance of patients undergoing the two types of surgical techniques, i.e. with or without sparing the pectoralis minor muscle.

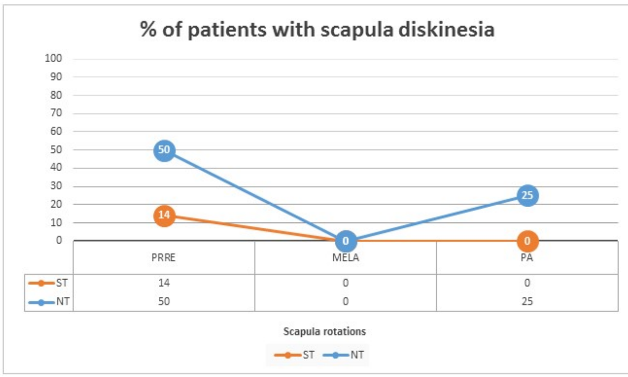
Methods

We considered fifteen patients (between 21 and 46 years old): n°8 patients underwent the standard Latarjet procedure (ST group); n°7 the new sparing technique (NT group). Each patient underwent one assessment session at 6 months after surgery, which included an orthopedic evaluation and the administration of the Scapula-Weighted Constant Murley score (SW-CMS). Shoulder kinematics was recorded with a stereophotogrammetric system (Vicon, UK) [2].

A descriptive statistical analysis of the primary outcome (SW-CMS) was performed, along with an in-depth study of scapular rotations (protraction-retraction (PRRE), mid-lateral rotation (MELA) and antero-posterior tilt (PA)) during humeral elevation (flexion and abduction). For each patient, we considered the three scapulo-humeral coordination plots (one for each scapula rotation) to compare scapula kinematics to reference bands.

Results

Similar values were obtained in terms of mean and standard deviation of the SW-CMS for the two groups: ST, 79±7; NT, 77±4. A detailed analysis of scapula kinematics showed: 1) for both groups, no pathological deviation of the scapula kinematics during shoulder abduction; 2) during shoulder flexion, the ST group showed a deviation of the scapula kinematics in PRRE for 50% of patients and in PA for 25% of patients, whereas the NT group showed a deviation only in scapula PRRE for 14% of patients (Figure 1).



Discussion

Based on our preliminary results, shoulder performance analyzed by means of SW-CMS seems to be the same for the two groups. The analysis of scapula kinematics highlights that, at 6 month follow-up, patients who underwent Latarjet standard procedure showed a reduction of scapular dyskinesia during shoulder flexion compared to the new surgical approach [3].

This trial was approved by the Ethics Committee of the AUSL della Romagna.

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Postural responses induced by intermittent visual occlusions in young and older adults

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Introduction

Postural control is essential for optimal performance of many daily activities and depends on the integration of inputs from visual, somatosensory and vestibular sensory channels. Older adults report impaired postural control compared to young subjects and exhibit increased visual reliance to compensate for altered somatosensory and vestibular systems [1]. Recently, intermittent perturbations of the visual system have been employed not only to better characterize visual contributions during postural control, but also to decrease visual reliance in people with somatosensory deficits [2,3,4]. No study, however, explored postural control differences between young and older people when an intermittent visual perturbation is provided. We aimed to investigate such differences and to assess whether the effect of an intermittent visual perturbation is determined by a different ability to reweight visual inputs during postural control.

Methods

20 young adults (22.1 ± 1.6 years) and 18 older adults healthy for age (72.2 ± 6.0 years), free of musculoskeletal, neurological and visual disorders, performed 3 trials of double-limb stance, each lasting 35 sec, on both firm and foam surfaces, for somatosensory perturbation, and in the conditions of eyes open (EO), eyes closed (EC), and stroboscopic vision (SV), for visual perturbation. Order of postural performances was randomized. SV was completed with specialized eyewear (Strobe Classic, Senaptec) that intermittently cycled between a transparent state state of 100 ms and an opaque state of 344 ms. Five center of pressure parameters were analyzed: transversal range, longitudinal range, sway path, sway area and mean sway velocity. We also calculated two Romberg ratios (EC/EO and SV/EO) in order to assess visual contributions during standing.

Results

Older adults reported greater postural sway than young participants, especially when both somatosensory and visual systems were perturbed. Longitudinal range, sway path and sway area showed that SV effect was greater in older adults, compared to young adults, only on foam surface, while transversal range and mean sway velocity demonstrated greater SV effect in olders also on firm surface. Almost all measures, except longitudinal range, expressed higher Romberg ratios in older adults indicating that they might have higher visual reliance compared to young individuals.

Discussion

Intermittent visual deprivation seems to induce greater postural instability in older adults compared to young adults and such effect may be due to older adults' lower ability to effectively reweight visual input for postural control.

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Efficacy of telerehabilitation training in stroke patients: evaluation of gait parameters

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Introduction

In recent years, the introduction of telerehabilitation in neurological disorders has attracted the greatest amount of interest. According to some studies conducted on post-stroke patients [1], telerehabilitation offers some advantages, such as the ability for patients to self-report pain and activity. To examine motor outcomes, most studies have used clinical scales [2] and very few studies have used gait analysis to show improvements in gait parameters following telerehabilitation [3]. The aim of this study was to evaluate the effects of a technological telerehabilitation training in stroke patients using gait analysis.

Methods

We enrolled 30 stroke patients (18M, 12F; 64±7 years). They were randomized into two different groups: one group (G-ARC) underwent home rehabilitation treatment in telerehabilitation with the ARC Intellicare device, while the other group (G-CON) underwent home rehabilitation treatment according to a treatment scheme planned by the physical therapist. All patients, regardless of group, underwent home rehabilitation for 60 minutes a day, 3 days a week, for 8 weeks. Gait analysis was performed using the SMART-DX optoelectronic system with 8 infrared cameras sampling at 200 Hz. We used the Davis model that includes 22 markers. All spatio-temporal parameters were calculated. To assess kinematics of the lower limb joints we also calculated hip, knee, and ankle range of motion (ROM) in the sagittal plane. The assessments were performed at the beginning (T0) and at the end of the treatment (T1).

Results

The within-group analysis revealed a statistically improvement only in G-ARC. In particular, we showed statistically differences in most of the gait parameters: Stance time and Swing time of the unaffected side (p=0.018), related to the affected and unaffected side in Gait cycle time (p=0.006 and p=0.003, respectively), Step Length (p=0.030 and p=0.005, respectively), Gait Cycle Length (p=0.009 and p=0.010, respectively), Swing Velocity (p=0.005 and p=0.006, respectively) and finally in Mean Velocity (p=0.004) and Cadence (p=0.004).
Regarding to the between-group analysis, the percentage improvement was higher in the G-ARC than in the G-CON in: Gait cycle time of the unaffected side (p=0.015), Cadence (p=0.041) and Swing Velocity of the affected side (p=0.041).

Discussion

This study demonstrated how the ARC Intellicare device is a useful tool for the enjoyment of rehabilitation at a distance, at home, while maintaining monitoring of the proposed rehabilitation activities and contact with the physical therapist. In our sample, telerehabilitation produced promising effects on functional and motor outcomes, improving walking strategies and obtaining a more physiological gait.

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Quantitative Assessment of Early Stage Passive Rehabilitation through Kinematic Indices

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Introduction

Orthopedic rehabilitation within rehabilitation clinics is pivotal, involving a deep understanding and critical assessment of orthopedic injuries to tailor effective treatment plans. Thorough evaluation of medical and surgical options is essential for therapists to design successful rehabilitation strategies. Understanding and evaluating the rehabilitation of orthopaedic injuries through quantitative analysis is critical to optimising the treatment process, allowing for personalisation to meet the needs of the patient. This supplements qualitative analysis, providing more precise rehabilitation outcome data. One of the main causes of orthopedic damage is osteoarthritis, also known as gonarthrosis or knee arthrosis. It's a chronic condition characterised by deterioration of the cartilage in the knee joint, leading to pain, limited mobility and, in severe cases, joint deformity requiring knee replacement surgery. This study aims to identify and analyze quantitative indices from gait analysis using wearable inertial units to assess rehabilitation progress in post-knee replacement osteoarthritis patients.

Methods

The study involved 28 patients (average age: 60±12, 19 females and 9 males) undergoing knee prosthesis surgery during rehabilitation. Their walking patterns were assessed at two stages: 15 days post-surgery (pre-phase) and after completing the initial passive rehabilitation cycle (post-phase). Kinematic analysis utilized the Mobility Lab and Instrumented Stand and Walk (ISAW) protocol, employing three Inertial Measurement Units (IMUs) on the lower back and feet. Patients stood for 30 seconds before a 7-meter walk, including a pivot turn. The Wilcoxon Test statistical analysis was used to assess and compare rehabilitation progress between the two phases.

Results

The statistical analysis revealed changes in walking abilities and assessed the impact of the knee prosthesis on mobility. Table 1 reports the quantitative kinematic parameters assessed for the pre and post phases, expressed as mean and standard deviation, along with the results of the Wilcoxon Test.

Table 3. Quantitative kinematic parameter and Wilcoxon Test Results.

	Parameters	PRE	POST	Pre/Post Significance
		Mean±Std	Mean±Std	
SWAY	Total sway area (m^2/s^5)	0.0079±0.0088	0.0057±0.0045	ns
GAIT	Gait Cycle Time (seconds) [Mean]	1.43±0.16	1.41±0.20	ns
	RoMKnee (degrees) [Mean]	48.5 ±5.1	51.3±4.7	***
TURN	Turning Duration (s) [Mean]	4.79±1.46	3.94±1.40	**
	Number of steps (number) [Mean]	6.89±1.62	6.4±1.86	*

ns: p-value>0.05; *: 0.01<p-value<0.05; **: 0001<p-value<0.01; ***: p-value<0.001.

Discussion

The pre- and post-phase comparison revealed no significant differences in Total Sway Area and unchanged Gait Cycle Time despite a highly significant RoMKnee change. However, Turning Duration and Number of steps showed significant differences. The significant differences observed in RoMKnee and Turn parameters highlight the effectiveness of passive rehabilitation exercises in improving knee movement range. They align with previous studies demonstrating various rehabilitation techniques' efficacy in enhancing prosthetic knee movement [1]. Additionally, this study highlights the potential of quantitative methodology using affordable, high-performance sensors to evaluate rehabilitation treatments, contrasting with traditional qualitative assessments.

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Upper limb muscle synergies in people with Poland syndrome

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Introduction

Poland syndrome is a rare congenital disorder, with uncertain aetiology, characterized by the partial or complete absence of the pectoralis muscle, typically unilateral, potentially leading to chest, breast, shoulder, arm, and hand abnormalities [1]. Treatments are mostly aesthetic, although it is still quite common the latissimus dorsi transposition. This invasive surgical practice has been increasingly questioned in recent years [2] and studying the reorganization of upper-body muscle activations could help to understand if it is needed. However, there is a lack of studies addressing this issue. This work aims to fill this gap by characterizing muscle activation patterns of subjects with Poland syndrome during movements using surface electromyography (sEMG) and muscle synergies, investigating whether and how other muscles compensate for the pectoralis absence.

Methods

Twenty-eight subjects participated in this study: fourteen individuals with Poland syndrome, six with pectoralis absence, and eight with preserved clavicular head and their age and gender-matched controls. The activation of twelve muscles of the torso and upper limb was recorded bilaterally during (1) ten repetitions with both arms of shoulder flexion, extension, abduction, adduction, while holding 0 or 1.5 kg weight (2) a task in which subjects slide the hand along an arc-shaped structure positioned in front of them. The envelope was extracted and segmented using the acceleration signal provided by the probe on the brachialis, and amplitude was normalized to the mean value of each muscle to compare different subjects' activations. Muscle synergies were extracted by applying the non-negative matrix factorization algorithm to the concatenation of the normalized sEMG envelopes of all tasks [3][4].

Results

We observed differences between the two populations in the activation timing and the amplitude modulation of the muscle envelopes mainly during adduction movements, requiring the higher recruitment of the pectoralis. The analysis of the six muscle synergies revealed compensation mechanisms involving a redistribution of activation to shoulder and back muscles (Figure). These differences were more evident in subjects without the pectoralis and for subjects with preserved clavicular head during movements with weights. These changes were minimal and allowed for efficient execution of all tasks.

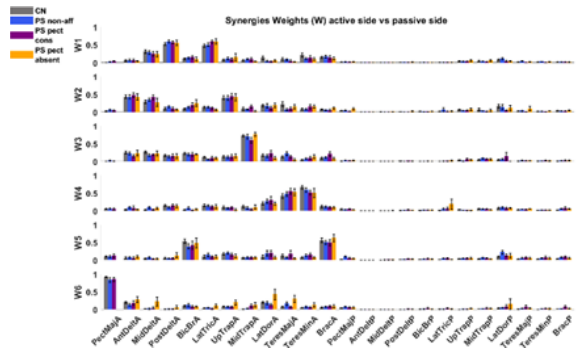

Figure 1. Synergies Weights for each muscle related to four groups: control subjects (grey), non-affected side population with Poland syndrome (blue), affected side with partially preserved pectoralis (purple) and affected side with pectoralis absence (yellow). Weights indicate the contribution of each muscle to the synergies. Synergy 6 has the highest contribution from the pectoralis muscle. Subjects without the pectoralis muscle exhibit a higher contribution from the muscles of the shoulder and the dorsal chain.

Discussion

Subjects with Poland syndrome optimally compensate for pectoralis absence by activating the shoulder and dorsal chain muscles, with only minimal differences in muscle activations with respect to controls and with preserved ability to efficiently perform arm movements. This suggests that replacing the pectoralis with the latissimus dorsi might not be necessary.

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TWIN-Acta controlled exoskeleton in gait rehabilitation for persons post-stroke. A pilot and feasibility study

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Introduction

Walking recovery is one of main priorities for most persons post-stroke [1]. Overground exoskeletons are increasingly being used in gait rehabilitation for persons post-stroke with moderate to severe gait disability. In this context an assistance tailored to the persons' residual skills is important for boosting recovery of a physiological gait pattern. In this feasibility and pilot study we applied TWIN-Acta, an adaptive control suite that allows asynchronous assistance as needed, for the lower limb exoskeleton TWIN during gait [2].

Methods

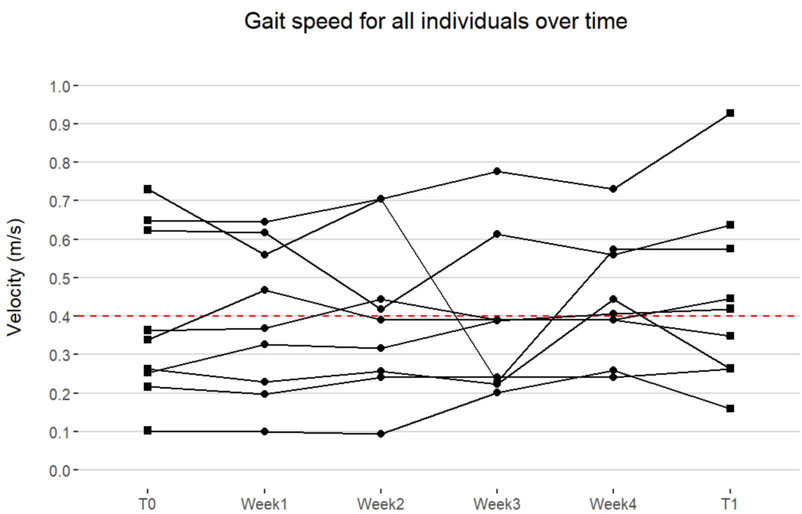
Nine persons post-stroke >3 months, with a Functional Ambulation Category score 1-3, were enrolled and underwent 20 sessions of gait rehabilitation (3-5 times per week) with exoskeleton TWIN controlled by TWIN-Acta. Before (T0) and after (T1) rehabilitation, participants underwent assessments: Ten meter walking test (Primary outcome, 10MWT), Ashworth scale (spasticity lower limb), Two minute walking test (2MWT), Stroke Impact Scale (SIS). The 10MWT and distance walked with the TWIN-Acta in 15 minutes was tested weekly. The usability and learnability of the TWIN were verified with the System Usability Scale (SUS).

Non-parametric tests were used for before and after comparisons.

Results

The participants were from moderately to severely affected in their gait and as a group were categorized as limited to household-walking (<0.40 m/s [3]).

At T1 the groups' gait velocity (see Figure 1 for all individual time points) had increased from Median(Interquartile) 0.34 (0.37) to 0.42(0.31) m/s (P=0.09) resulting categorized as limited community walkers (0.40-0.80 m/sec). Spasticity (P=0.04) and 2MWT (P=0.02) improved. Distance walked in TWIN-Acta increased from mean 49 meters in the first week to 155 meters in the last week of gait training. Only three of the 10 participants judged the TWIN as usable and learnable (SUS score > 70).



Discussion

The TWIN with the TWIN-Acta control system led to improvements in gait ability in persons post-stroke that were clinically important for daily life participation outside of the home. Despite the perceived complexity of use, the exoskeleton TWIN with the TWIN-Acta based asynchronous assistance as needed during gait is a promising tool for gait rehabilitation in persons post-stroke.

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Neuromotor recovery of walking in post-stroke individuals using TWIN-Acta-based robotic assisted gait training

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Introduction

Stroke is a leading cause of acquired, permanent disability worldwide. The most effective rehabilitation approaches require post-stroke patients to engage in voluntary training to optimize recovery through neural reorganization, enhancing functional independence [1]. Recent technological advancements have led to robotic controllers for lower-limb exoskeletons to assist individuals who have experienced brain injuries such as strokes. However, only 14% of these exoskeletons use adaptive control strategies [1]. To address this, we developed TWINActa [2], an adaptive control suite for lower limb exoskeletons, and tested its feasibility and preliminary impact on gait rehabilitation for post-stroke individuals.

Methods

Nine persons post-stroke were enrolled and underwent 20 sessions of gait rehabilitation treatment with exoskeleton controlled by TWIN-Acta, 3 to 5 times a week. Before (T0) and after (T1) rehabilitation, participants underwent clinical and instrumented assessments, during which participants were asked to perform dynamic and static motor tasks (e.g., overground walking and sit-to-stand). The muscle activity of 12 muscles from electromyographic (EMG) sensors (5 placed on the lower limb and one on the upper limb, bilaterally) and movement data from 2 IMUs on the shanks were recorded during a 10-meter overground walk. Fifteen healthy subjects (66.6±5.9 yrs) provided the normative reference. Non-negative matrix factorization was carried out on EMG signal from muscles to identify muscle synergies [3]. Pearson's correlation coefficient was used to evaluate the similarity, between HS and PS, of motor modules (module composition) and of modules activation profiles [3] for both assessments.

Results

The number of completed treatments being 18.4±2.6, indicates a good adherence to the treatment protocol (>90%). Healthy subjects exhibited 4.8±0.51 synergies, whereas post-stroke subjects showed a reduced number of synergies both pre-intervention (4.0±0.5, p<0.001) and post-intervention (3.9±0.92, p<0.01). Overall similarity in module composition and activation profiles remained low after training. However, the average similarity of modules activation profiles showed an increase towards the physiological pattern (pre-intervention: 0.08±0.20; post-intervention: 0.25±0.10, p=0.09).

Discussion

Despite the small sample size of the study here presented, the observed trend of improvement is encouraging. The feasibility and good adherence to the protocol, with most participants completing the treatment sessions with increased similarity of muscle synergies with those of healthy subjects, support future investigation of the device as rehabilitation tool in a larger population of post-stroke patients.

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Predicting 60-day Recovery Outcomes After ACL Surgery Using Machine Learning

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Introduction

Anterior Cruciate Ligament (ACL) surgery is a common procedure to repair or reconstruct the ACL after injury. Postoperative rehabilitation plays a crucial role in returning ACL-reconstructed (ACLR) patients to sports activities as safely as possible. Predicting outcomes of ACL surgery and rehabilitation programs using machine learning (ML) models could enhance patient care by providing personalized recovery forecasts and optimizing treatment plans [1,2]. In this work, we cross-validated and tested ML models targeting the 60-days recovery of ACLR patients, using the knee circumference (CircK) and the knee flexion Range of Motion (RoMflex) as recovery metrics.

Methods

Data from 431 patients admitted to Casa di Cura Villa Stuart (Rome, IT) after a severe ACL injury were enrolled in this prospective study. Independent variables included etiology data (lesion and sport characteristics, severity levels), pre-surgery examinations (e.g., lower limb/joint circumferences and/or laxity), and surgery-related data (type of interventions, graft, and fMRI data), for a total of 101 features. The pre-processing pipeline included removal of variables with low standard-deviation (less than 0.01 after normalization) and of mutual correlated variables (retaining the most correlated with outcome). Then, feature transforms as PCA and univariate feature selection (mutual information-based) were derived from the train set (80%) and applied to the test set (stratified by recovered percentage). Model optimization (XGBoost) was performed using Optuna [3] by maximizing 10-fold (from the train set) cross-validation accuracy. CircK and RoMflex were selected as recovery metrics and the patient's status was defined as recovered if the difference healthy-injured for these two metrics was, respectively, less than 1 cm and equal to 0°.

Results

Four-hundred thirty-one patients were enrolled (311 males, median age of 25 years [IQR = 15]), of which 148 were professional athletes. The initial screening reduced the dataset to 62 variables, before entering PCA (N=18) and cross-validated feature selection (N=10). The best performing solution reached a test accuracy of 70% for CircK and 65% for flexion RoMflex (Figure 1) where corresponding cross-validation accuracy was of 76% and of 73%. Computing the area under the RoC (AuRoC) on the test-set predicted posteriors resulted an AuRoC of 0.73 on CircK and of 0.70 on RoMflex.

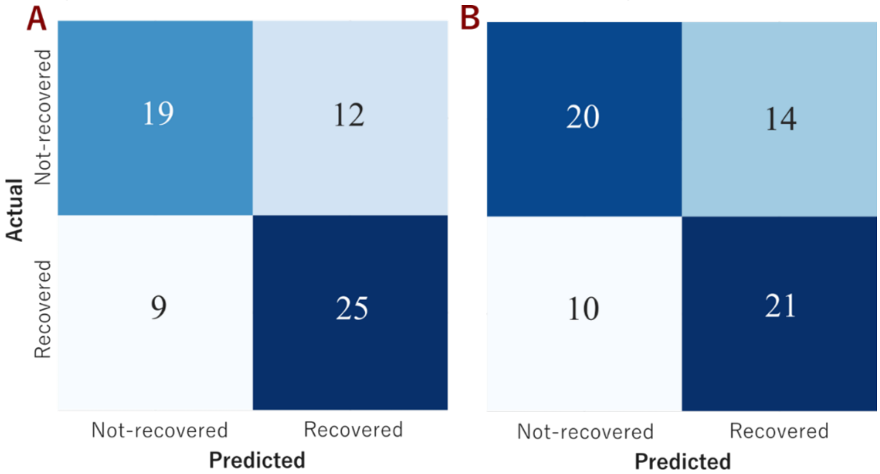

Figure 1.

Discussion

In this study, we aimed to enhance the prediction of recovery outcomes following ACL surgery by applying rigorous data preprocessing and model optimization techniques on a comprehensive dataset taken before and after the surgery. Future works should aim to refine these models by including mid-term evaluations and externally validating the deployed models.

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Influence of walking path length on 2-minute walk test gait parameters in healthy young adults

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Introduction

Human walking is a complex motor function requiring the integration of motor and sensory systems [1]. To assess patients overall functional capacity and estimate health status, various walking tests, such as the 6- and 2-Minute Walk Tests (6MWT, 2MWT), are used [2]. The widely employed 6MWT is typically conducted in a straight corridor of at least 30 meters, according to the American Thoracic Society [1] guidelines, and measures the total distance walked. The 2MWT, instead, is often applied in the clinical setting due to its greater tolerability, especially with populations with walking difficulties [3]. However, the space requirement of 30m is rarely feasible in clinical facilities. This study aims to determine how different walking path lengths affect gait patterns in the 2MWT.

Methods

Twenty healthy young adults (10 males; age: 27.3 ± 2.9 years) performed three 2MWT trials on straight hallways of 5m, 15m, and 30m lengths with 180° turning points at the extremities. Participants walked at self-selected speed while wearing three inertial measurement units (IMUs) (Captiks Srl, Rome, Italy, 100Hz) placed on both ankles, and lower back (L5) and gait spatio-temporal parameters were obtained. Repeated measures ANOVA or Friedman test were applied to detect differences among the three walking distances using SPSS software ($\alpha < 0.05$).

Results

Results are reported in Table 1. WS and WD for the 5m walk were significantly lower than the 15m and 30m walks, and the 15m WS and WD were significantly lower than the 30m WD and WD ($p<0.001$). No significant differences were observed for the other parameters between the 15m and 30m configurations. However, the 5m configuration showed higher stride duration, swing time, and single support time, and lower cadence compared to the 15m and 30m configurations ($p<=0.001$).

	5m		15m		30m			
	Mean	± SD	Mean	± SD	Mean	± SD	P-value	Effect Size
Walking Distance (m)	123.698^{a,b}	14.363	161.771^{a,c}	14.674	179.376^{b,c}	19.420	**<0.001**	$\eta\rho^2 = 0.952$
Walking Speed (m/s)	1.624^{a,b}	0.169	1.687^{a,c}	0.164	1.761^{b,c}	0.162	**<0.001**	W = 0.473
Stride Duration (s)	1.045^{a,b}	0.071	1.012	0.057	1.004	0.056	**<0.001**	$\eta\rho^2 = 0.625$
Stance Time (s)	0.613	0.057	0.600	0.045	0.594	0.046	**0.01**	$\eta\rho^2 = 0.268$
Swing Time (s)	0.432^{a,b}	0.027	0.412	0.020	0.409	0.019	**<0.001**	$\eta\rho^2 = 0.561$
Single Support Time (s)	0.421^{a,b}	0.024	0.412	0.020	0.410	0.019	**<0.001**	$\eta\rho^2 = 0.508$
Double Support Time (s)	0.191	0.050	0.188	0.041	0.184	0.043	0.265	$\eta\rho^2 = 0.067$
Cadence (steps/min)	115.478^{a,b}	7.300	119.046	6.657	119.970	6.763	**<0.001**	$\eta\rho^2 = 0.658$

Table 1. P value of each main effect is reported, and bold numbers indicate statistically significant differences ($p<0.05$). Effect size is reported as Eta-squared ($\eta\rho^2$), for parametric tests, or Kendall W (W), for non-parametric tests.
[a] Significant diff. from 30m, [b] Significant diff. from 15m, [c] Significant diff. from 5m.

Discussion

This study reinforces the hypothesis that walking path length significantly influences walking performance in the 2MWT. Longer paths (30m) resulted in higher WD and WS, while shorter paths (5m) showed altered gait patterns due to frequent turning points and phases of acceleration and deceleration [4]. These findings support the recommendation of using a 30m straight path also for the 2MWT. However, the 15m path represent a valid alternative for assessing temporal parameters, but caution is needed when interpreting WS and WD. In clinical settings with limited space, is crucial to consider the impact of shorter paths on gait patterns. This study provides value ranges of specific parameters, indicating their extent of underestimation when walking in limited spaces.

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A graph-based approach to study motor coordination in Parkinson's Disease gait: a longitudinal study to assess the effectiveness of Deep Brain Stimulation neurosurgery

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Introduction

Graph theory is emerging as a promising technique in different contexts [1], and it can be used to extract a network of muscles based on their coordinated activity during gait. This work aims to investigate the motor control strategies of Parkinson's Disease (PD) patients through graph theory and Louvain clustering and to evaluate the successfulness of Deep Brain Stimulation (DBS) in alleviating PD motor symptoms.

Methods

Gait analysis, inclusive of surface electromyography (EMG) of the main muscles involved in locomotion, was carried out on 30 PD patients and 30 controls. A detailed description of the acquisition protocol is provided in Ref. [2]. PD patients were longitudinally followed-up, with assessments at 3 time points: pre-DBS implant (T0), 3-month post-DBS implant (T1), and 12 months post-DBS implant (T2). Intermuscular adjacency matrices computed from EMG data of 12 lower-limb and trunk muscles were used to extract graph networks. Each graph network consists of nodes (i.e., muscles) and edges (i.e., weighted connections between muscles). The graph "modularity" was extracted from each graph, as defined in Ref. [3]. A 1-way ANOVA with Bonferroni correction for multiple comparisons was performed to discriminate statistically significant differences in graph modularity among PD patients (at the 3 time points) and controls.

Results

Muscle-network graph of a representative PD patient is shown before (Fig. 1A) and 12 months after DBS (Fig. 1B). The graph modularity increased from 0.28 to 0.49 during the follow-up of this specific patient. The modularity of the PD population at T0, T1, and T2 vs. controls are shown in Fig. 1C. The PD modularity at T0 was significantly smaller than that of controls (PD at T0: 0.35±0.01 (mean±SE); controls: 0.40±0.01; p=0.019), becoming not different from that of controls at T1 (0.36±0.01; p=0.18) and T2 (0.38±0.01; p=1.00).

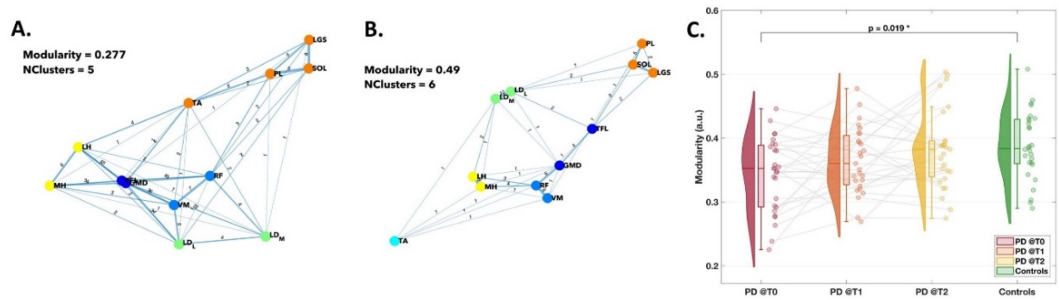

Figure 1. Examples of muscle-network graphs and PD improvements in modularity after DBS implant.

Muscle-network graph of a PD patient before (Fig.1A) and after DBS implant (Fig.1B). Muscle considered: Tibialis Anterior (TA), Lateral Gastrocnemius (LGS), Peroneus Longus (PL), Soleus (SOL), Vastus Medialis (VM), Rectus Femoris (RF), Lateral Hamstring (LH), Medial Hamstring (MH), Gluteus Medius (GMD), Tensor Fasciae Latae (TFL), Longissimus Dorsii of the more- and less-affected side (LDM and LDL). Fig.1C shows graph modularity of PD patients (T0: baseline; T1: 3 months after DBS; T2: 12 months after DBS) vs. controls.

Discussion

Modularity is a metric that reflects the separability of muscle groups that activate synergistically. Lower graph modularity may indicate reduced independence among the muscle groups and decreased motor control complexity. Graph modularity proved a sensitive measure to assess short- and long-term motor improvements in PD patients following DBS. Acknowledgements: This study was carried out within the project "PD-DBS", protocol N° 2022KWSJJT – funded by European Union – Next Generation EU within the PRIN 2022 program (D.D. 104 - 02/02/2022 Ministero dell'Università e della Ricerca). This manuscript reflects only the authors' views and opinions and the Ministry cannot be considered responsible for them.

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The mnesys-cmsyn study: exploring cortico-muscular coherence during hand and upper limb movements

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Introduction

Cortico-muscular coherence (CMC) index quantifies the synchronization between motor neural oscillations and the related voluntary muscle activity (EMG). Hence, it reflects the functional relationship between the cortico-efferent descending command from motor areas and muscles [1]. CMC has been primarily studied using single muscle EMG recorded during isometric contractions, however, these movements are not ecologically relevant actions employed during daily life activity [2,3]. Moreover, this approach does not reflect the neurophysiological principles by which the central nervous system (CNS) controls voluntary movement. Recent neurophysiological studies have shown that the CNS controls movement through the coordinated recruitment of multiple muscles (muscle synergies) aimed at achieving a specific goal (e.g manipulating an object) [4]. Therefore, this study aims to develop and apply a novel methodology capable of analyzing the coherence between EEG signals and muscle synergy during phasic movements. This will be referred as cortico-muscular coherence using synergies (CMSyn).

Methods

This research will focus on the upper limb and will be conducted on 10 healthy, voluntary participants. All subjects will undergo brain magnetic resonance imaging (MRI) scans, which will be used to guide transcranial magnetic stimulation (TMS) for mapping the dorso-ventral and rostro-caudal extension of the human hand-knob region. This is needed to accurately locate the motor output regions for the upper limb and hand on subject dominant side. The acquisition protocol will consist of 2 phases: 1) execution of isometric contraction, 2) execution of ethologically relevant action. In phase 1, subjects will execute isometric contraction trying to isolate single muscle as much as possible. In phase 2, subjects will perform visuo-guided reaching, and reaching to grasping actions with different hand configuration: precision grip, unusual precision grip (pinching with ring finger and thumb). During both phases, EEG and EMG of target muscles (dominant side arm, 4 proximal and 4 distal muscles) will be recorded. Data processing flow is shown in Figure 1.

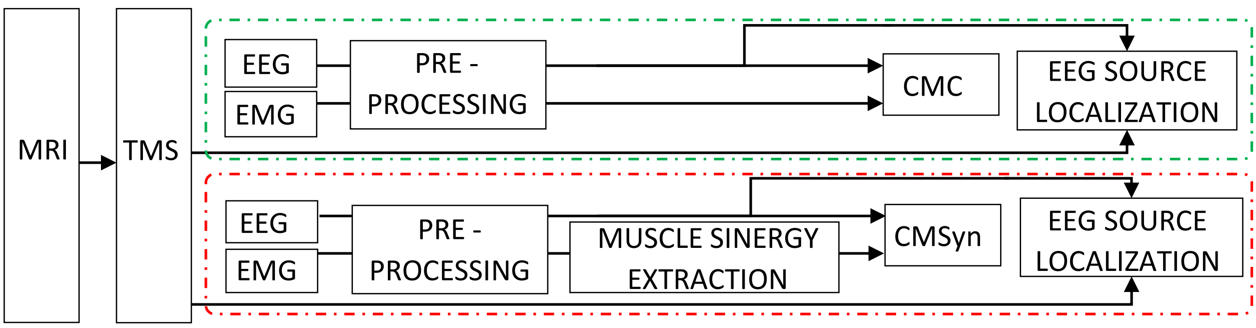

Figure 9. Block scheme of data processing and analysis. Phase 1 is highlighted in green. Phase 2 is highlighted in red.

Results-Discussion

Being more adherent to neurophysiological mechanism, CMSyn is expected to reflect the cortical organization of muscle synergies employed in prehension actions, thus providing the fine-grained description of the EEG-synergies source localization in terms of magnitude within the beta and gamma frequency [3]. The defined experimental setup and data acquisition software will be tested in next future with the acquisition of data from healthy volunteers.

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Characterization of upper-limb biomechanics during center-out reaching task: preliminary results of motor learning during repeated execution in a single training session

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Introduction

Motor learning refers to the process of improving performance through the practice and the repeated execution of a specific task [1]. This phenomenon plays a significant role in rehabilitation contexts [2], for example in the design of strategies for functional recovery after stroke [3], and in sports, leading to the acquisition and the perfection of new motor skills [4]. In literature, several studies comparing the performance of pathological and healthy subjects can be found, as well as those reporting improvements in the subjects' performance at the end of a rehabilitation program, but there is a lack of studies investigating motor learning in a single training session.

The aim of this study is to assess the biomechanics of the upper limb during a reaching task performed by healthy subjects. The objective is to investigate the presence of motor learning, evaluating kinematic parameters (joint angles, manipulandum trajectory, and their variability) and electromyography activity during 60 repetitions of 5 different targets to be reached.

Methods

Nine healthy subjects (3M6F, aged 23 ± 2 years) performed with their dominant arm a 2-D center-out reaching task towards 5 different positions equally spaced and located in a semi-circle. The experimental session consisted of 6 runs of 50 trials reaching one of the 5 targets (10 repetitions for each target). Kinematic data were recorded using a motion capture system (8 cameras VICON™ Vero 2.2, 100Hz). The experimental protocol involved 8 anatomical markers, located on the trunk, arm, and forearm segments and one marker on the manipulandum. Trunk rotation, shoulder (flexion/extension, abduction/adduction, and intra/external rotation) and elbow angles (flexion/extension) together with manipulandum trajectory kinematic features (movement time, straightness, speed metrics, time to peak velocity, smoothness) were computed. Bipolar surface electromyography activity of 4 muscles (biceps, triceps and wrist flexor and extensor) was also detected (Cometa System, MiniWave, 2000Hz).

Results

Joint and manipulandum kinematics were subject-specific. Results of two representative subjects are reported in Figure 1 for one target. This was further confirmed by the repeatability of the electromyographic activity evaluated both inter- and intra-run.

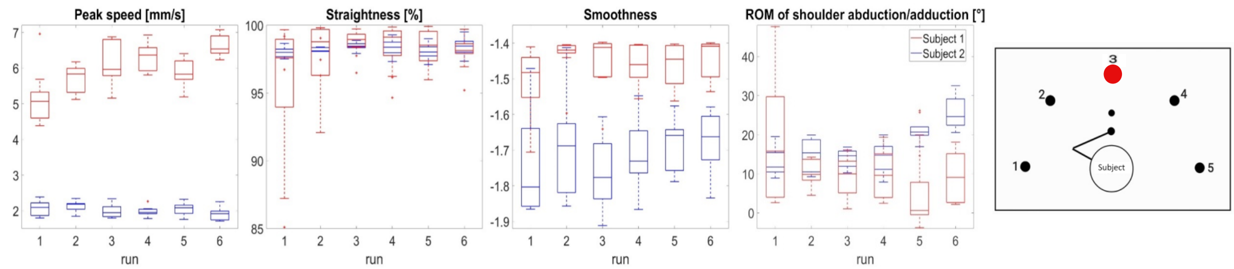

Figure 1. Left: Results of manipulandum and joint kinematics of two representative subjects for the central target (3). Right: Experimental setup with the five targets equally spaced and located in a semi-circle on the planar surface around the central rest position.

Discussion

Results supported the observation of non-paradigmatic upper limb movements. The joints and manipulandum kinematics showed a high inter-subject variability, indicating the adoption of subject-specific motor strategies for center-out reaching task. Before extending this analysis to pathological conditions, it's crucial to characterize the biomechanics of upper limb movements on large samples of healthy subjects investigating for possible clustered strategies based on motor performance.

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The feasibility study of EMG- and kinematics-based assessment and future directions for the Othello project

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Introduction

Stroke causes long-term disability, frequently resulting in upper limb motor impairments, such as muscle weakness and dexterity loss, significantly compromising patient ability to perform daily activities independently [1]. The OTHELLO project (Efficacy of a rehabilitation treatment using Observation THerapy Enhanced by muscLe synergy-derived eLectrical stimulatiOn in post-stroke patients (PS)) combines the positive effects of Action Observation Therapy (AOT) [2] and Neuromuscular Electrical Stimulation (NMES) prior to motor execution. This combination can induce long-term changes in motor areas cortical excitability and enhance motor learning by generating sensory feedback from muscle contraction to the brain [3]. OTHELLO will recruit sixty post-stroke patients randomized in three groups: (a)AOT-NMES, and (b)AOT, observing reaching-grasping action videos, with synchronized synergy-based NMES in (a), and (c)Motor Neutral Observation (MNO), observing non-action videos. This work aims to introduce the OTHELLO project and to assess the feasibility of the instrumented protocol for evaluating the effects of training on upper-limb motor deficits in PS, according to physiological muscle synergies time- and intensity-dependent activation.

Methods

To date eight subjects have been recruited. Assessment is performed before (EG-T0) and after (EG-T1) training, through six grasping-lifting tasks of the ARAT. Ten healthy subjects have been recruited as normative reference (NR). During the evaluation, 12 upper limb muscle activity and kinematics are recorded using respectively electromyography sensors (EMG) and optoelectronic system. From kinematic data, joint angles related to shoulder, elbow, wrist and fingers are extracted and ranges of motion (ROM) are computed. The protocol consists of 15 sessions, each 60-minute long, over 3 weeks. Due to the subjects limited number recruited so far, only analyses of the main factors -Groups PS vs NR (between-factor), and Time EG-T0 vs EG-T1(within-factor)- are reported. Specifically, unpaired statistics between NR and PS and paired statistics between EG-T0 and EG-T1 are presented, with a significance level of 5%.

Results

As preliminary results, elbow flexion-extension of overall group of PS is considered. Figure 1 shows ROM distributions for one reaching task. A significant difference is found between EG-T0 and EG-T1 (p-value=0.03) and between NR and EG-T0 (p=0.002). No significant difference is found between NR and EG-T1 (p=0.1).

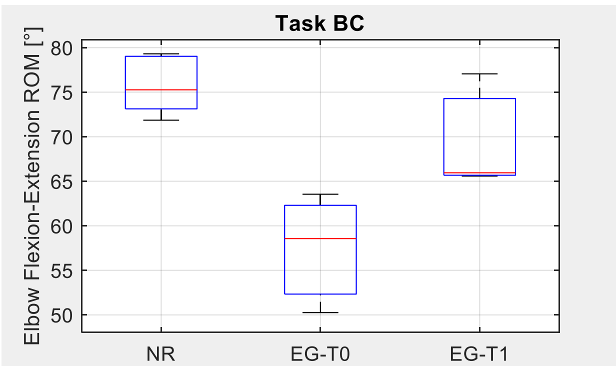

Figure 10. Distributions of the elbow flexion-extension ROM of the normative reference (NR), and of the experimental group before (EG-T0) and after (EG-T1) the rehabilitation protocol, of the task involving grasping and lifting the bigger cube (BC).

Discussion

All subjects successfully completed the motor tasks. Preliminary results show a 20% increase in elbow ROM from EG-T0 to EG-T1 and a non-significant difference between NR and EG-T1. These suggest that OTHELLO protocol can enhance motor recovery and the EMG- and kinematics-based evaluation method can measure training impacts on post-stroke upper-limb deficits.

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Comparison of inertial-based filters for orientation estimation in indoor and outdoor running

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Introduction

Stride velocity (SV) is a crucial parameter for running characterization. Its computation in outdoor conditions requires to determine foot accelerations obtained by subtracting the gravity vector projection from the accelerometer signal recorded by a magneto-inertial measurement unit (MIMU). Therefore, accurate MIMU-based orientation estimation during highly dynamic conditions is required, as small errors can lead to unacceptable inaccuracies in SV evaluation [1]. To this purpose, a fine-tuning of the sensor fusion algorithm (SFA) parameters is crucial to reduce errors [2]. The aim of this preliminary study was to quantify the sensitivity of SV estimates to variations of parameter value(s) of four established open-source SFAs [3-6] during indoor and outdoor running at 8 km/h and 10 km/h.

Methods

Five recreational runners ran 400 meters on an indoor treadmill and an outdoor track at constant speeds (8 km/h and 10 km/h), instrumented with MIMUs placed on feet dorsum and pressure insoles (fs = 100 Hz). Strides were segmented between consecutive zero-velocity instants provided by the pressure insoles. To remove the gravity contribution, four SFAs [2] were tested to select the ones showing the most stride-by-stride repeatable orientation: complementary filters by Madgwick et al. (MAD) [3], Valenti et al. (VAC) [4] and Seel et al. (SEL) [5] and a Kalman filter by Guo et al. (GUO) [6]. A quality check on magnetometer data excluded the presence of ferromagnetic disturbances. The selected methods were fine-tuned with a grid search approach to define the optimal parameter(s) enabling the minimization of averaged SV errors with respect to the nominal constant speeds. SV was estimated as the average of the norm of the antero-posterior and medio-lateral velocity obtained from the acceleration integration between consecutive zero-velocity instants.

Results

Table 1 shows errors in SV estimates averaged across all subjects for each SFA with its optimal parameter(s). To assess sensitivity to parameter variations, total SV ranges obtained from all possible parameter combinations are reported.

Table 1. Errors in the SV estimates with the optimal parameter/s chosen for each SFA at different running conditions.

SFA	Sub-optimal parameters	SV errors (km/h)				Total SV estimate range (km/h)
		Indoor at 8 km/h	*Outdoor at 8 km/h*	*Indoor at 10 km/h*	*Outdoor at 10 km/h*	
MAD	β=0.07 rad/s	0.35 ±0.59	-0.53 ±0.73	-1.50 ±0.61	-1.29 ±0.99	4.35 – 9.07
VAC	ath2= 1 a.u. gainmag=0.1 a.u.	0.08 ±0.57	0.30 ±0.70	-1.15 ±0.60	0.08 ±0.90	5.08 – 10.30
SEL	τmag=0.1s τacc=0.02 s	-3.17 ±0.52	-3.42 ±0.67	-5.24 ±0.53	-4.74 ±0.97	1.6 – 7.7
GUO	σgyr=0.08 rad/s	-2.50 ±0.81	-3.13 ±0.75	-4.51 ±0.79	-4.45 ±0.99	1.24 – 8.19

Discussion

This preliminary study revealed that the fine-tuning of SFA parameters highly affects the SV estimation in running: a wrong parameter setting can increase SV errors by about 40%. In general, SV estimates at 10 km/h led to higher errors (1.5-5.24 km/h) than those at 8 km/h (0.3-3.42 km/h), possibly due to the lower accuracy in the detection of the zero-velocity instants increasing the speed. Results suggested that MAD and VAC could be preferable for the orientation estimation in running analysis (errors below 1.5 km/h).

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Observational pilot study of the correlation between indices deriving from the acceleration of trunk and emg parameters of the muscles in the lower limb

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Background

The human gait corresponds to the physiological mode of locomotion, which can be influenced by various disorders [1]. Instrumental gait analysis allows the quantification and analysis of locomotor function and alterations associated with specific pathological conditions; this type of analysis can therefore support the definition of the rehabilitation project [2]. The primary outcome was the analysis of the correlation between the stability of the trunk and the musculature of the lower limbs, the secondary outcome was the evaluation of the stability indices in the normotype, in particular the correlation between muscle coactivation and the stability indices deriving from the Harmonic Ratio [3] and the Maximum Lyapunov [4] Exponent.

Methods

The sample size and methodology were calculated according to the international guidelines of the CONSORT declaration [5]. 28 healthy adult subjects were recruited, 7 of whom were women and the remaining men. Each subject repeated the test three times: once walking at a self-selected speed, once walking at a reduced speed and, finally, the last time walking at a higher speed. Each measurement corresponds to a pace, which is why data for normal, slow and fast pace were processed. The BTS FREEMG 1000 surface electromyography and the G-SENSOR were used for the measurements. Analyzes were performed at 95% statistical significance and 80% power using JASP software, vers. 16.0.

Results

The correlation analysis examined the values of the Harmonic Ratio, a stability index that provides an indication of the acceleration, smoothness and walking rhythm patterns, in all planes of space and the Maximum Ljapunov Exponent (LLE), which characterizes the behavior of a dynamic system and is expressed as a coefficient that detects local divergences, quantifying how the system continuously responds to small local perturbations. The values of the Harmonic Ratio in the medial – lateral direction (HRML) were significantly directly correlated to the muscle coactivation values during the stance phase of the step (Fig 1).

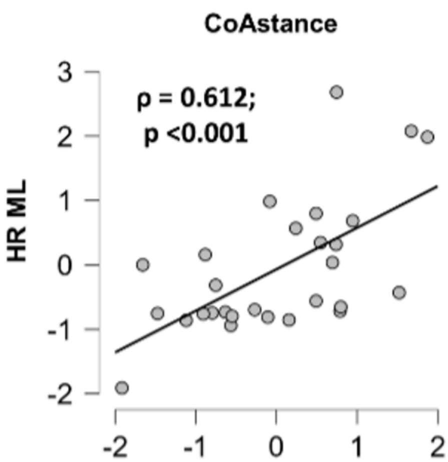

Figure 1.

Discussion

The results obtained through the study of Bland Altman graphs which analyze the values of the Harmonic Ratio on the Antero-Posterior axis, show how these values correlate negatively to the asymmetry of muscle coactivation. Considering that the higher the Lyapunov exponent (LLE), the more unstable the gait will be, we can consider how it also represents a potential biomarker of maladaptation of the trunk to asymmetries of strength of the lower limbs, which is reflected in the stability of the gait.

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Continuous estimation of vertical ground reaction force during unconstrained walking by lower limb EMG recordings

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Introduction

Volitional regulation of robotics and rehabilitative devices, based on residual electromyographic (EMG) activity, is a key aspect for improving usability and patients' comfort, by enhancing the interaction between the human and the machine. Lower limb prosthetic devices play a central role in restoring fundamental motor functions, such as walking capabilities. A great part of research efforts is devoted to the estimation of the lower limb angular kinematics during gait, in order to enable proportional control strategies for driving powered prosthetic devices [1,2]. However, relatively less attention was given to the estimation of ground reaction force, that could add meaningful information for achieving a more physiological modulation of gait, in particular during the stance phase, thus improving the continuous regulation of lower limb devices [3]. This work aims to assess the feasibility of the estimation of the vertical component of the ground reaction force (VGRF) during unconstrained walking from the EMG activity of shank and thigh muscles.

Methods

Three healthy subjects were enrolled. They were requested to walk back and forth for about 4 minutes on a 11 m walkway with six dynamometric force plates embedded in the center. Each subject performed four trials, for a total 350 stance periods recorded. Surface EMG probes were placed on the gastrocnemius medialis (GAS), tibialis anterior (TIB), vastus lateralis (VSL), and biceps femoris (BPF) of the dominant limb. VGRF and EMG were sampled at 1 kHz. The VGRF were normalized by the subject's weight. From the EMG signal, the linear envelope was computed as the only feature for VGRF estimation. As regression model, a long short-term memory (LSTM) network was employed with shank and thigh muscles. Further, GAS and TIB were also evaluated separately. For each subject, two gait trials were used for training, one for validation, and one for testing. Performances were assessed by the R2 coefficient, and root-mean-square error (RMSE).

Results

Regression parameters (training, validation, and testing) are reported in Table 1 for shank and thigh muscles, and separately for GAS and TIB.

Table 1. Average (SD) values of R^2 and RMSE for all the considered configurations.

		GAS+TIB	VSL+BPF	GAS	TIB
R^2	Training	0.89 (0.09)	0.57 (0.15)	0.72 (0.07)	0.27 (0.04)
	Validation	0.85 (0.11)	0.52 (0.13)	0.65 (0.09)	0.28 (0.06)
	Testing	0.86 (0.08)	0.59 (0.11)	0.64 (0.09)	0.25 (0.07)
RMSE (%BW)	Training	9.22 (1.11)	19.04 (1.53)	15.55 (1.88)	25.10 (3.21)
	Validation	11.40 (1.44)	20.52 (1.87)	17.43 (2.14)	24.91 (2.87)
	Testing	11.08 (1.73)	18.71 (2.31)	17.71 (2.35)	25.35 (2.94)

Discussion

The best muscles configuration for VGRF estimation involved GAS and TIB, likely because the modulation of the stance phase is driven mainly by shank muscles. Thigh muscles and TIB alone failed in providing a reliable estimation of the VGRF. It is remarkable that GAS alone showed higher performances with respect to both thigh and TIB, suggesting that a single muscle configuration can be a suitable solution for VGRF estimation during walking.

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Markerless estimation of sit-to-stand kinematics through an optimized DeepLabCut model

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Introduction

The advancement in artificial intelligence has impacted the field of human movement analysis, where markerless motion capture (MMC) solutions based on deep learning have started to gain prominence. Despite substantial advancements in MMC technology, tools such as OpenPose (OP) [1] still exhibit limitations in reliably estimating landmarks and in 3D movement reconstruction [2]. This underscores the need to further refine MMC techniques to ensure an improved reliability. This study develops an enhanced MMC model that integrates DeepLabCut (DLC) [3] and OP. The study focuses on Sit-to-Stand movements, taken as a clinically relevant yet simple and controllable task for testing the model.

Methods

The used dataset consists of 405 smartphone captured STS videos [4], in varying conditions and with an angle of 45° with respect to the chair. Our proposed approach is DLC-based and OP-informed. The training set consists of an automatic OP labeling of 5 selected anatomical landmarks (left shoulder, hip, knee, ankle and fifth metatarsal). The training set was refined with a likelihood-based filtering of the OP estimates, removing frames with likelihood < 0.9 for at least one of the 5 landmarks [5]. The model was built on a deep ResNet architecture with 200k iterations. The trained MMC model was tested on a dataset of 4 young healthy subjects performing 5 times STS, consisting of videos recorded from a pair of cameras (C920 HD PRO WEBCAM) mounted over a support, with an inter-camera distance of 30cm, plus a lateral camera placed at 90° to capture sagittal plane kinematics. 3D reconstruction of the landmarks was performed both with our model and the OP model alone. The system was calibrated with an A0 28x20 aruco marker chessboard.

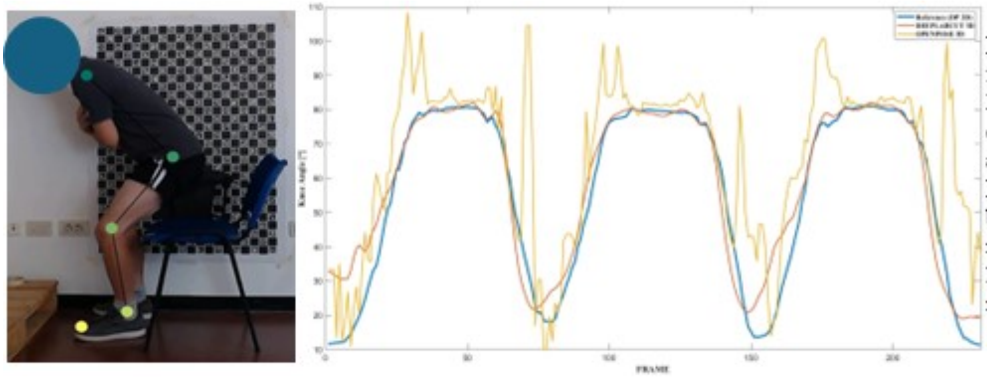

Figure 1. STS Recorded from the side camera 2D landmark estimation (left). Joint angle obtained from DLC-based 3D, OP-based 3D and reference side 2D landmarks reconstruction.

Results

Sagittal plane knee joint kinematics obtained from the 3D reconstruction with our approach and with OP-alone were compared to those recorded by the lateral camera, taken as a reference measure. The kinematics obtained with our model displayed a lower RMSE (7.56°) and a higher correlation (R = 0.96) when compared to OP alone (RMSE =15.96°, R = 0.83).

Discussion

The results underscore the enhanced reliability of our model in capturing kinematics with respect to OP alone, both in 2D landmarks estimation and in 3D movement kinematics reconstruction. Expanding the scope of our analysis to include other joints and movements could provide a comprehensive understanding of human movement biomechanics through MMC techniques. Further research is needed to validate these models against gold standard marker-based stereophotogrammetric systems.

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Assessing lower limb coordination during heel strike in Parkinson disease patients

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Introduction

Parkinson's disease (PD) is characterised by a multitude of motor symptoms, including walking disorders, which significantly influence the quality of life of those affected. It has been shown that in PD patients, interlimb coordination is impaired, resulting in reduced stability during walking. The heel strike phase is particularly critical, as it follows the single stance phase and precedes the shift of body weight from one limb to the other. This phase represents a crucial moment of gait that requires precise control, and impaired coordination during this phase may further worsen the reduction in stability, thus worsening walking problems in PD patients. On this basis, the aim of this study was to understand the physiological coordination pattern of the lower limbs during the heel strike phase and to investigate possible alterations in PD patients, with a focus on lower limb coordination during this critical phase of walking.

Methods

23 PD patients and 23 matched healthy controls (HC) with no neurological or psychiatric disorders, and with no physical or medical conditions that could affect gait, participated in this study. The gait of each participant was recorded using a stereophotogrammetric system, with 55 reflective markers placed on the whole body. After identifying heel strike events data were trimmed in a +/-15msec around the event to capture preparation and execution of the heel strike. Ankles, knees, and hips acceleration time series were pair-wise correlated to obtain coordination patterns of lower limb joints during heel strike.

Results

The results show that in PD patients the left heel strike is associated with decreased coordination, which affects the right and left lower limbs, involving all three joints of the left lower limb, and ankle and hip of the right lower limb. In addition, the difference in coordination between each patient and the average HC group coordination significantly correlated with both disease duration and UPDRS-III scores, underlining the association with PD severity and progression.

Discussion

These results show that PD reduces lower limb coordination, particularly during the heel strike phase. This phase, critical for the transition from single to double stance, requires precise synchronisation and coordination of several joints to maintain balance and stability. In addition, the greater the deviation of patients from the mean coordination value of the control group, the greater the level of motor impairment, as assessed by the UPDRS III clinical scale, and the longer the duration of the disease.

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Detecting co-contractions among multiple muscles: a time-frequency perspective

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Introduction

Various electromyography (EMG) approaches have been proposed to comprehend the interactions among multiple muscles [1,2]. The majority of these methods focused exclusively on EMG timing and amplitude, overlooking spectral characteristics that could reveal significant neural strategies [3]. This study presents a novel technique able to quantitatively characterize the co-activation of multiple muscles in the time-frequency domain by means of the continuous wavelet transform (CWT).

Methods

The co-activation signal among multiple muscles in the time-frequency domain was provided as the CWT cross-energy localization of multiple EMG signals, extending the approach reported in [4]. We refer to this methodology as the pooled scalogram. The algorithm performance was evaluated on thousands of synthetic EMG signals with varying signal-to-noise ratios. The capability of the pooled scalogram to identify informative content in the time and/or frequency domain is evaluated on experimental surface EMG data, collected from three lower-limb muscles during walking of 31 young, healthy participants at Movement Analysis Lab, Università Politecnica delle Marche, Ancona. Moreover, significant modules were identified through Non-Negative Matrix Factorization Analysis (NMF) to determine time-frequency invariants.

Results

The onset and the offset of co-activation provided by the pooled scalogram across the complete dataset of simulated sEMG signals were assessed with an accuracy of 100%. Associated mean absolute errors (MAE) are on average below 30 ms. The large variability of the NMF-modules extracted in the walking participants was condensed to just four time-frequency clusters. Significantly, one cluster was identified in 90% of participants, indicating the presence of consistent features across participants. The congruence of the experimental results with literature suggests the capability of the pooled scalogram to detect the physiological frequency bands at which multiple muscles synchronize their activations, as shown in Figure 1.

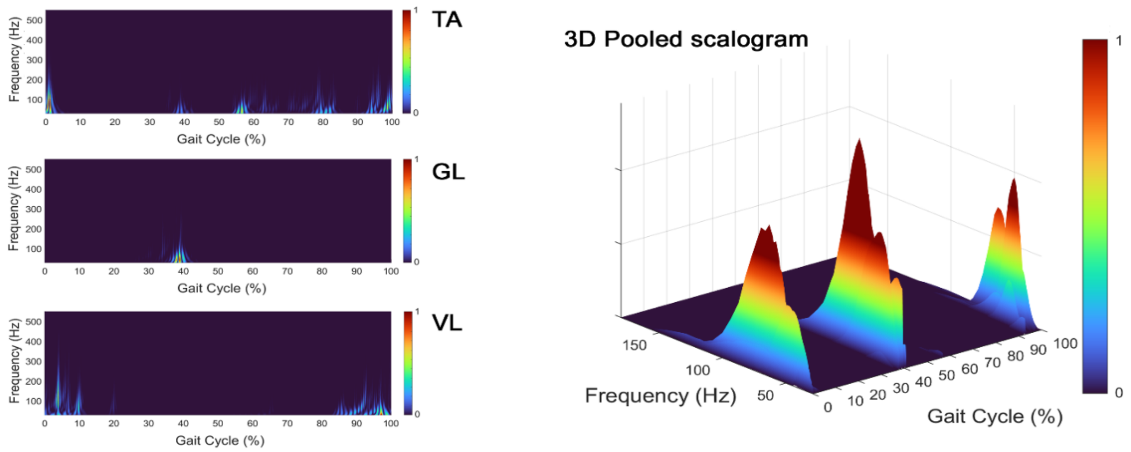

Figure 1. Example of CWT pooled scalogram among tibialis anterior (TA), gastrocnemius lateralis (GL), and vastus lateralis VL, represented as CWT scalograms.

Discussion

The pooled scalogram accurately supplied the timings of the co-activation of multiple muscles, and provided results in frequency domain that were consistent across healthy participants, thus suggesting the suitability of this methodology to analyze the neural laws underlying the motor control, as a potential marker of pathological neural conditions or a quantitative evaluation of the progress of a rehabilitation.

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Fatigue-induced neuromuscular alterations in single-leg hop for distance jumps suggest an increased risk of anterior cruciate ligament injury

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Introduction

Neuromuscular fatigue is a physiological phenomenon reducing muscle force generation and altering neuromuscular control strategies, hence affecting movement biomechanics. Whether such alterations increase musculoskeletal injury risk is controversial [1]. We investigated whether fatigue-induced alterations in jumping neuromechanics increase the risk of anterior cruciate ligament (ACL) tear, one of the most common injuries in sports.

Methods

24 healthy male participants performed 4 repetitions of single-leg hop for distance jumps, before and after a fatiguing protocol on a cycle-ergometer until exhaustion. The fatiguing protocol was tailored to each participant's fitness level by setting the exercise workload 10% above the power achieved at their anaerobic threshold, previously identified on a separate session. We evaluated jump length, joint angles and moments, ground reaction forces (GRF) during propulsion, and thigh-muscles electromyography (EMG) around landing. Variables were compared before and after the fatiguing session, evaluating whether fatigue induced alterations typically associated with an increased ACL injury risk [2].

Results

Following fatigue, we observed a reduction in jump length (Δ=-8±2 cm, p<.001), as well as a decrease in hip (Δ=-3.2±0.9°, p=.001) and knee (Δ=-2.7±0.5°, p<.001) flexion, and in ankle dorsiflexion (Δ=-0.8±0.3°, p=.01) during propulsion. Similarly, we observed a reduction in hip (Δ=-2.7±0.8°, p=.001) and knee (Δ=-1.6±0.5°, p=.001) flexion at foot contact after jumping. Finally, we found an increase in hip (Δ=1.7±0.6°, p=.004) and knee abduction (Δ=0.8±0.4°, p=.039) during landing (i.e. dynamic valgus). Hip extension moment (Δ=-0.29±0.09 Nm/kg, p=.003) and GRF propulsive impulse (Δ=-0.005±0.003 Ns/kg, p=.014) decreased following fatigue despite the increase in peak GRF (Δ=0.6±0.1 N/kg, p<.001) – associated with a higher ankle plantarflexion moment (Δ=0.05±0.01 Nm/kg, p<.001). Following fatigue, hamstrings muscle activity decreased and quadriceps muscle activity as well as hamstring-quadriceps co-contraction increased (p<.05) both before and after landing.

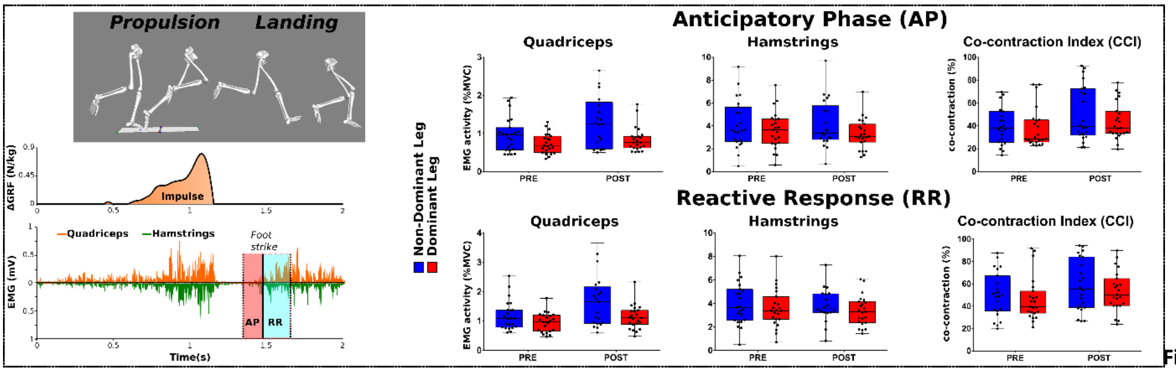

Figure 1.

Discussion

Kinematics alterations of hip and knee joints at landing suggest an increased ACL injury risk (i.e. knee valgus) [2]. The fatigue-induced reduction in jump performance is mainly attributable to a loss in propulsion efficiency of hip and knee – as supported by the reduced GRF impulse, only partially compensated by increased ankle plantarflexion. Such increase likely originates from increased plantar-flexor muscles activity that further loads the ACL [3]. Finally, changes in muscle activation during landing suggest the adoption of a quadriceps-dominant strategy, increasing ACL loading [4], and an increase of joint stiffness resulting from agonist-antagonist muscles co-contraction [5]. Taken together, results suggest that fatigue increases ACL injury risk by altering neuromuscular parameters of jumping and landing.

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TrainAR project: integrating AR technology with wearable physiological signals monitoring for personalized physical training programs

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Introduction

Physical training provides significant benefits for health and helps in developing useful skills. Traditional training programs are usually time consuming, expensive, poorly personalizable and, as such, may lead to burnout. Lately, extended reality (XR) environments and wearable sensor technologies (WST) have gained increasing popularity for monitoring and improving human performance in various contexts [1,2,3]. Nowadays, WST allow users to seamlessly monitor multi-modal physiological information from their body. Among such WST, inertial measurement units, electrodermal activity and heart rate sensors are reliable candidates for monitoring the biomechanical and physiological status of a person operating in various conditions [4].

Methods

The project aims at developing a WST platform to quantitatively assess the subject motor performance by monitoring its physiological status. Using WST with XR environments, it is possible to adapt a personalized training program in real time based on a closed loop between XR training scenarios and user's state.
In this context, the integration of an XR technology (HTC Vive XR Elite headset) with wireless and compact WST (Shimmer3 equipped with Galvanic Skin Response, Electrocardiography and Photoplethysmography sensors) could provide an enhanced monitoring experience in a controlled environment.

Results

Figure 1 shows the selected use case scenarios, each requiring different levels of physical and cognitive engagement. The subject is motivated to improve and practice a squat task and mini-golf through a stimulating XR environment while enhancing both motor control and performance. In the third scenario, a cognitive test is implemented in XR, so that its complexity may be adapted to the users' performance and physiological/cognitive response.

Figure 1. Design of motor and cognitive-motor tasks in an extended reality environment.
(1a) Squat (1b) Mini-golf (1c) Kohs Block test.

Discussion

The project encompasses different technological advances and is the first attempt to integrate biomechanical and physiological user data in a closed loop with an XR scenario. We envision that the technological solutions and the knowledge developed within the project will have applications in clinical settings, especially in neurorehabilitation, where the interplay between rehabilitation exercises and user's engagement and motivation is key to the efficacy of therapy.

Acknowledgements

Project titled: "TrainAR - a wearable sensors plaTfoRm and an Augmented reality enviroNment for the design of personAlized physical tRaining programs" funded under Mission 4 "Education and Research" of the National Recovery and Resilience Plan - Component C2 – Investment 1.1, Fund for the National Research Program (PNR) and Projects of Relevant National Interest (PRIN) – Next Generation EU program. Project code Prot. P20223L22R- CUP J53D23013950001.

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Integrated instrumental evaluation of the upper limb in the rehabilitation process in children with neuromotor disabilities

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Introduction

Upper limb (UL) function in developmental neuro-motor disabilities is an important factor in autonomy and social integration. Increasing the quality of the rehabilitation process is an essential strategy for improving the quality of life of these patients.

Several studies [1-3] demonstrate the efficacy of the robotic rehabilitation treatment for UL, in particular with the Armeo Spring Pediatric. The outcome measures generally include the output from the integrated sensors of the robotic device and clinical scales specific for UL. It appears not to be explored enough the integration of the kinematic evaluation with the robotic treatment and the clinical scales measures.

The aim of this study is to verify the correlation between the kinematic index by optoelectronic system (Vicon), the Armeo Spring Pediatric measures, and the clinical scale scores.

Methods

15 hemiparetic children (10 cerebral palsy, 5 miscellaneous; age from 8 to 16 ys) were involved, evaluated before (T0) and after the treatment period (T1) which lasted 4 weeks and included a daily session of robotic treatment, a physiotherapy and occupational therapy.

The outcome measures include the Arm profile Score (APS) from the kinematik, Armeo specific measures and clinical score from Quest, Cheq and the Modified Melbourne scales. The study provides a 6 months (T2) and 1 year (T3) follow up.

Results

We performed an analysis on 13 patients with Kendall's Tau B at T0 and at T1, indicates a significant correlation between the APS Score of the hemiplegic hand and the clinical scales at T1 (QUEST, $p<0.006$; Melbourne, $p<0.041$; CHEQ (one hand task), $p<0.010$); between the APS Score of the hemiplegic arm and the Armeo measures (minimum prono/supination [°]) at T1 ($p<0.001$). The Quest scale correlate well with three measures obtained by the Armeo (maximum flex/extension of shoulder [°], $p<0.05$; minimum prono/supination [°], $p<0.05$; instability [cm], $p<0.05$), and similarly the CHEQ scale (two hands task) with the minimum flex/extension of the elbow (T0: $p<0.05$; T1: $p<0.05$). 8 patients completed the T2, not enough for a statistical analysis and the group of patients is still expanding.

Discussion

Although the data presented are preliminary, they illustrate a significant correlation between the clinical evaluations, the robotic index, and the kinematic values. As we know, kinematic analysis enables to quantify upper limbs movements in more ecological way compared the Armeo's or clinical scales tasks separately, providing a sound base for its clinical application.

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Within-session variability of different gait quality indices in neurological disorders

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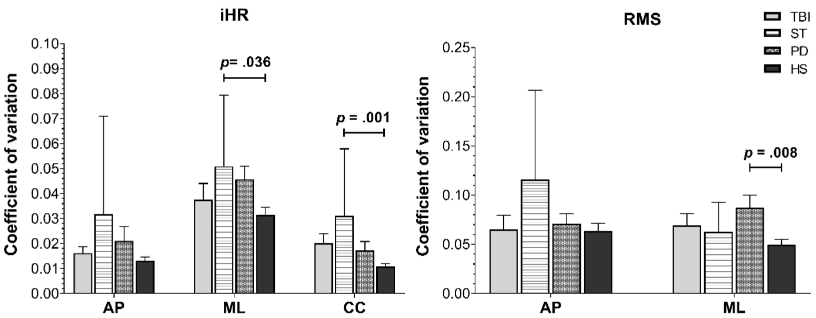
Introduction

Quantification of gait variability during walking may provide disease-specific information in people with neurological disorders [1]. Gait variability can differentiate between distinctive neurological conditions [1, 2], but previous investigations only focused on a limited number of spatio-temporal parameters (e.g., cadence and stride length), providing an incomplete survey of other gait characteristics. Exploring the within-session variability of a set of measures, that characterizes the overall quality of gait (i.e., dynamic stability, symmetry, and smoothness) through inertial measurement units (IMUs), could help understanding how changes in walking patterns affect the consistency of these measurements when multiple trials are used. This may be relevant since its results may be influenced by variations in the execution of the walking task in clinical practice. Thus, the aim of this study is to analyze the within-session variability of different gait quality indices extracted from IMUs during straight walking in people with different neurological disorders.

Methods

Fifty-eight people with neurological disorders (severe traumatic brain injury (sTBI), n=11, 7 F, 31.7±13.9 y, Functional Ambulation Classification scale median=5; subacute stroke (ST), n=10, 2 F, 66.8±8.1 y, FAC median=5; Parkinson's disease (PD), n=14, 5 F, 69.1±4.2 y, Hoehn & Yahr median=2) and healthy adults (HS), n=23, 13 F, 49.9±15.4 y) were asked to perform 5 repetitions of a 10-meter Walk Test (10mWT) [3] while wearing five IMUs (APDM, Opal, 128 Hz) on both lateral malleoli, pelvis, sternum, and head. Stride segmentation was performed from leg IMUs. Lumbar acceleration-based features related to stability (Root Mean Square-RMS and Attenuation Coefficients-AC), symmetry (improved Harmonic Ratio-iHR), and smoothness (Log Dimensionless Jerk-LDLJ) of gait were obtained. For each feature, the coefficient of variation (CV) from the 5 trials was used to quantify the inter-trial variability of each participant. One-way ANOVA was performed to test the differences in CV for each feature between groups.



Results

Significant differences were found in the iHR in the ML direction (F(3,54)=2.822, p= .047) and CC (F(3,54)=4.861, p= .005) as well as RMS in ML (F(3,54)=3.369, p= .025) among groups. Post hoc test showed greater variability in iHR for ST and RMS in PD when compared to HS (Figure 1).

Figure 1. Mean and SD of CV for symmetry and stability indices of the 10MWT.

Discussion

ST patients showed more within-session gait variability in symmetry, while PD in stability indices. This finding suggests attention on the impact of repeated trials when analyzing gait quality assessments in neurological populations, particularly when making inferences about disease-specific characteristics of gait impairment using these quality indices.

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A Deep Learning approach based on a Convolutional Neural Networks architecture towards Abnormal Human Activity Recognition

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Introduction

Human Activity Recognition (HAR) represents a new approach for remotely monitoring human behavior to analyze and assist patients either at home or in a rehabilitation program. The wide availability of inertial measurement units (IMU) sensors could enable the implementation of Ambient Assisted Living solutions that are based on the recognition of activities of daily living (ADLs) and capable of identifying possible unsafe situations and providing real-time feedback. Deep Learning (DL) models can be exploited to perform HAR through raw data, thus avoiding time-consuming feature engineering stages. The aim of this study is the testing of a DL-based workflow for HAR. The model was trained on data recorded from ten healthy subjects and tested on nine different subjects, with one subject simulating abnormal motor patterns typical of neurological patients. Despite a limited number of abnormal actions were tested, the proposed framework can accurately classify motor patterns, making it potentially helpful to provide patient care.

Methods

Nineteen healthy subjects (34.94±11.58 years old) were recruited and informed about four ADLs, which were walking, turning, lying-down, and sit-to-stand. The dataset used in [1] was augmented by adding to the test dataset trials of the same tasks but performed in anomalous way to simulate pathological motor patterns (e.g., hemiplegic gait or trunk retropulsion during sit-to-stand).

Four wearable IMUs OpalTM were placed on the two sides of the human pelvis (LP and RP), right wrist (RW), and sternum (S). Kinematic data (sampling rate of 128Hz) were normalized into a range [-1,1], manually segmented, and divided into overlapping windows of 1 s. After coping with dataset unbalance, a custom Convolutional Neural Network (CNN), which was already exploited in the authors' previous work [1], was further tested with the goal of recognizing activities even if performed incorrectly.

Results

Table 1 reports the classification metrics evaluated on different sensor combinations with by means of an averaging technique [1].

Table 1. Model performance on the test for different sensor combinations with accuracy over 85%.

Combination	Accuracy [%]	Inference Time [s]
RP+LP	85.85 ± 7.20	0.31 ± 0.09
RW+S	85.79 ± 3.38	0.29 ± 0.08
RW+LP+S	**89.88 ± 1.46**	**0.35 ± 0.08**
RW+RP+LP+S	88.92 ± 3.79	0.37 ± 0.10

Discussion

The best performance is obtained by placing sensors on RW, LP, and S. The classifier benefits from the placement on S, since the trunk exhibits different intra- and inter-class motor patterns, as well as RW and LP, which carry information about both human body sides. Nonetheless, the inference time has not excessively increased with respect to using sensor pairs. Such promising results pave the way to the recognition of correct or incorrect activity executions and prevent unsafe situations on time.

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Postural control during quiet stance with different sensory conditions among female adolescents with idiopathic scoliosis: preliminary results

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Introduction

Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional deformity of the spine and trunk characterized by frontal plane deviation and vertebral body rotation [1]. Previous studies on changes in postural stability deficits in individuals with AIS compared to typically developed adolescents (TDAs) showed inconsistent results regarding postural stability. These ranged from no differences to significant differences [2], the latter thought to be due to impaired dynamic regulation of sensorimotor integration as a result of an inaccurate weighting of sensory inputs. Based on this hypothesis, we aimed to investigate whether geometrical measures derived from the Center of Pressure (CoP) during quiet stance are affected under different sensory conditions in AIS.

Methods

A total of 8 adolescent girls with AIS (age 12.6±1.4 years, range 11-16; Cobb angle 21.7°±6.1°, range 18°-31°) and 4 age-matched TDAs were recruited. AIS had not yet worn a brace or started physiotherapy. They were asked to remain upright for 60 s under two base of support conditions, solid and foam, in two visual conditions, eyes open (EO) and eyes closed (EC), and two touch conditions, no-touch and light-touch (LT), resulting in a total of eight experimental conditions: EO, EO+LT, EO+FOAM, EO+FOAM+LT, EC, EC+LT, EC+FOAM, EC+FOAM+LT. The sway area (SA) and sway path (SP) of the CoP, and the ratio of SA and SP between AIS and TDAs, were calculated. The prevalence of mediolateral (ML) and anteroposterior (AP) directions on the CoP sway path was analyzed and correlated to the laterality of the AIS curve.

Results

Under all experimental conditions, SA, but not SP, was lower in AIS. Indeed, across conditions, the average ratio of SP between AIS and TDAs was 98.4% while the average ratio of SA was 67.2%. No differences were found between the two groups in the ML and AP contribution to the sway path. In ML direction, the AIS group did not show predominant oscillations to the side corresponding to the convexity of the primary curve.

Discussion

When analyzing geometrical measures derived from the CoP, AIS did not show increased body sway, indicating no clear instability during quiet stance, at least in not severely affected subjects [3]. However, the decreased ratio of SA between AIS and TDAs suggests a stiffening of the body [4]. This phenomenon appears to be independent of the sensory conditions and the difficulty of the task.

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Ankle foot orthosis for children with cerebral palsy: what impact on participation?

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Introduction

Children with Cerebral Palsy (CP) often encounter challenges in mobility and functional independence due to motor impairments [1]. Ankle Foot Orthosis (AFO) is a therapeutic aid to improve gait pattern and joint alignment in these subjects [2]. The contemporary rehabilitation paradigm emphasizes the importance of promoting participation and integration of children with disabilities into societal contexts [3]. While existing literature extensively examines the biomechanical benefits of AFOs on gait parameters, their influence on broader aspects such as activity and social participation remains relatively underexplored [4]. This study aims to investigate the impact of AFOs on both biomechanical parameters and social participation outcomes in children with CP.

Methods

This retrospective case-series study includes 3 children (S1, S2, S3, mean age 7 years) from the Children Rehabilitation Unit of Azienda USL-IRCCS di Reggio Emilia with hemiplegic (2) or diplegic (1) CP diagnosis (GMFCS I and regular orthosis users). Subjects were evaluated in two condition (AFO versus only SHOES) by: 3D gait analysis, gait functional tests and a questionnaire. Gait efficiency was measured by maximum knee and hip extension and normalized maximum power produced by the ankle during push-off [5]; global gait performance by normalized speed and normalized stride length. Functional aspects were evaluated through the 10 Meter Walk Test, 2 Minute Walk Test and Time Up and Go Test. PEM-CY questionnaire was utilized to assess the participation.

Results

S1 demonstrates increased knee extension, enhancing biomechanical efficiency while power peak decreases. Despite a slight decrease in speed, step length increases, impacting functional tests positively. S2 also experiences improved knee extension and decreased power peak; speed and step length increase, positively affecting functional tests. S3 shows decreased knee extension, affecting efficiency. However functional tests demonstrate improved speed. Overall, all subjects demonstrate active participation in various activities.

	EFFICIENCY			GLOBAL PERFORMANCE		FUNCTIONAL TEST			PEM-CY
	MAX KNEE EXTENSION (mean dx/sn) [deg]	MAX HIP EXTENSION (mean dx/sn) [deg]	PUSH OFF POWER PEAK (mean dx/sn) [w/kg]	SPEED [%h/s]	STRIDE LENGHT [%h]	10MWT [s]	2MWT [m]	TUG [s]	ACTIVITY - INVOLVEMT
S1	11/6.5	-10/-10	1.8/1.2	70/68	74/78	5”9/4”9	120/120	8”4/9”7	80% - 90%
S2	7/1.5	-13.5/-14	1.6/1	66/69	75/78	5”7/5”7	110/120	8”9/9”	70% - 74%
S3	6/10.5	-13.5/-9.5	0.9/0.5	88/88	80/79	7”7/5”2	/	12”1/ 12”5	56% - 82%

Table 1. The values of the main parameters are presented for SHOES/AFO condition

Discussion

All subjects in our study showed good functional levels and wore AFOs for many hours daily. While all subjects experienced reduced peak power during push off with orthoses, efficiency parameters didn't significantly differ between conditions. Functional evaluations favored AFO. Regarding participation, all subjects demonstrated high engagement, likely due to their motor capabilities. Our findings do not reveal a superiority in the evaluations with AFO compared to the use of shoes alone. This suggest a need for individualized orthotic prescriptions and periodic reassessment for information on use. Understanding the impact of orthotic use in highly functional children with CP is crucial for optimizing their mobility and participation.

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Open-loop and closed-loop control of upright stance in adolescents with idiopathic scoliosis

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Introduction

Adolescent Idiopathic Scoliosis (AIS) is a spinal deformity characterized by frontal plane deviation (Cobb angle > 10°) and vertebral body rotation [1]. Spinal deformities can lead to changes in head position and asymmetric activity of the spinal muscles, which can affect the subject's balance [2]. A dysfunction in sensorimotor integration may underlie the pathogenesis of AIS [3,4].

Frequency analysis of the center of pressure (CoP) is useful for investigating postural control strategies in AIS with respect to sensory processing. The objective of this study was to examine the involvement of both the open-loop and closed-loop postural control systems during simple balance tasks. The open-loop system operates independently of real-time feedback (CoP frequencies >1Hz), whereas the closed-loop system relies on input from the somatosensory, vestibular, and visual systems, which operate at frequencies of 0.5-1 Hz, 0.1-0.5 Hz, and <0.1 Hz, respectively [2,5].

Methods

A total of 29 participants were recruited for this study, comprising 14 adolescent girls with AIS (mean Cobb: 24°) and 15 age-matched healthy girls (CTRL). All participants were asked to remain upright on a force plate with both eyes open (EO) and closed (EC) for at least 40 s [6]. The CoP (Fs = 125 Hz) in the mediolateral (ML) and antero-posterior (AP) directions was decomposed using the Discrete Wavelet Transform. The energy was calculated for the following frequency ranges: [>1] Hz, [0.5-1] Hz, [0.1-0.5] Hz, and [<0.1] Hz, and normalized to the total energy of the signal. The statistical significance of the differences between the groups and conditions was evaluated using the Wilcoxon test for each CoP direction.

Results

In the ML direction, in EO condition, the energy of adolescents with AIS was significantly lower in the open-loop frequencies ([>1] Hz, p<0.01) and higher in the frequencies characterizing the somatosensory and vestibular systems ([0.1-1] Hz, p<0.05) (Figure 1a). In the AP direction, the CTRL group appears to rely primarily on the visual system ([<0.1] Hz, p<0.05) (Figure 1b). When participants closed their eyes, the differences between the two groups diminished.

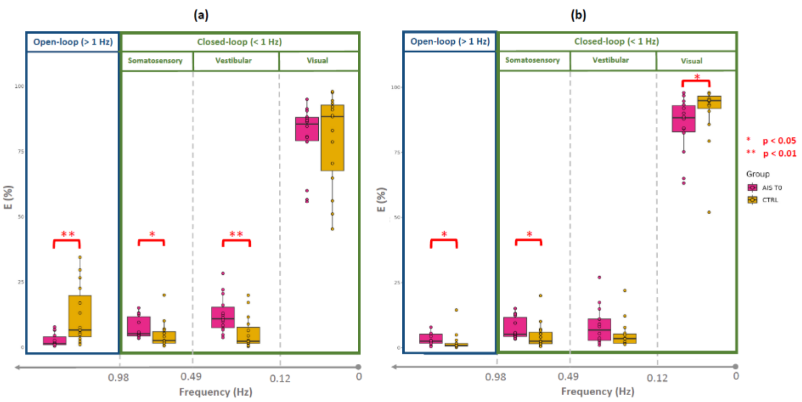

Figure 1. Energy of the Center of Pressure signal in the frequency ranges [>1] Hz, [0.5-1] Hz, [0.1-0.5] Hz, and [<0.1] Hz along the mediolateral (a) and antero-posterior (b) directions in adolescents with Idiopathic Scoliosis (AIS) and healthy controls (CTRL) during upright standing with eyes open.

Discussion

The divergence in postural behaviour between adolescents with AIS and CTRL is more evident in the ML direction, which is the plane of the spinal deformity. Adolescents with AIS appear to continuously adjust posture based on sensory feedback rather than using pre-programmed open-loop movements.

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Rehabilitation with kinematic biofeedback improves shoulder function in patients surgically treated for rotator cuff tear: indications from a randomized controlled trial

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Introduction

A randomized control trial was conducted considering a group of patients recovering from rotator cuff tear surgery. The combination of an upper limb rehabilitative protocol with a kinematic visual biofeedback tool based on inertial sensors (ISEO protocol [1]) was tested. The main goal of the study was to test the efficacy of this new rehabilitative protocol, assessing the functionality and activity of the patients both in the short and medium term.

Methods

Forty patients (aged between 35 and 65 y.o.) were randomly assigned to two groups: Control group (C, n°21 patients, age 54±5) and Biofeedback group (B, n°19 patients, age 52±6). Patients were assessed longitudinally: before surgery (T0), 45 days after surgery (T1), at time of return-to-work (T2), and at a follow-up between 6 and 12 months from the surgery (T3). Each session included the administration of a set of clinical scores including the Scapula-Weighted Constant-Murley Score (SW-CMS), and the application of the ISEO protocol for the acquisition of shoulder kinematics. The asymptomatic contralateral limb was also evaluated. The primary outcome used for the assessment of shoulder functional performances was the SW-CMS [2], and the difference between the scapulo-humeral coordination of the symptomatic and asymptomatic side was calculated, and compared to reference bands; lastly, the final SW-CMS was normalized relative to the CMS of the asymptomatic side [3]. Possible statistical significant differences between groups were analyzed with non-parametric statistics (Mann-Whitney), and the difference of the median values (ΔSW-CMSm) was compared to the correspondent Minimal Clinically Important Difference (MCID = 10 points).

Results

The results showed no bias for the two groups before the administration of the experimental protocol. When comparing the SW-CMS median values of C and B, statistically significant differences were found only at T2 (p-values = 0.045) (Figure 1). At T2, ΔSW-CMSm was also greater than the MCID: the C median (63.5) is 12.3 points lower than the B median (75.8).

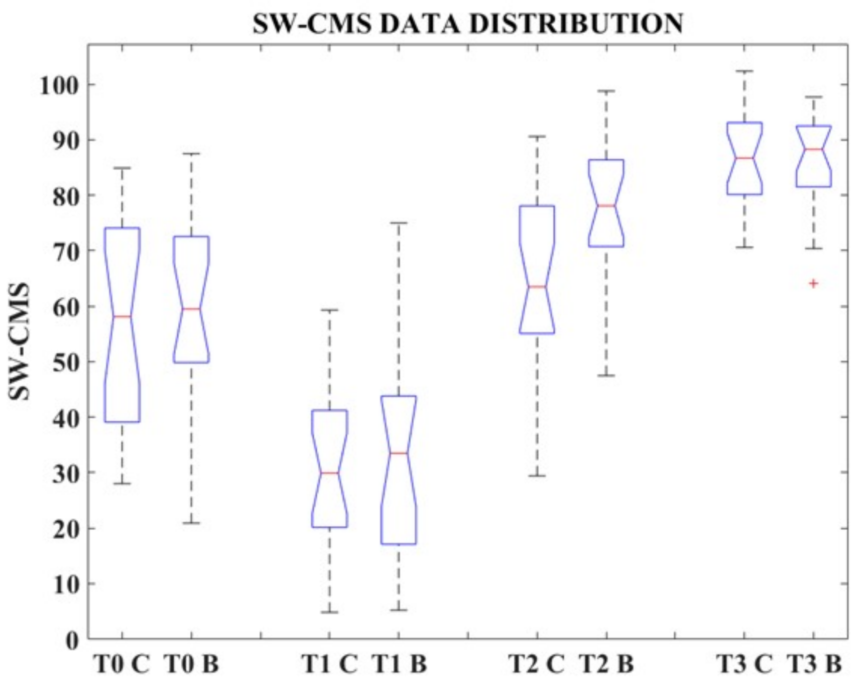

Figure 1. Boxplots of data distribution for Control group (C) and Biofeedback group (B), at T0, T1, T2 and T3.

Discussion

Based on results, we could conclude that the biofeedback training allowed patients to return to work in a better functional condition. This trial was funded by the National Institute for Insurance against Accidents at Work (INAIL).

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iTUG variables as predictors of falls in older people after femur fracture

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Introduction

Femur fractures are common in older adults [1]. While most individuals recover gait, balance, and activities of daily living after a femur fracture [2], a substantial proportion do not return to pre-fracture levels of physical function [3]. The risk of falling again after a femur fracture is 20 times higher for older adults compared to their peers of the same age [4]. Although the trajectories of falling are complex, functional mobility measures may improve the prediction of future falls. Therefore, we hypothesized that the objective measures of the instrumented Timed Up and Go (iTUG) test, which covers a variety of gait metrics, would improve fall prediction more effectively than gait speed or cognitive status alone.

Methods

We recruited 157 elderly subjects with diagnosis of femur fracture (123 female, 78.4±9.5 years) at the end of their inpatient rehabilitation process. Each patient was assessed with the iTUG test in order to collect additional variables compared to the time recorded during the standard TUG. Demographical data, along with motor and cognitive outcome measures, were collected. Participants underwent telephone follow-ups at 1-month post-discharge to collect the number of falls and assess their functional status. Logistic regression models were created with binary outcome of a new fall versus no fall within 1-month after discharge, with the goal to find the best model in the prediction of a prospective fall.

Results

Among the 157 enrolled patients, 133 finished the follow-up. At 1-month follow-up, 8 patients reported one episode of fall, with a fall rate of 6%. The logistic regression model with the highest predictive ability (R^2=0.47) in identifying patients at risk of falls was composed of three variables collected with the iTUG and 2 cognitive measures (Table 1). The model had an AUC of 0.94, with a sensitivity and specificity of 100% and 50%, respectively. Without iTUG metrics, cognitive measures alone demonstrated an R^2 of only 0.20, with an AUC of 0.81.

Table 1. Summary of the logistic regression model performed to determine future falls, r^2=47%.

Predictors	Odds Ratio	95% CI	*p-value*
FIM cognitive score at discharge	0.348	0.134-0.904	*0.03*
SPMSQ level:			
1 – 0	118.128	3.746-3724-733	*0.007*
Walk Duration	0.516	0.274-0.968	*0.039*
RMS of the Vertical Acceleration during Walk	1.299	1.016-1.660	*0.036*
RMS of the Medio-Lateral Angular Velocity during Walk	8668.718	6.756-11100000	*0.013*

Abbreviations: FIM, Functional Independence Measure; RMS, Root Mean Square; SPMSQ, Short Portable Mental Status Questionnaire.

Discussion

The best fall-prediction model supports the notion that elderly may fall due to a variety of factors and gait impairments [5]. In particular, our findings indicate that the use of some iTUG variables, together with cognitive factors, allows to create a model able to identify the 100% of patients who will experience a new fall upon returning home after rehabilitation for femur fracture. Identifying these patients at discharge will therefore allow healthcare providers to provide targeted rehabilitation interventions.

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Gait initiation, a phase transition containing rehabilitative information

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Introduction

In the control of the interactions between the body and the ground, the control variable is the Centre of Pressure (CoP), while the controlled variable is the Centre of Mass (CoM) [1]. In other words, variations in the centre of pressure on the ground govern the movement of the body's centre of mass. However, this depends on the task and context. The redundancy of the organism's dynamic solutions allows this role to be reversed [2]. But what are the differences in individuals with CNS pathologies?

Methods

It is necessary to analyse other variables: the ground reaction vector and electromyography. In this initial phase of the study, we proceeded using a graphical method. We graphed, using MATLAB (USA), the displacement of the CoP, and the displacement of the CoM along with the ground reaction vector in healthy subjects and people with neurological pathologies using data from the VICON system (UK).

Results

The longitudinal projection of the ground reaction vector is well-known in walking, but much information is contained in the other two projections. The Centre of mass is directed towards the contralateral side from a push of the hindfoot of the leg that is about to swing. The CoM is simultaneously accelerated forward. To govern this trajectory, the CoP transfers under the supporting foot while the ground reaction vector continues to point at the CoM, until the double support phase when the control is transferred to the contralateral leg. Dynamically speaking, the CoM is never outside the base of support but is constantly controlled by the dynamic pushes exerted by the ground reaction vector. Co-activation of lower limb muscles responsible for the initial push is observed. The movement initiation is determined by their resultant, leading to a push on the ground with the hindfoot. In hemiplegic patients, a lack of push and load transfer is observed, CoM variations are used to keep the CoP within the base of support, contrary to healthy individuals [3]. (Figure 1) The hemiplegic who cannot implement this alternative solution is the one who does not walk.

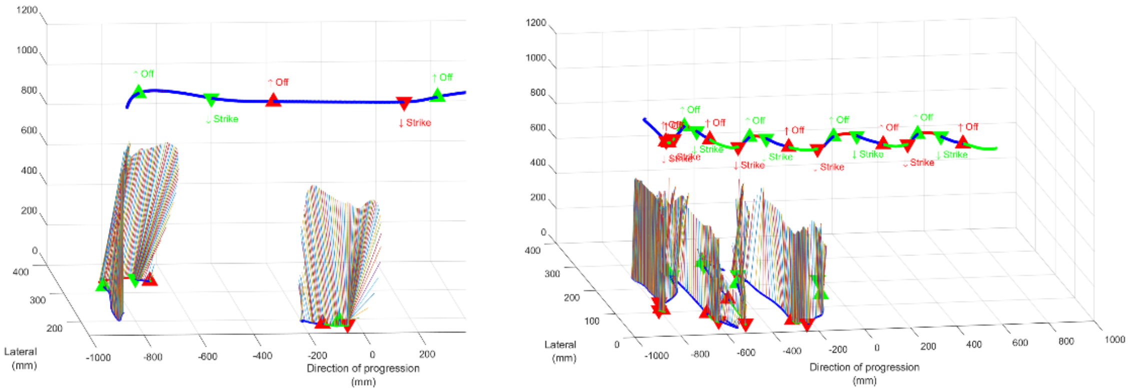

Figure 1. CoP, CoM and reaction force relationship. On the right the gait initiation in healthy subject. On the left the gait initiation of a subject with hemiplegia. The figure shows the absence of dynamic properties in hemiplegic subject. In red the left cycles. In green the right cycles. Upper arrows indicate the toe-off and down arrows indicate the foot strike.

Discussion

In conclusion, load transfer is an alternative solution for governing the upright stance immediately available when is no longer feasible the dynamic push strategy. This alternative is immediately available thanks to the redundancy of the organism's dynamic solutions. Practising load transfer is a training activity for a pathological condition that should be conducted after verifying that there are no conditions for restoring dynamic function.

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Motor control hypothesis embedded in the controller of robotic knee orthosis

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Introduction

The gait is a dynamic function influenced by dynamical factors such as speed, the nature of the terrain, or cognitive activities. We developed a robotic knee orthosis to better understand and rehabilitate it [1]. The need was to verify a control hypothesis of the locomotor function and understand the relationship between force interaction and information.

Methods

The orthosis controller was configured to act according to Feldman's hypothesis on the frame reference of body segments [2]. Consequently, two inertial sensors detected the posture of the leg and thigh, an encoder measured the rotation angles, while current flows on the actuator defined and detected the exerted torque. We then asked 10 young adults to walk on a treadmill at a comfortable speed. We moved along three trajectories: follow the natural gait without producing interaction (transparent mode), induce an increase or decrease of the maximum target flexion angle 20%, and use a low or high force interaction 2 and 4 Nm. The torque and posture control prevented the motor from being activated until the knee moved from the initial to the final expected posture. This mode mirrors what we know about muscle activation and the role of the CNS during gait motor control [2]. We gathered 20 cycles for each condition.

Results

We observed a statistically significant knee flexion increase compared to free walking (from 53°±9° to 60°±11° and to 62°±13° lower and higher torque, respectively). The two induced modifications are not statistically different from each other. When attempting to cause a reduction in the flexion angle using both torques, we observed the same statistically significant angle reduction (43°±8°). In the case of increased flexion, we observed an increase in the rotation speed and an increase in current absorption by the actuator (pushing) in the initial flexion phase. In the case of decreased flexion, we observed current generation by the actuator (braking) throughout the flexion, with a reduction in rotation speed (Figure 1).

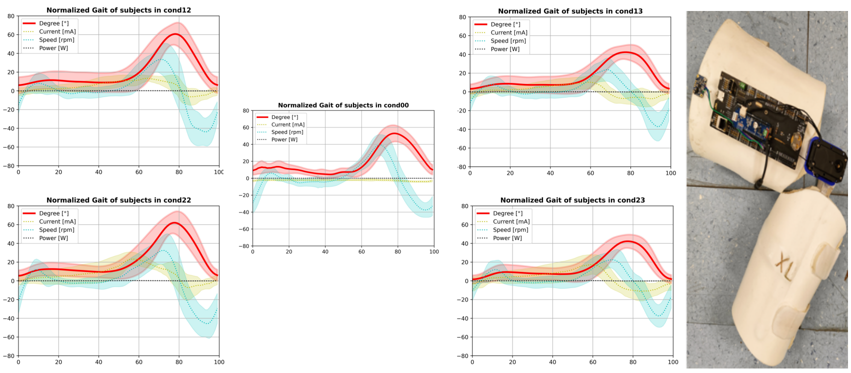

Figure 1. Knee flexion modification induced by robotic knee orthosis during gait. Mean and standard deviation of 20 cycles on 10 participants. Cond00=free walk. Cond12=increased flexion of 20% and torque of 2Nm. Cond22= increased flexion of 20% and torque of 4Nm. Cond13= decreased flexion of 20% and torque of 2Nm. Cond14= decreased flexion of 20% and torque of 4Nm.

Discussion

In conclusion, we obtained the same result by applying different torques. It was not the amount of force used, but the information enclosed in the force interaction that modified the pattern. This demonstrates that the CNS cannot avoid doing from following the context modifications induced by implicit information. These results have an impact on the development of future rehabilitative devices and on physiotherapy practice, pointing out both functional training and the specificity of the dynamic of the proposed experiences.

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Compensation strategies during perturbed gait

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Introduction

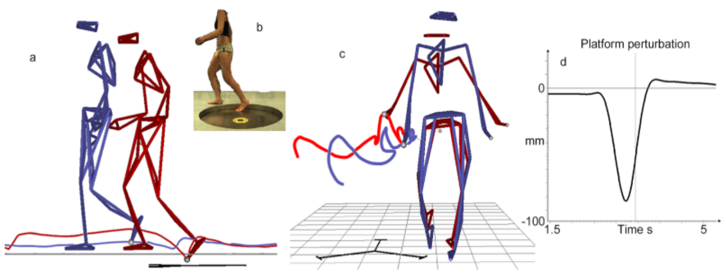
Walking is characterised by the ability to adapt the function to dynamical events derived from internal and external body perturbations. Gait perturbations could arise from irregular terrain, leading to expected or unexpected disturbances which are compensated by Anticipatory, Predictive and Reactive strategies [1]. Compensation abilities are compromised in pathological conditions [2], meanwhile, they are still developing in children. The purpose was to detect gait strategies and the key joints involved in the counter-reacting perturbation.

Methods

To address this question, we developed an ad-hoc robotized platform (Mufy, IT) for inducing perturbations during walking [3]. We recruited ten healthy young adults (3 males and 7 females, with a mean age of 31 ± 7 years). Participants walked along a path where the upper plate of a Stewart Platform was camouflaged. A control in force moved the platform vertically downward when participants stepped on it. The fall down of the platform was normalized based on the leg length and mass of the participants personalizing the stiffness of the simulated spring. The platform descended 10% of the leg length. The sequence repetition to induce expected or unexpected conditions was defined (See Figure 1, Upper Row). Each sequence was repeated with both legs. We conducted a full body 3D gait analysis of three strides before, on, and after the platform using an optoelectronic system with 12 cameras (Vicon, UK) to gather kinematics data.

Results

Statistical analysis was performed using one-dimensional Statistical Parametric Mapping to compare perturbed conditions (both expected or unexpected) to normal walking. The main findings revealed alterations in spatiotemporal parameters ($p<0.0001$), increased clearance ($p<0.02$ expected perturbation, $p<0.01$ unexpected perturbation, $p<0.009$ for unexpected non-activation), and increased dorsiflexion of the ankle ($p<0.001$) (see Figure 1, Lower Row), with minor effects on knee and hip flexion, hands elevation and anteversion of pelvis and trunk.



FW	FW	FW	UA		EA	UNA		ENA	ENA	UA		EA	UNA
			X	X	X					X	X	X	

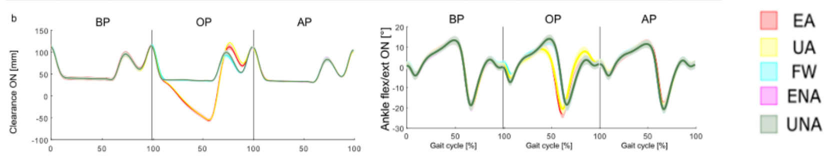


Figure 1. Upper Row. Panel a, unperturbed in blue, and perturbed in red schematic representation highlighting toe clearance. Panel b, frame of the perturbation. Panel c, frontal schematic representation emphasising hand elevation. Panel d, kinematic descend movement of the platform. Administrated sequence, FW= Free Walk, UA=Unexpected Activation, EA=Expected Activation, UNA=Unexpected Non-Activation, ENA=Expected Activation. Lower Row. Foot clearance and ankle flexion/extension, BP=Before Platform, OP=On Platform, AP=After Platform.

Discussion

In summary, our observations indicated an overlap between Anticipatory and Predictive strategies. Nevertheless, we find evidence of Anticipatory strategies looking at the increased foot clearance during the unexpected absence of perturbation and signs of Predictive strategies looking at hand elevation during the presence of perturbation. The perturbations were mainly absorbed at the ankle level raising the importance of focusing on this joint to assess the residual ability for gait compensation.

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Evaluation of relationship between neuro-muscular fatigue and manual dexterity in physiotherapists: an observational study

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Introduction

Neuro-muscular fatigue (NMF), localized in the upper limbs, is a common non-specific symptom that can impair strength and manual dexterity in many workers, including healthcare providers [1,2]. Among them, physiotherapists (PTs) are particularly vulnerable to this due to the physically demanding nature of their job, which often requires repetitive and prolonged use of the hands and forearms [3]. The primary aim of this observational study was to evaluate whether the NMF, expressed as a reduction in the manual dexterity, occurs over the course of a workday or workweek in a population of PTs. The secondary aim was to examine whether there are relationships between the reduction in manual dexterity and independent variables, such as age and sex.

Methods

23 PTs (11 men, age 43 ± 12 years), working in hospital setting 5/7 days for 7 h/day, were recruited. The Functional Dexterity Test (FDT) was administered to each participant before and after the work shift, both at the beginning and at the end of the workweek, three times in each assessment. Mean values, separately for dominant and non-dominant hand, were analyzed by a two-way ANOVA between days (Monday, Friday) and within repeated measures (morning, evening). Subsequently, the post-hoc Tukey test was conducted. A linear regression model was applied for assessing the association between the workday change in FDT and the clinical independent measure (PT's age and sex).

Results

All PTs were right-handed and the time employed by the dominant hand was less than the one taken by the non-dominant hand in each assessment ($p<0.0005$; Figure 1). ANOVA showed a significant worsening in FDT performance after the daily work shift in both hands ($p<0.0005$), without interaction with the first and last day of the week.
Regression analysis showed a relationship between FDT and age, both in dominant ($R^2=0.23$, $p<0.05$) and non-dominant hand ($R^2=0.16$, $p<0.05$); in particular, younger PTs showed a lesser performance degradation following the daily work shift.

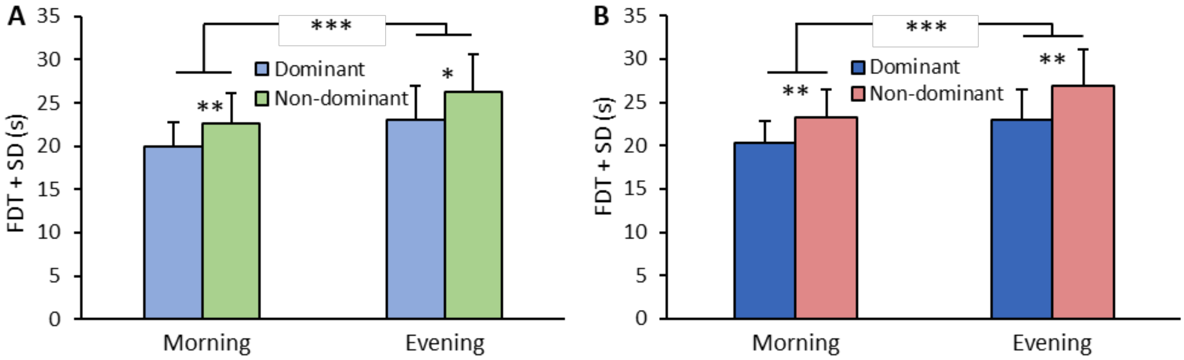

Figure 1. Results of Functional dexterity test (FDT) expressed as mean values + SD in dominant and non-dominant hand on Monday (A) and Friday (B). *, p<.05; **, p<.005; ***, p<.0005.

Discussion

Work-related neuro-muscular fatigue negatively affected the manual dexterity of PTs during the workday, but not between the beginning and end of the workweek. NMF builds up severely during the workday and it is influenced by age. Factors such as physical workload, work time, posture, and lack of adequate breaks may contribute to the onset of NMF [4,5]. Future studies should explore preventive solutions in order to reduce NMF in PTs.

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Do people with persistent postural-perceptual dizziness really sway? An instrumental sensor-based study

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Introduction

Persistent postural-perceptual dizziness (PPPD) is a chronic functional disorder characterised by persistent dizziness, instability and non-rotational vertigo, often induced by visual stimuli [1,2]. While peripheral vestibular conditions are common triggers of PPPD, other conditions including vestibular migraine, vestibular disorders and mild traumatic brain injuries can also precipitate PPPD [3]. The first aim of this study is to compare parameters of gait in patients with PPPD or subacute unilateral vestibulopathies (sAUVP) to healthy controls (HC). The second aim is to verify the correlation between gait parameters and Patients-Reported Outcome Measure in patients with PPPD.

Methods

This cross-sectional study involved 9 patients with PPPD, 10 patients with sAUVP and 11 HC. Participants completed the 10 Meters Walk Test (10MWT) and the Fukuda Stepping Test (FST) wearing five inertial measurement units (IMUs) located on the occipital cranium bone, at the centre of the sternum, at L4/L5 level and above lateral malleoli. IMUs were used to quantify parameters of stability (normalized Root Mean Square), symmetry (improved Harmonic Ratio), and smoothness (Log dimensionless jerk) of gait. These parameters were compared among groups and correlated with Dizziness Handicap Inventory scores for PPPD group.

Results

During the 10MWT the stability index at pelvis level along the medio-lateral (ML) axis was significantly higher for PPPD and sAUVP patients than HC. Simmetry of gait was lower for PPPD patients compared to HC group. Instead, during the FST, the simmetry index along the ML axis was significantly lower in sAUVP patients compared to PPPD patients and HC group. Smoothness of gait was significantly lower along the cranio-caudal axis in both patients groups with respect to HC group. Positive correlations were found between the self-assessed severity of dizziness symptoms and postural stability along the antero-posterior axis at head level in patients with PPPD.

Discussion

Patients with PPPD exhibit objective alterations, assessed through a sensor-based evaluation, of postural stability compared to HC. Remarkably, in absence of visual information PPPD performed better than sAUVP patients concerning the gait symmetry, implying an altered visual sensitivity. The positive correlations between the self-assessed severity of dizziness symptom and postural stability for PPPD patients suggests the combined use of Patient-Reported Outcome Measure and instrumental assessments in clinical practice. The observed differences between sAUVP and PPPD patients in maintaining postural stability enable rehabilitative professionals to consider new treatment paradigms, based on the necessity of patients with PPPD to overcome visual sensitivity.

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Estimation of joint moments during ball throwing in simulated altered gravity conditions using a musculoskeletal modelling approach: preliminary results

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Introduction

Exposure to altered gravity causes detrimental effects on the motor system [1]. A strategy to investigate gravity influence on motor planning involves the use of mixed reality (MR). In this framework, using a recently developed serious game [2], we studied the upper limb muscular dynamics by means of a musculoskeletal model when performing a ball throwing while exposed to a MR environment featuring different gravity conditions.

Methods

Three healthy subjects wearing a MR headset (HoloLens2, Microsoft) were asked to throw a real tennis ball superimposed to a virtual one, toward a holographic target (1.3 m ⌀, 1.73 m height, 2.44 m distance) in a MR environment simulating different gravity accelerations: a) 9.81 m/s2 (Earth), b) 3.72 m/s2 (Mars), c) 1.62 m/s2 (Moon). Motion data were recorded at 100Hz with a 12-camera optoelectronic stereophotogrammetric system (Vicon) and used as input of the musculoskeletal model. The analysis focused on the throwing phase, beginning at the time of minimum of the antero-posterior trajectory (tminAP) and ending at the ball release time (tBR). The upper limb musculoskeletal model developed by [3] was employed. The model includes 7 degrees of freedom (shoulder: elevation plane, thoracohumeral angle, internal/external rotation; forearm prono-supination; elbow flexion/extension; wrist: deviation, flexion/extension) and 50 muscles (shoulder: 15 muscles, elbow: 9 muscles, forearm: 8 muscles, wrist/hand: 18 muscles). The mass segments correspond to approximately 6.4% of body mass. OpenSim software (version 4.5) was used to estimate muscular dynamics. Musculoskeletal model was scaled to each subject's anthropometry, then inverse kinematics were performed. Inverse kinematics and an external load representing the real ball (Fball≈0.1% body mass) were used to perform inverse dynamics. For each subject, net joint moments were averaged among five trials for each gravity condition.

Results

Figure 1 reports the net elbow flexion/extension moment that shows differences among the gravitational acceleration values. The maximum net moment appears to decrease for reduced gravity conditions.

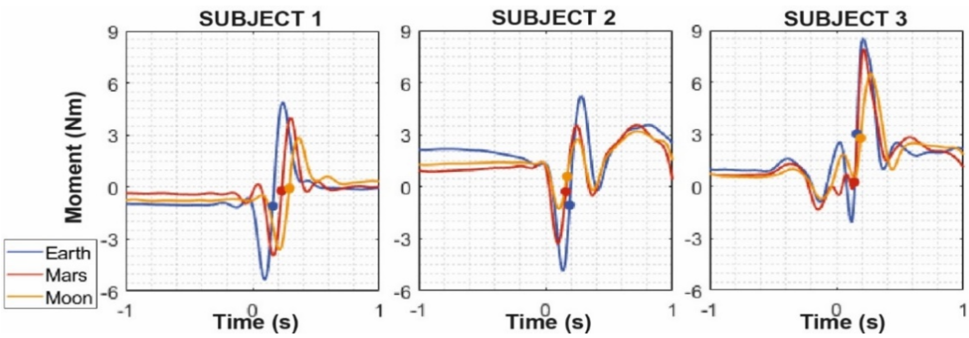

Figure 1. Subject's average elbow flexion-extension moments at each gravity condition. The time 0 s corresponds to t*minAP*, while the dot on each curve indicates the average t*BR*.

Discussion

The outcomes are consistent with previous studies concerning ball-throwing movements [4]. These preliminary results highlight variation of muscle behaviour among different gravitational levels, supporting further investigation of muscular dynamics in altered gravity. However, limitations of the chosen musculoskeletal model may affect our results; clavicle and scapula motion depend on humerus motion, therefore affecting shoulder muscles activity. Future studies should focus on improving model accuracy.

Acknowledgement. This work was developed within the project eINS-ECS00000038 funded by the Italian Ministry for Research and Education under the National Recovery and Resilience Plan.

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Design and validation of a novel accelerometer-based test for the assessment of the sensorimotor control of the shoulder

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Introduction

Myers introduced the Single-Arm Dynamic Stability (SADS) test to assess the sensorimotor control of the shoulder (SSC) by analysing the sway of the centre of pressure of the supporting hand during a one-handed push up position on a force platform [1]. As a closed kinetic chain configuration weakly reflects the injury patterns of the shoulder and limits load accommodation only to portions of body mass, the goal of this research is to design and validate a variation of the SADS test as performed in an Open Kinetic Chain (SADS-OKC) with the subject lying supine while holding a dumbbell still in one hand with the extended arm.

Methods

The dumbbell is assumed as the tip of an inverted pendulum linked in the shoulder and its sway can be characterised by a wireless triaxial accelerometer using the same set of stability parameters that are normally obtained for assessing standing balance with a waist-mounted accelerometer [2]. SADS-OKC test was administered to 20 healthy subjects (16 males and 4 females aged 23±2 years) in two sessions of day1, in one session of day2 and in a further session of day 2 after a shoulder's fatiguing protocol [3] aimed at mimicking an altered SSC. Each session was performed with both dominant and non-dominant arms and consisted of three randomised trials with 15%, 25% and 35% of a personalised reference load (RL) previously measured with a scale placed under the hands during a quadruped position. Stereophotogrammetry was used for monitoring any elbow and wrist motion invalidating pendulum assumption. Test duration was set at 30 s but stability parameters were also computed over the first 20 s. ICC was performed on such parameters to assess their inter-session and inter-day reliability and, if reliability was satisfied, ROC analysis was used to evaluate their specificity and sensitivity in detecting an altered fatigue-induced SSC.

Results

Both elbow and wrist flexion never exceed 5° during the test. Among all the stability parameters, jerk showed the highest inter-session and inter-day reliability in all conditions, with a good sensitivity in detecting unaltered SSC when using 35% of RL and 30 s duration for both arms (Table 1).

Table 1. Reliability (ICC) and ROC analysis (AUC = area under the curve, Cr = criterion, Se = sensitivity, Sp = specificity) for average jerk with 35% of RL during a 30 s SADS-OKC test.

average jerk (35% of RL, 30 s duration)	Dominant arm		Non-dominant arm	
	Inter-session	Inter-day	Inter-session	Inter-day
ICC (3,1)	0.775	0.739	0.645	0.534
ROC analysis	AUC=0.645; Cr>0.58 m^2/s^5 Se=78.9%; Sp=52.6%		AUC=0.668; Cr>0.55 m^2/s^5 Se=89.5%; Sp=42.1%	

Discussion

Results showed that the SADS-OKC test, as performed for 30 s and with the 35% of the RL, is reliable and able to detect a non-deficient SSC, suggesting its applicability to an athletic population following a shoulder instability rehabilitation program.

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Evaluation of WIMU sensor performance in estimating running stride time and vertical stiffness: a comparison with smart pressure insoles

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Introduction

Temporal parameters are crucial for assessing running performance. Recently, wearable inertial measurement units (IMUs) have gained popularity as a non-invasive method for in-field performance monitoring. IMUs provide valuable data on temporal parameters during activities like running, including contact (CT) and flight time (FT) [1]. Understanding vertical stiffness (Kvert) is essential for optimizing human locomotion, as it measures the body's ability to absorb and return potential elastic energy. This study aims to investigate the relationship between both temporal parameters and Kvert measured by IMUs and smart pressure insoles during outdoor running activities.

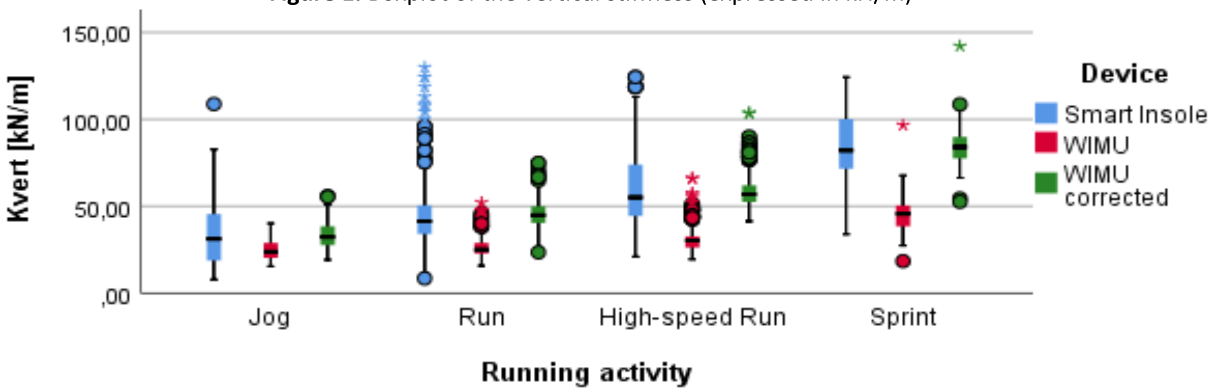
Methods

The study included ten healthy male subjects. Participants performed a time-box-to-box run. The test consisted of four paced, high-speed runs. Each run was 60 meters long and the players had to complete the run in 12 seconds [2]. The WIMU PRO™ device was used to collect physical data, and smart insoles were employed as gold standard. The data were processed with SPRO™ software and Python to extract CT and FT. Kvert was computed using Morin's method [3]. Statistical analyses, including Shapiro-Wilk, Wilcoxon tests, Pearson correlation, Cronbach's alpha, and intraclass correlation (ICC), evaluated data normality, non-parametric comparisons, linear relationships, and measurement reliability and consistency.

Results

The analysis revealed that the WIMU consistently measured longer CT and shorter FT compared to the smart insoles across various running speeds. Kvert values were also lower with WIMU: for jogging, 23.8 kN/m vs. 31.3 kN/m ($p<0.001$). Statistical tests showed significant differences ($p<0.001$) between the two devices for all parameters, with ICC values indicating moderate reliability for jogging but lower reliability for running and sprinting. Pearson correlation coefficients and Cronbach's Alpha values supported these findings, highlighting variability in measurements between the devices. A multiple linear regression model was applied to correct WIMU's Kvert values, including running velocity. Using a leave-one-out cross-validation model aligned them more closely with the smart insoles' measurements, which improved WIMU's accuracy (the RMSE% decreased from 54.8% to 30%), particularly at high speeds, as reported in Figure 1.

Figure 1. Boxplot of the vertical stiffness (expressed in kN/m)



Discussion

The study found distinct patterns in CT and FT variations correlated with changes in Kvert across different running activities. The corrected WIMU values showed significant improvement matching more closely with the smart insoles' readings. The study emphasizes the importance of assessing the validity of wearable devices, such as GPS units, to ensure adequate accuracy in in-field measurement.

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Analysis of head-trunk movements during gait in healthy and multiple sclerosis subjects: a systematic review

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Introduction

The Head-Trunk System (HTS) is involved in maintaining visual acuity and stabilizing the head during various activities, such as walking [1]. It has been reported that People with Multiple Sclerosis (PwMS) showed head movement instability and asymmetry during linear walking, even in the early stage of the disease [2]. However, there is still no consensus regarding the different methodologies to measure HTS movements during walking. Thus, the aim of this study was to summarize the methods and tools commonly used to evaluate the HTS in Healthy subjects (HS) and PwMS.

Methods

The search strategy (Scopus, Embase, and Pubmed) was launched on August 22, 2023. No time restrictions were applied. Full-text articles were analyzed for inclusion by two screeners. If there was disagreement amongst the two screeners regarding inclusion, a further reviewer was consulted. We included only cross-sectional studies with the following inclusion criteria: i) HS or PwMS, ii) linear walking activities iii) instrumented head movements assessment.

Results

The search strategy identified 1848 records. After the screening process, 18 studies were included in this systematic review showing different HTS evaluation methodologies and parameters.

The review considered data (17 studies) of 365 HS aged between 20 and 80 years, performing overground walking. Only two studies involved PwMS (n=35, age: mean±SD 54.7±9.2 years) performing overground or treadmill walking activity.

Considering HS, the most reported outcome was the range of motion (ROM) of pitch, with a mean around 5-10°, none of the studies including PwMS reported ROM as an outcome. All the studies on HS showed greater pelvis and upper trunk attenuation during walking. Harmonic ratio was used to evaluate equilibrium and step symmetry reporting worse scores in PwMS compared to HS.

Moreover, PwMS showed higher pitch head sways and head asymmetry during walking compared to HS. (Head sways: 19.24±11.14 cm2 PwMS vs 10.0±3.0 cm2 HS; head asymmetry:75.9%±51.0% PwMS vs 8.6%±5.5% HS).

Discussion

Our study reported that the outcome measures used in clinical settings are still heterogeneous. However, the importance of an accurate head assessment is crucial to identify head instability in PwMS. This could be relevant for clinicians when planning tailored exercises aimed at stabilizing the head during walking.

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A preliminary test to evaluate throwing performance in altered gravity conditions

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Introduction

It is well known that the exposure to altered gravity conditions causes visual-motor coordination disorders [1] due to the perturbation of internal models based on a priori expectation [2]. The effect of altered gravity conditions on the motor planning can be then partially studied by means of visual simulations. To this end, using a recently developed serious game [3], we studied the differences occurring in the upper limb's kinematics when throwing a virtual ball immersed in a gravitational field different from the Earth's, and looking at its trajectory.

Methods

Three healthy subjects wearing a headset (HoloLens 2, Microsoft) were asked to throw a real tennis ball superimposed to a holographic one, toward a holographic target (1.3 m ⌀, 1.73 m height, 2.44 m distance) while exposed to a Mixed Reality environment featuring three gravity values: a) 9.81 m/s2 [Earth], b) 3.72 m/s2 [Mars], c) 1.62 m/s2 [Moon]. To determine the elbow's flexion-extension angles as proposed by [4], a marker set adapted from [5] was employed for every subject, and their instantaneous 3D position was measured at 100 Hz by a 12-camera optoelectronic stereophotogrammetric system (Vicon, Oxford, UK). The throwing phase was defined between the instant of minimum in anteroposterior hand's trajectory (tminAP) (end of takeback phase) and the following time of maximum hand velocity norm in the sagittal plane (tBR) (ball release). In this interval, the elbow's Range of Motion (ROM) was calculated. Subjects whose level of familiarity with the serious game was not controlled, were asked to practice throwing for thirty minutes. Five throws were processed for each subject in each gravity condition.

Results

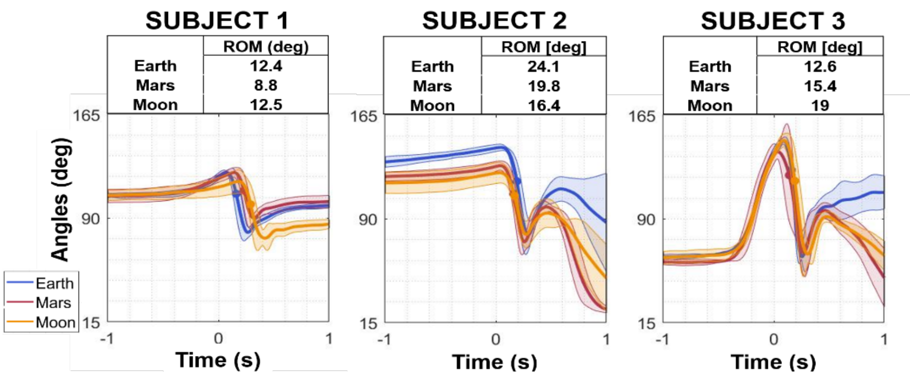

Figure 1. Subject's average elbow flexion-extension angles at each gravity condition. The time 0 s corresponds to t*minAP* while the dot on each curve represents the average t*BR*. Above each plot the relevant ROM is reported.

Discussion

The elbow angles reported in Figure 1 show different behaviors at different gravity values for each subject. In particular, subject 2 shows a decreasing ROM as gravity values decreased, which could be a sign of higher joint freezing due to lack of familiarity with the lowest gravity values [6]. However, subject 3 shows an inverse trend, which in turn could be related to a higher familiarization with the game itself. Future studies will include a higher number of subjects and the randomization of the gravity values order.

Acknowledgement. This work was developed within the project eINS-ECS00000038 funded by the Italian Ministry for Research and Education under the National Recovery and Resilience Plan.

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Development and validation of an algorithm based on ankles-IMU setup for the extraction of gait parameters

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Introduction

The estimation of spatio-temporal gait parameters using inertial measurement units (IMUs) has becoming increasingly popular as an alternative to optoelectronic systems (gold standard in the gait analysis field). Despite the widespread use of wearable inertial sensors in clinical practice, there is still a lack of knowledge about their validity also due to the different sensor placement. This study aims to develop and validate a novel algorithm for estimating spatio-temporal gait parameters using inertial signals (angular velocity around the mediolateral axis) acquired by means of two IMUs placed on the ankles. The validation of the algorithm was performed by comparing measurements obtained with the algorithm developed by the authors with those computed using a commercial wearable inertial system (Mobility Lab System, APDM Inc. USA) that uses two IMUs mounted on the feet.

Methods

Thirty healthy subjects, each equipped with two foot-mounted IMUs (Mobility Lab System) and two ankle-mounted IMUs, performed a 10-meter walk. The angular velocity signals around the mediolateral axis were filtered and segmented to detect Regions of Interest (ROIs) for calculating relevant gait event timings. The signals were rectified and filtered using a Savitzky-Golay filter. Start and stop points identifying the ROIs were obtained from the intersection between the filtered signal and an empirical threshold set for each subject. These points were then applied to the original signal. Gait events (toe-off, mid-swing, and heel-strike) were identified within each ROI, and the corresponding times were extracted. Spatio-temporal parameters, including cadence (steps/min), gait cycle time (s), swing duration (%), stance duration (%), and double support duration (%), were calculated for both legs and averaged. The agreement between the two methods was assessed using a two-tailed paired test, Passing-Bablok linear regression analysis, and Bland-Altman analysis.

Results

A two-tailed paired test was performed to evaluate whether there was a statistically significant difference in mean values between the measurements obtained by the two analytical methods while Passing-Bablok regression and Bland-Altman analysis were performed to assess the agreement and therefore the presence of systematic errors both constant and proportional or other types of errors. Table 1 summarize the results of the agreement analysis between the parameters extracted using the commercial wearable system and the algorithm developed by the authors.

Table 1. Results of agreement

Spatio-temporal parameters	Level of Agreement	Type of error
Cadence (steps/min)	No agreement	Constant systematic error
Gait cycle time (s)	Agreement	-
Swing duration (%)	No agreement	Constant systematic error
Stance duration (%)	No agreement	Constant systematic error
Double support duration (%)	No agreement	Constant systematic error

Discussion

Study results showed a perfect agreement only for the gait cycle time parameter. However, the only type of error found was a constant systematic error; this type of error can be easily eliminated zeroing the bias with a subtraction operation. In conclusion the algorithm developed by the authors can be considered acceptable for gait analysis evaluation.

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Fall prevention and self-care in elderly: the FREECARE case study

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Introduction

Falls are a leading cause of morbidity and mortality in elderly patients, often resulting in fractures, loss of independence, and prolonged hospitalizations [1]. Implementing effective assessment and prevention strategies, based on a multidisciplinary approach, can help identify risk factors and develop personalized interventions. This paper presents a project aimed at developing an integrated system for fall prevention and patient self-care.

Methods

The Free-Care (Fall Prevention and Self-Care Smart Shirt System) is a research and experimental development project that consists of a system for fall risk assessment and prevention and patient self-care management. It comprises three specific modules: the Wearable Module, which consists of a t-shirt with embedded sensors capable of detecting and wirelessly transmitting physiological signals (electrocardiographic signal (ECG) and galvanic skin response (GSR)); the Mobile Module, which comprises an application on a mobile device that is capable of: a) receiving and processing physiological signals detected by the wearable device; b) administering clinical assessment scales to the patient; and c) proposing and administering appropriate exercises provided by the OTAGO method according to the consequently estimated level of risk [2]; and the Desktop Module, which refers to system software that is capable of processing and transforming the detected signals into parameters and dynamically classifying the level of fall risk using prediction algorithms.

Results

Figure 1 shows the complete architecture of the system. The user wears the smart shirt for ECG and GSR monitoring. The signals are transmitted via Bluetooth to a mobile application that records and stores them on an online platform. The desktop module allows the clinician to examine the signals and process them to extract parameters of clinical interest. The MORSE and STRATIFY clinical scales for assessing fall risk are also administered to the user using the mobile app. The results of the scales and the parameters resulting from the signal processing are processed by an expert prediction system based on PSO algorithms, which provides a fall risk level. The user is then presented with exercises selected by the OTAGO programme according to the identified risk level.

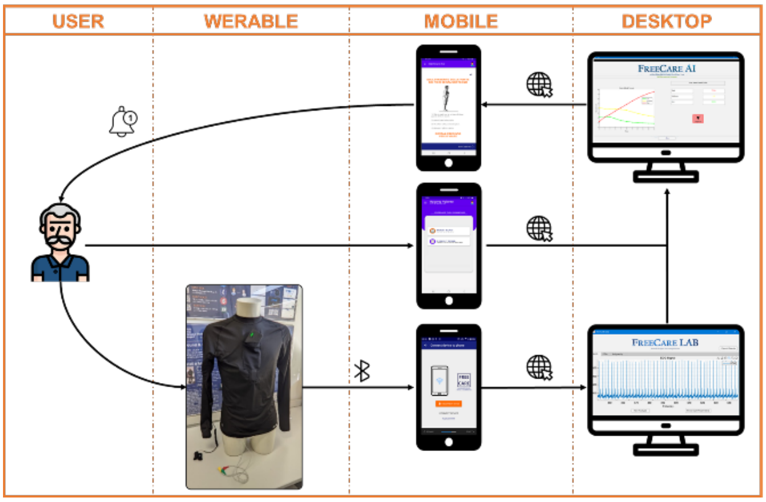

Figure 11. Architecture of FREECARE system.

Discussion

By providing continuous monitoring, personalized exercise regimens, and real-time risk assessment, FREECARE promotes greater independence and safety among elderly users. This comprehensive system not only addresses the immediate need for fall prevention but also empowers elderly individuals to take an active role in managing their health, thereby potentially reducing the incidence of falls and improving overall quality of life [3].

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Predicting ACL and PCL overloading for injury prevention through a 6DOF knee EMG-driven model

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Introduction

The primary cause of knee injuries during sport activities is non-contact injuries during cutting maneuvers and landings [1]. The majority of the knee injuries involve both anterior and posterior cruciate ligaments (ACL and PCL) as well as collateral ligaments, due the application of forces that are greater than these tissues can withstand.

As ligament forces cannot be measured in vivo, in order to determine preventive strategies that take these variables into account, musculoskeletal modeling (MSM) approaches should be considered. However, currently available knee MSMs [2] still present some limitations: they do not allow deep squat movement, and they don't consider the subject motor control strategy. The current study proposes a 6-degree of freedom (DOF) knee model, for application in deep squat movements driven by surface electromyography data (sEMG) that possibly reflects individuals' motor control strategies.

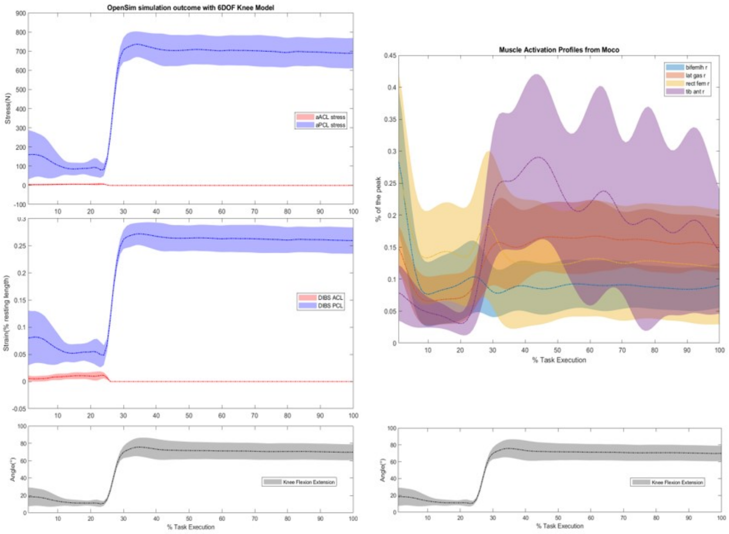
Methods

Five healthy subjects (mean age: 25.2 ± 0.75 years, BMI: 21.9 ± 1.83 kg/m²) were acquired while performing single leg drop landing (SLDL) tasks, which represents one of the main return to play tests following ACL reconstruction [3]. A 6-camera optoelectronic system (BTS, 60 Hz), synchronized with two Bertec force platforms (960 Hz) and an 8-channel sEMG system (1000 Hz) was used. sEMG sensors were placed on the vastus lateralis, tibialis anterior, semitendinosus, and gastrocnemius medialis muscles bilaterally. IORGait protocol was applied [4].

Moco, a EMG-driven MSM toolbox [5], was used to include the muscle-driven simulation in a previously developed 6-DOF knee model [6]. All simulations were performed in Opensim (v4.4). Direct collocation was performed to generate muscle-driven simulations and compute the optimized muscle activations for each trial. A MATLAB code was implemented to extract the mechanical parameters of the different ligament's bundles. To resume the overall strain of the ligaments, differential intra-bundle strain (DIBS) [2] were computed. The simulated muscle activity was compared with the experimental one through the coefficient of multiple correlation and root mean square error.

Results

Figure 1. Stresses (top left), DIBS (mid left) for the ACL (red) and PCL (blue). Muscular activations (right) computed with Moco for the monitored muscles. Knee flexion extension (bottom, grey) during the task



Discussion

As shown in Figure 1, both the ACL and the PCL exhibited a mechanical behavior in line with the literature [1]. The introduction of Moco in the processing pipeline allowed determining more reliable muscle activations, thus ensuring a better validity of the model.

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Reliability assessment of a 3D markerless body pose estimation in children with and without applying a multi camera triangulation algorithm

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Introduction:

In recent decades, gait analysis has become very popular in studying motor disturbances as it offers the possibility to quantitatively measure the joint and muscle alterations associated with these impairments. When dealing with children and elderly, lengthy preparation procedures and/or the presence of markers on the body can be an obstacle. This is even more important when children with autism spectrum disorder are involved. In this context, markerless techniques, especially AI-based, could be a preferable solution. However, validity assessment of their use in children is still lacking. This study aims to assess the reliability of an AI-driven markerless technique applied as a multi-camera solution in comparison with a monocamera solution and stereophotogrammetry.

Methods

The video sequences of a cohort of 10 children (Age: 9.81±3.47, BMI: 18.8±5.0 kg/m^2) belonging to a previously acquired dataset were used [1]. Several walking trials were, synchronously, acquired through four video cameras (GoPro Hero3, 30fps) and a 6-cameras optoelectronic system (BTS, 60 Hz). IORgait protocol was applied [2]. Videos were processed, the 3D joint trajectories reconstructed and flexion-extension lower limb joint kinematics computed as follows: with TrackOnField (ToF), an automatic-tracking software (BBSoF s.r.l.) [1], with MediaPipe [3] and through the stereophotogrammetric system; joint rotations were computed in Matlab (v2024). For both ToF and MediaPipe the images from 2 cameras were considered to obtain the 3D marker or joint center trajectories respectively, and the triangulation algorithm was applied. The results were compared across the different approaches by computing the Root Mean Square Error (RMSE), the Coefficient of Multiple Correlation (CMC) [4] and the Minimal Detectable Change. 1D-Statistical Parametric Mapping (SPM) was used to test for statistical differences [5].

Results

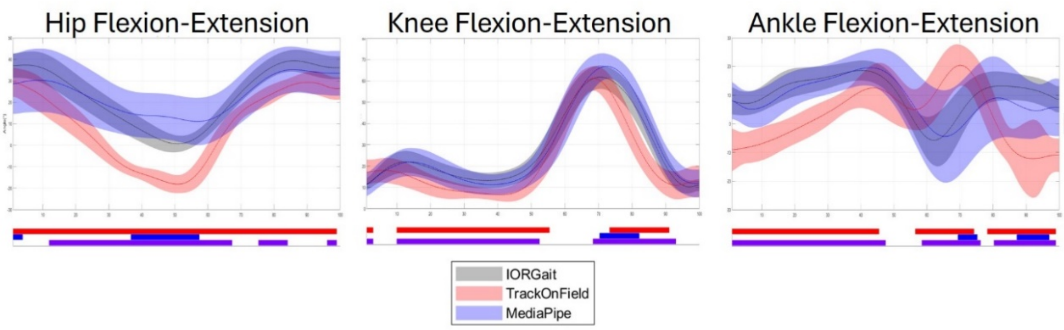

Figure 1. Hip, knee and ankle estimated flexion-extension. Markerbased (grey), ToF (red) and MediaPipe (blue): mean ± standard deviation. Bars in the lower part of the figure represent the statistical significance ($p<0.05$): Markerbased vs ToF = red, Markerbased vs MediaPipe = blue, ToF vs MediaPipe = Violet.

Discussion

As shown in Figure 1, the triangulation approach provided results with a better agreement towards the stereophotogrammetry based calculations, both in terms of RMSE (< 7°) and CMC (>0.7). Considering these results, a deeper investigation on a larger cohort of individuals will take place for generalization purposes. Indeed, a further development will include analyzing the, already available, video sequences of a cohort of children with Fragile X syndrome [6].

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What is the minimum stiffness of dynamic AFOs for people with foot drop? A gait-analysis based dynamic study

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Introduction

Dynamic ankle foot orthoses (AFOs) are medical devices prescribed to patients with foot drop (FD), a condition characterized by limited or absent active foot dorsiflexion due to weakness of the ankle dorsiflexor muscles. Dynamic AFOs allow to restore the foot-to-ground clearance in the swing phase of walking, whilst storing and releasing some energy. While current 3D scanning and manufacturing technologies allow to design and produce custom AFOs best fitting individual's foot and leg morphology [1], the knowledge on the optimal stiffness of these devices are still limited. The aim of this study was to determine the minimum AFO stiffness capable to support the foot and footwear in the swing phase of walking for individuals affected by FD.

Methods

Ten unilateral FD patients were enrolled (8M, 2F; age 65 ± 11 years; BMI 26.2 ± 2.1 kg/m2) and ethical approval was granted for the purposes of the study. At least 3 walking trials at self-selected speed were recorded for each participant in shod conditions (footwear mass = 0.164 kg). Foot and ankle kinematics were obtained from a skin-marker based protocol [2]. Foot mass and inertial components were estimated according to Pavol et al. [3] and Hinrichs et al. [4]. For each participant, the maximum plantarflexion moments acting on the foot were calculated in static and in dynamic conditions, i.e. during the swing phase of walking. The maximum plantarflexion moment in static conditions was assessed also in a population of 97 subjects from a previous study [4]. The theoretical minimum AFO stiffness supporting the affected foot was calculated according to the maximum plantarflexion moment in both static and dynamic conditions.

Results

The anthropometric-based estimation of the foot mass across the 10 participants was 1.15 ± 0.15 kg and 1.18 ± 0.16 kg respectively for the affected and non-affected foot. The mean moment of inertia at the ankle was 0.0133 ± 0.0026 kg*m2 and 0.0141 ± 0.0035 kg*m2 respectively for the affected and non-affected foot. The maximum plantarflexion moment during the swing phase in the affected (Figure 1) and non-affected foot was 1.66 N*m and 2.14 N*m, respectively. Thus, by setting a maximum plantarflexion angle of 1 deg while wearing the AFO, the theoretical minimum AFO stiffness results in 1.66 N*m/deg.

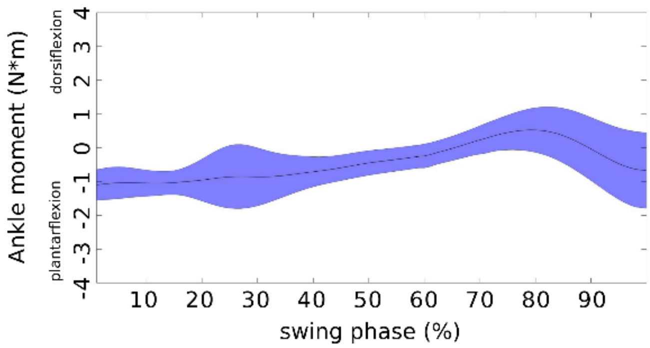

Figure 12. Mean (± 1 SD) moment at the ankle (N*m) during time-normalized swing phase of gait in 10 FD participants.

Discussion

This pilot study has the potential to provide useful information on the minimum stiffness that dynamic AFOs should have in order to support the foot in the swing phase of walking, while minimizing the limitations to foot dorsiflexion in the stance phase.

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An inertial-based method to characterize response to footwear features

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Introduction

Running footwear influences running biomechanics and economy [1,2]. As such, runners should select shoes that improve performance or optimize biomechanics to reduce injury risk considering the type of training and running terrain. However, there is still debate in the literature about optimal footwear recommendations, partially due to highly individualized footwear response, as well as the lack of investigation of footwear effects in-the-field [2]. To overcome this limitation, magneto-inertial sensors (MIMUs) can be used to quantify running biomechanics outside the lab [3]. Since most studies use optical motion capture to assess footwear response, the aim of this study was to evaluate the ability of MIMU-based parameters to identify individual response to different running footwear. We used within and between footwear variations in midsole resiliency (ability to absorb energy and release it upon unloading), because of its known effect on running economy.

Methods

Ten recreational male runners ran on a treadmill at 14 km/h for eight 6-min trials with 3 different shoes (mass equalized at 282g) combined with 3 different insoles over 8 combinations resulting in various energy returns: 51%, 54%, and 55% (shoe A, C1-C3); 59%, 60%, 62%, and 63% (shoe B, C4-C7); 74% (shoe C, C8). Participants were equipped with 8 MIMUs attached to their pelvis, trunk, thighs, shanks, and feet. MIMU-based estimates of stride, stance, and swing durations, stride length, stride velocity, vertical oscillation of the center of mass were validated against a stereo-photogrammetric system. By modelling running as a spring-mass system, vertical and leg stiffness were calculated [4]. Stride-by-stride peak values of body segments angular velocity, acceleration, and excursions were computed. The effect of midsole resiliency on each running parameter was quantified with repeated measures ANOVA.

Results

Stance duration and foot angular velocity significantly varied across footwear conditions C1-C8 ($p < 0.05$). For the sake of brevity, only stance and peak foot angular velocity in frontal plane ($p < 0.001$) are reported in Figure 1.

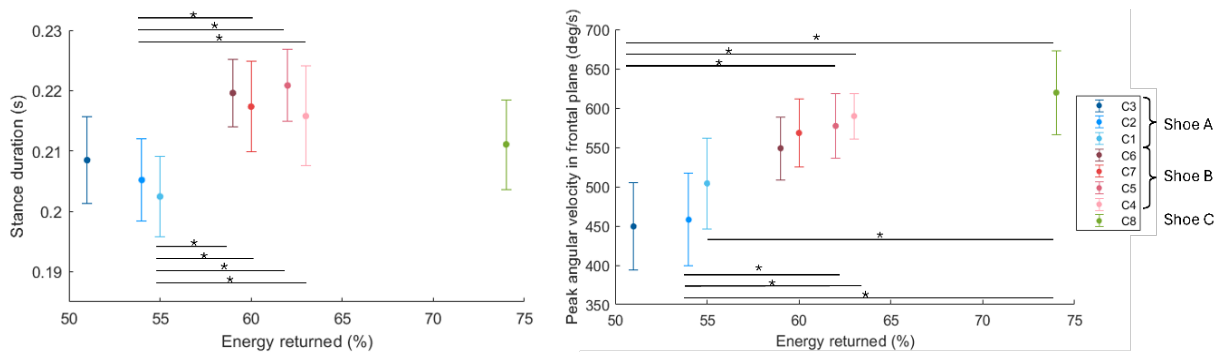

Figure 1. Stance and foot angular velocity with respect to midsole resiliency (* significant difference $p < 0.05$).

Discussion

MIMU-based running parameters detected responses to different footwear. Shoe B led to longer stance durations than shoe A, while shoe C, which has a different midsole technology, reversed this trend. Foot angular velocity in frontal plane, commonly not reported for optical motion capture data, strongly correlated with midsole resiliency ($r = 0.9$). Foot-mounted MIMUs are thus a promising solution for an ecological running analysis to quantify responses to different footwear and provide shoe recommendations. Funding provided by Diadora S.p.A.

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Assessing gait impairments in neurological populations: a preliminary study of an ecological protocol

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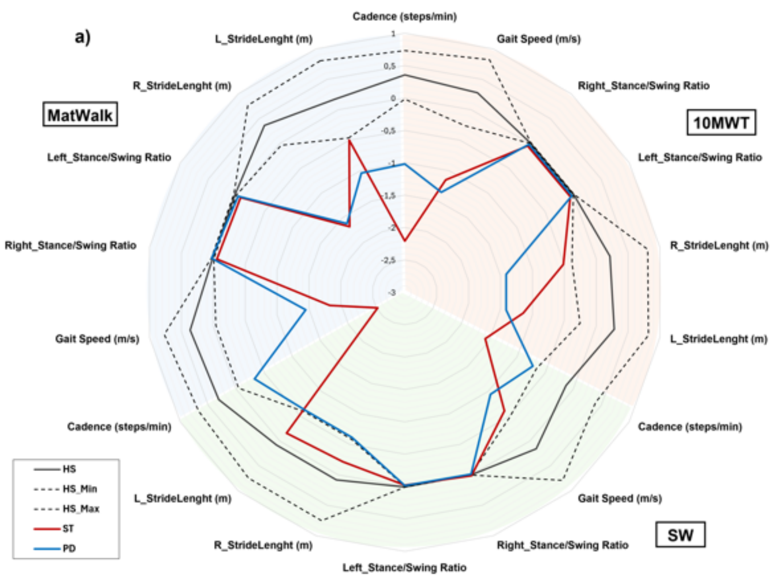
Introduction

In neurological disorders, nervous system damages may be the cause of alterations in gait and balance, potentially leading to physical disability, independence's loss, life quality reduction, and increased risk of accidental falls [1,2]. Wearable inertial measurement units (IMUs) allow to quantify locomotion patterns, offering objective indices to manage patients' conditions and guide rehabilitation treatment [3]. This assessment is usually conducted in clinical environments which do not necessarily reflect the complex environmental determinants of functional mobility in daily life, possibly leading to underestimation of results [4]. Creating evaluation protocols that reflect the daily struggles of neurological patients fis important. In this preliminary study, the goal is to propose an assessment protocol that simulates everyday scenarios, aiming to bringing out biomarkers capable of highlight subtle motor impairments not recognizable with the solely standardized tests of clinical settings.

Methods

Ten Healthy Subjects (HS), (6 females, 57±10y), one chronic Stroke patient (ST), (female, 49y, right hemiparesis; Fugl-Meyer_LowerExtremity: 33) and one Parkinson patient (PD), (male, 70y, Hoehn & Yahr: 2), were asked to perform five repetitions of three motor tests in different conditions: 1) linear walking: standard clinical evaluation (10-meter walking test, 10MWT), straight walk (SW) on a led floor surrounded by a mountain landscape, and on a mats with no elastic resistance (MatWalk); 2) curvilinear walking: standard clinical evaluation (Figure-of-eight walking test, Fo8WT), curvilinear walk (CW) with the mountain landscape, and a grocery shopping (walk and memorize items); timed up and go test (TUG): standard clinical TUG and TUG mimicking kitchen activities (RTUG). A set of spatio-temporal parameters was extracted from 16 IMUs (Captiks srl, Italy, 100Hz) through validated algorithms implemented in the Captiks Motion Analyzer software [5]. Mean values and standard error were considered for each parameter.

Results



Linear walking results in the three proposed motor tasks are reported in Figure 1. Similarly to curvilinear and TUG tests, PD (blue) and ST (red) patients show increased motor impairments in all proposed motor tasks against HS. Both participants seem to suffer the increasing complexity of the task showing a deterioration of investigated spatio-temporal parameters.

Figure 1. Radar plot of linear motor task. The bigger the radar, the better the performance. HS = healthy subjects; ST = stroke; PD = Parkinson's disease; 10MWT =10-meter walk test; SW = straight walking; CW = curvilinear walking; Fo8WT = Figure of 8 walk test; RTUG = real life TUG.

Discussion

Preliminary results seem to reinforce the need of introducing more complex tasks, which mirror real-life challenges, to better understand the functional status of patients. Increasing number of participants will be necessary to highlight biomarkers related to the disease-specific motor impairments.

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Balance and gait impairment in patients with cognitive decline in the elderly: a multidisciplinary assessment

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Introduction

The ongoing rapid demographic aging will lead to a higher prevalence of diseases and disabilities, with a significant focus anticipated on cognitive function impairments [1]. Memory loss, learning difficulties, and decreased ability to concentrate on a task characterize cognitive decline in the elderly, also affecting physical performance such as balance and gait [2-3]. In these subjects, it is not known whether the cognitive impairment produces an alteration in balance and gait that may have important functional relapses and increase the risk of morbidity and mortality in these subjects [4]. Our study aims are to investigate balance and gait characteristics in a cohort of elderly patients with cognitive impairment and to correlate any altered patterns with comorbidities such as sensory impairments and pain.

Methods

In the context of the multicenter study "Development of an ensemble learning-based, multi-dimensional sensory impairment score to predict cognitive impairment in an elderly cohort of Southern Italy" we will enroll, 22 patients with > 65 years, with Montreal Cognitive Assessment (MoCA test) < 17.5 at ICS Maugeri in Pavia. All patients will be given a multidisciplinary assessment which includes:

- Medical history and blood test.
- Volumetric brain MRI without contrast.
- Physical assessment: Short Physical Performance Battery (SPPB), handgrip, stabilometry (eyes open and eyes closed), baropodometry.
- Cognitive assessment: Geriatric Depression Scale (GDS-30), MoCA test, Short Form Health Survey (SF-36).
- Nutritional assessment: food frequency questionnaire, bioelectrical impedance analysis (BEA).
- Pain assessment: Numerical Rating Scale, Brief Pain Inventory, Quantitative Sensory Testing.
- Sensory assessment: visual loss assessment, hearing loss assessment (otoscopic, tympanometric examination, audiometry), taste and olfaction assessment (Sniffin' Stick and Taste Strips).

Results

The expected results of this research will provide information regarding the alteration in balance and gait of patients with cognitive decline and correlate the patterns with sensory and nociceptive alterations. This knowledge may improve the clinical management of the aging population more susceptible to cognitive decline.

Discussion

The purpose of this study is to highlight the importance of monitoring gait, balance and their correlation with sensory impairments and pain, in patients with cognitive decline.

Regular assessment of these parameters can help in the early identification of at risk individuals and in implementing targeted interventions to improve quality of life and reduce the risk of falls [5]. Further research is needed to delve into the underlying mechanisms and to develop more effective intervention strategies.

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Muscle pre-activation prior to landing in athletes with anterior cruciate ligament reconstruction: detection of EMG onset using artificial intelligence

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Introduction

In Return-to-Sport evaluation of athletes after Anterior Cruciate Ligament Reconstruction (ACL-R), motion analysis of specific tasks, such as Single-Leg Hop (SLH), can provide unique measurements. Muscle pre-activation prior to SLH landing is adopted as a discriminant parameter between ACL-R and control athletes [1]. To detect muscle pre-activation from electromyography (EMG) signals, algorithms for activation-interval detection can overcome the limitations of manual segmentation. Long Short-Term Memory recurrent neural network for Muscle Activity Detection (LSTM-MAD) [2] proved successful, in gait analysis, as a tool for EMG-onset detection based on Artificial Intelligence (AI). LSTM-MAD directly works on raw EMG signals without requiring additional pre-processing or input parameters (e.g., background-noise power and Signal-to-Noise Ratio). The aim of this work is to quantify muscle pre-activation and asymmetry in ACL-R and control athletes, adapting LSTM-MAD to the evaluation of SLH task.

Methods

The EMG activity of 4 lower-limb muscles - Vastus Lateralis (VL), Vastus Medialis (VM), Semitendinosus (ST), and Biceps Femoris (BF) – was acquired bilaterally from 12 ACL-R and 17 control athletes. LSTM-MAD was applied to evaluate muscle pre-activation before initial contact while landing. The median value of the EMG pre-activation across 3 trials was considered for the analysis. A derived parameter - named "pre-activation asymmetry" - was obtained for each subject, defined as |EMG_preactivation_left - EMG_preactivation_right|. In other words, the asymmetry between the reconstructed and contralateral side of patients was calculated and compared against the "physiological" asymmetry between the dominant and non-dominant side of controls. Two 2-way ANOVAs with Bonferroni adjustment for multiple comparisons were performed to test differences in muscle pre-activation and pre-activation asymmetry between populations (ACL-R athletes vs. controls) and knee flexor/extensor muscle groups (knee flexors: ST and BF; knee extensors: VL and VM).

Results

Figure 1 shows the muscle activation intervals of a representative ACL-R athlete, and results on ACL-R and control populations. Statistically significant differences in muscle pre-activation were found between populations (ACL-R: 167±6 ms (mean±SE); controls: 137±5 ms; p<0.001) and muscle groups (knee flexors: 169±5 ms; knee extensors: 135±5 ms; p<0.001). Moreover, pre-activation asymmetry was higher in ACLR athletes compared to controls (ACL-R: 55±6 ms; controls: 29±4 ms; p<0.001) and in knee extensors compared to knee flexors (knee flexors: 29±5 ms; knee extensors: 55±5 ms; p<0.001).

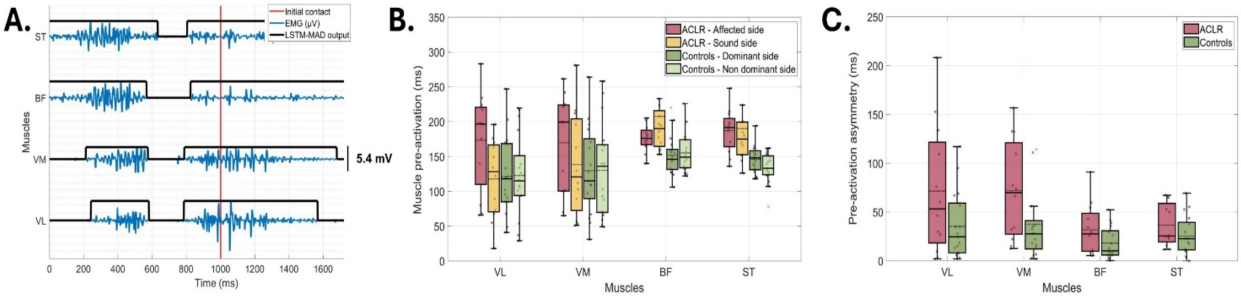

Figure 1. Example of LSTM-based detection of EMG activation intervals and boxplots of muscle pre-activation and asymmetry in athletes after ACL-R and controls. Fig.1A shows activation intervals of the VL, VM, BF, and ST muscles, detected by LSTM-MAD, of a representative ACL-R athlete during SLH task. Boxplots showing differences in muscle pre-activation and asymmetry between the ACL-R group (affected and sound side) and control group (dominant and non-dominant side) are represented in Fig.1B and Fig.1C, respectively.

Discussion

AI proved useful in the automatic detection of muscle activity, allowing for the extraction of muscle pre-activation and derived parameters such as pre-activation asymmetry during SLH landing in ACL-R and control athletes.

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Capturing gait signature: a biomechanically driven marker-less approach based on multiple RGB cameras

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Introduction

Gait is a "biometric signature", reflecting everyone's unique way of walking [1]. Automatic video-based gait recognition can be performed with model-free methods, relying on image-based features. However, model-free gait recognition depends on viewpoints and scale [2]. Alternatively, model-based methods use biomechanical features extracted from joint coordinates in the video [3], allowing greater explainability (relevant in clinical scenarios) and robustness to scale and view changes in the image. This study aims to select salient biomechanical features from marker-less video data to recognize people by their gait.

Methods

Fifteen healthy subjects were involved in the study (25.8±2.8 years old). Participants walked at comfortable speed along a 5m-straight walkway while recorded by three RGB cameras (fs: 30 fps) on the frontal and sagittal planes. Joint centres were tracked semi-automatically using Movenet [4] frame-by-frame and used for stride segmentation. Ninety stride-by-stride features were computed, including joint angles, spatio-temporal parameters, asymmetry and correlation indices from upper and lower limbs. Features were ranked using the minimum redundancy maximum relevance (MRMR) algorithm [5]. A preliminary feature selection was performed by excluding features with MRMR score lower than 0.002. The final dataset was split into a construction set (71,4%) and a test set (28,6%). Then, top-down wrapper feature selection [4] was performed with five classification models: (i) Discriminant Analysis (DA), (ii) Error-Correcting Output Codes (ECOC), (iii) k-Nearest Neighbors (KNN), (iv) Naïve Bayes Classifier (NBC) and (v) Neural Network (NN). Performance was evaluated by classification accuracy on the construction set with 5-folds cross-validation. For each model, the selected feature set was the one achieving the highest accuracy. Models' hyperparameters were tuned by grid-search protocol and 5-folds cross-validation using the features selected in the previous stage. Finally, trained models were evaluated on unseen test data and their performance quantified by F1-score.

Results

Table 1 shows selected features of each model. ECOC, DA, KNN, NB and NN models achieved a F1-score of 77,2%, 76,3%, 74,7%, 57.0% and 53,9%, respectively.

Models	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}	f_{12}	f_{13}	f_{14}	f_{15}	f_{16}
ECOC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
DA	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
KNN	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
NBC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
NN	✓	✓	✓	✓	✓	✓	✓	✓	✓							

Table 4. Best set of features for each classification model. $\boldsymbol{f_1}$: max. cross-correlation (cc) between right (R) and left (L) shoulder frontal angles (FA); $\boldsymbol{f_2}$: cc in 0 between R and L shoulder sagittal angles (SA); $\boldsymbol{f_3}$: max. cc between R and L shoulder SA; $\boldsymbol{f_4}$: standard deviation (std) of both R and L knee SA; $\boldsymbol{f_5}$: std of L hip FA; $\boldsymbol{f_6}$: std of R knee FA; $\boldsymbol{f_7}$: std of trunk FA; $\boldsymbol{f_8}$: std of L knee FA; $\boldsymbol{f_9}$: range of pelvis FA; $\boldsymbol{f_{10}}$: std of head FA; $\boldsymbol{f_{11}}$: step asymmetry index on sagittal plane (SP); $\boldsymbol{f_{12}}$: absolute asymmetry angle of arm swing on SP; $\boldsymbol{f_{13}}$: range of head SA; $\boldsymbol{f_{14}}$: range of L shoulder FA; $\boldsymbol{f_{15}}$: range of hip SA; $\boldsymbol{f_{16}}$: std of R shoulder FA

Discussion

The most relevant features included indices of correlation between contralateral upper and lower limbs and trunk kinematics. The trained ECOC, discriminant analysis, and k-NN models achieved consistent performance (F1-score>74.7%), suggesting that the selected features have discriminative potential for gait recognition. Performance may benefit from including more subjects and experimental conditions in the training dataset. This study paves the way to the development of biomechanically driven gait recognition methods with promising applications in clinical assessment and video surveillance.

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Machine learning applied to gait analysis data in cerebral palsy and stroke: a systematic review**

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Introduction

Machine learning (ML) methods show great potential in analyzing gait analysis (GA) data from individuals with cerebral palsy (CP) [1] and stroke [2]. However, the translation of ML methods into clinical applications poses significant challenges. In this systematic review, we addressed this issue in terms of three indices: suitability, as the appropriateness of the ML methods to meet clinical requirements; feasibility, as the practicality of them in clinical settings; and reliability, as the consistency of ML methods [3].

Methods

Two reviewers screened the retrieved articles from 4 databases independently. Full papers using ML for classifying GA data from CP and strokes were included. A tailored set of 16 quality questions for the critical appraisal process was designed. Each question was scored on a three-level basis: 1 for yes, 0.5 for limited details, and 0 for no. Overall scores were computed for each study in percentage. Studies were categorized as high (> 80%), medium (51% - 79%), and low (< 50%) quality [4]. Moreover, the methods' suitability, reliability, and feasibility were assessed by aligning them with relevant questions. Questions were rated based on the percentage of studies providing complete answers. Ratios of questions at each level (low, medium, high) to the total linked to each property were calculated and presented as percentages.

Results

Of the 2450 unique retrieved studies, 63 were included. Among the 31 studies implementing supervised algorithms, 7 were rated high, 19 medium, and 5 low. No questions about suitability or feasibility received a high rating, whereas 9% of the questions concerning reliability were rated as high quality (see Figure 1a). Out of the 32 studies utilizing unsupervised algorithms, 6 received high, 19 medium, and 7 low scores. For unsupervised methods, 17% of the questions related to suitability resulted in high scores, while the rates were 25% for feasibility and 22% for reliability (see Figure 1b).

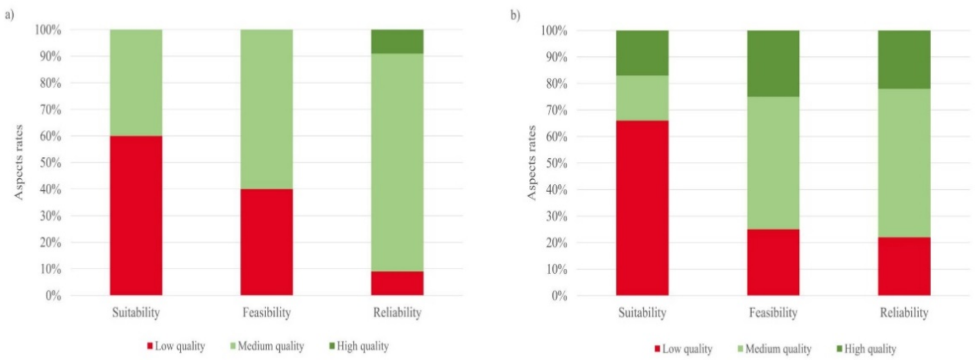

Figure 1. Quality of addressing the methods' suitability, feasibility, and reliability

Discussion

Adapting ML algorithms for clinical applications is challenging regarding suitability, primarily due to the lack of justification in selecting both features and ML algorithms. Additionally, the low clinical interpretability of the results is another issue that affected suitability, especially in unsupervised methods. The reliability of the systems gained the highest score, indicating that many researchers prioritized accuracy in their systems over other aspects. The findings in this review can be used to develop more robust gait data analysis methods using ML algorithms that are better suited to clinical scenarios.

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A mixed reality system for the evaluation of the effects of exoskeletons on cognitive load during manual handling task

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Introduction

The "Industry 5.0" paradigm was recently proposed, underlining the need for a "human-centric" approach within the industries, shifting focus to the well-being of operators by utilizing enabling technologies, such as exoskeletons [1-3]. Exoskeletons are the most studied solutions to limit the occurrence of disorders or diseases affecting the musculoskeletal system in work environments [4]. However, these technologies have not yet been thoroughly analyzed regarding their impact on cognitive load and motor control during working tasks. This preliminary study aims to develop an integrated system for the evaluation of the effects induced using exoskeletons on cognitive load.

Methods

A single healthy participant performed a motor-cognitive dual-task. The motor task consisted of box lifting and was completed without assistance and then repeated (Fig1.a) while wearing a hybrid upper-limb exoskeleton (LBE30, Wearable robotics). Considering the cognitive task, the subject performed a free-hand task administered with a mixed reality headset (Hololens 2, Microsoft) and relied on its eye-tracking as an assessment tool. In particular, the subject should reach a series of selected targets with the gaze (Fig1.b). The cognitive assessment was performed under three different conditions: (1) static condition, (2) while performing the manual handling motor task, and (3) while performing the motor task but with the exoskeleton. Accuracy data and reaction times were collected for the cognitive task, while the motor performance was assessed with wearable inertial measurement units (MVN Awinda, Xsens, The Netherlands) and surface EMG systems (Cometa MiniWave, Italy).

Results

The accuracy of the hit target for the three conditions was 93.7%, 77.8%, and 75%, while the average reaction time was 0.67s, 0.69s, and 0.75s. These results indicate that the accuracy decreased and time increased when performing motor tasks while using the exoskeleton. Fig. 1c depicts the right shoulder flexion-extension angle in a specific time window for the free-body acquisition and the task with the exoskeleton. The dashed green vertical lines indicate the occurrence of the fixation cross, and the dashed magenta vertical lines indicate when the targets appear. The figure highlights how the presence of the exoskeleton modifies the shoulder flexion pattern.

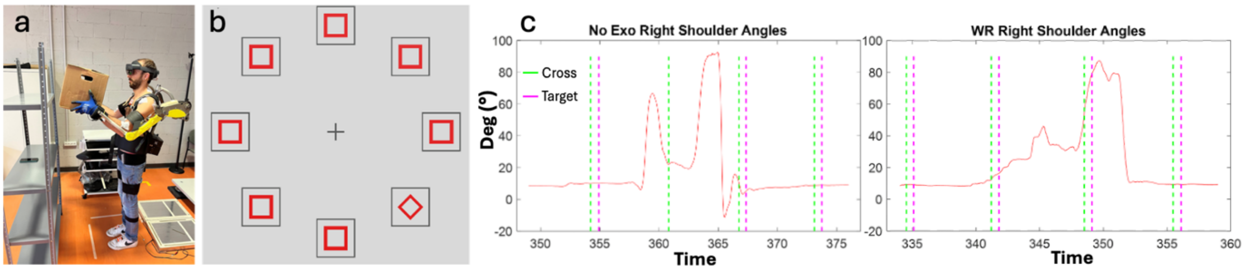

Figure 1. a. Motor task executed with exoskeleton; **b.** The holographic panel observed by the user; **c.** Shoulder flexion-extension angles during task without (left) and with exoskeleton (right) at a specific time window. The dashed green vertical lines indicate the appearance of the fixation cross, and the magenta ones are the targets.

Discussion

The present study aimed to present a technological approach for the evaluation of the effects induced by the use of exoskeletons on cognitive load, and its possible interaction with motor skills. From the main findings obtained in this preliminary study, emerged that the use of the exoskeleton affects cognitive effort, at least in a short-term period.

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Enhancing Injury Prevention and Performance Monitoring in Athletes through EMG Analysis

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Introduction

Hamstring injuries are a prevalent issue in sports requiring repetitive high-speed sprints such as soccer, rugby, athletics, and basketball. These injuries constitute approximately 30% of all sports-related injuries and lead to extended recovery periods, significantly impacting athletes' performance and incurring high costs [1,2]. In professional sports, the cost of treating hamstring injuries can reach millions of dollars annually due to lost playing time and rehabilitation expenses [2]. The Kin.ai project addresses these challenges by advancing muscle injury prevention and decision support systems for athletic training.

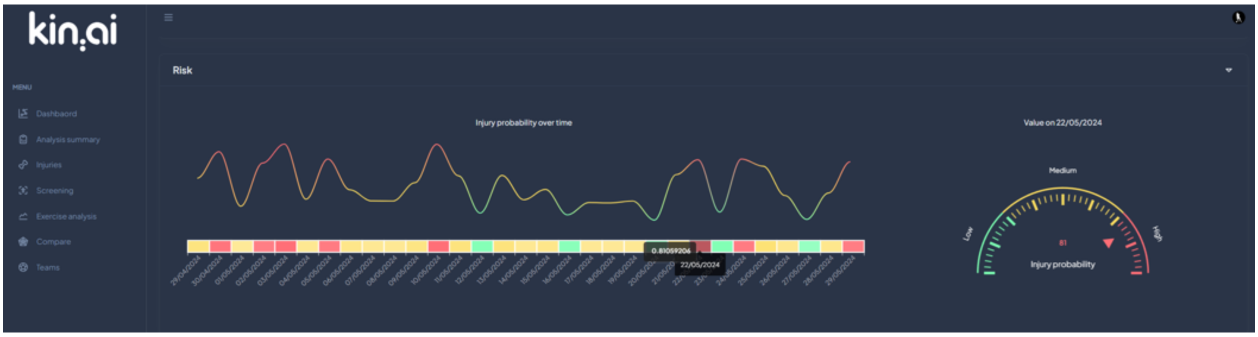
Methods

The Kin.ai project employed surface electromyography (EMG) to monitor muscle activation patterns, fatigue, and performance in professional athletes [3,4]. EMG data were collected using high-resolution, reliable signal acquisition devices during both static exercises (e.g., leg curls) and dynamic exercises (e.g., running on a treadmill and 40-meter sprints). The data were analyzed to identify activation onset, fatigue levels, and overall muscle performance. These metrics were then integrated into a comprehensive index to evaluate the athletes' overall muscle health.

Results

Preliminary experiments indicated that surface EMG effectively captures muscle activation patterns, identifies fatigue levels, and assesses overall muscle performance. In some cases, significant differences in activation delays between the long and short heads of the biceps femoris were observed [3]. Also, athletes with known injuries exhibited marked asynchronous activation and higher fatigue indices, correlating with their injury status [3]. The Root Mean Square (RMS) of the EMG signal served as an indicator of muscle performance and fatigue, validating its effectiveness in assessing muscle condition. These metrics were combined into an Injury Probability Index (see Figure 1), providing a quantifiable measure of the athletes' muscle health and potential injury risks.

Figure 13. Visualization of Injury Probability Index over time.



Discussion

The findings suggest that surface EMG is a promising tool for real-time monitoring and injury prevention in athletes. The observed correlations between EMG patterns, fatigue levels, muscle performance, and injury status support the development of personalized training plans and early warning systems for potential injuries. The comprehensive index developed from these metrics can be used to monitor the recovery of physical fitness and provide early warnings of potential issues. Future work will involve refining the experimental protocols, expanding data collection, and incorporating advanced artificial intelligence algorithms to enhance predictive capabilities. The project envisions a comprehensive screening protocol to evaluate athletes' physical conditions, compute a probabilistic injury index, and ultimately contribute to safer and more effective athletic training regimens.

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Does muscle fiber recruitment strategy in children with Fragile x syndrome differ from typically developing children during gait?

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Introduction

Fragile X syndrome (FXS) is a genetic disorder determined by a dysfunction of the FMRP binding protein, essential to a correct development of the nervous system [1]. There are two main categories of FMR1 mutations, premutation and full mutation (FXSFull), that are associated with different clinical phenotypes, and somatic mosaicism (FXSMos) can represent a strong FXS phenotype modulator [1]. The typical musculoskeletal manifestations justify a referral for gait analysis. Differences in muscle activity at the level of the lower limb in FXS children, when compared with controls, both in terms of timing (i.e. on-off, duration) and intensity (i.e. envelope) have been recently highlighted [3]. The aim of this was to investigate if a relationship exists between the observed alterations and the motor fiber recruitment strategy in FXS children during gait.

Methods

35 FXSFull children (BMI (Kg/m^2) 18.9±6.6; age (years) 10.2±3.6), 20 FXSMos (BMI (kg/m^2) 17.15±6.6; age (years) 9.6±3) and 15 typically neuro developed children (HS=healthy subjects), (BMI (kg/m^2) 19±3; age (years) 9.4±2.3) were enrolled. Several gait trials were acquired at self-selected speed through four synchronized cameras (GoPro Hero7, 30fps) and a surface electromyography (sEMG) system (Cometa, 2000 Hz); 3 left and 3 right trials were processed per subject. The sEMG activity of gastrocnemius lateralis, tibialis anterior, rectus and biceps femoris were acquired and the envelope peak, its occurrence within the gait cycle, on-off and duration of the activity were extracted [3]. The continuous wavelet transform (CWT) was computed with the 'bump' mother wavelet, and the percentage distribution of signal energy in 9 frequency bands of 50 Hz, considering a spectrum of 450 Hz - 10 Hz, as well as the instantaneous mean frequency (IMNF) time-frequency distribution were extracted [4,5].

Results

These results showed that both FXSFull and FXSMos present a different fiber recruitment strategy with respect to HS together with higher value of IMNF ($p<0.05$); in general, they showed higher percentage values of the total energy ($p<0.05$) with the only exception of the frequencies associated with the slow twitch fibers (50-10 Hz).

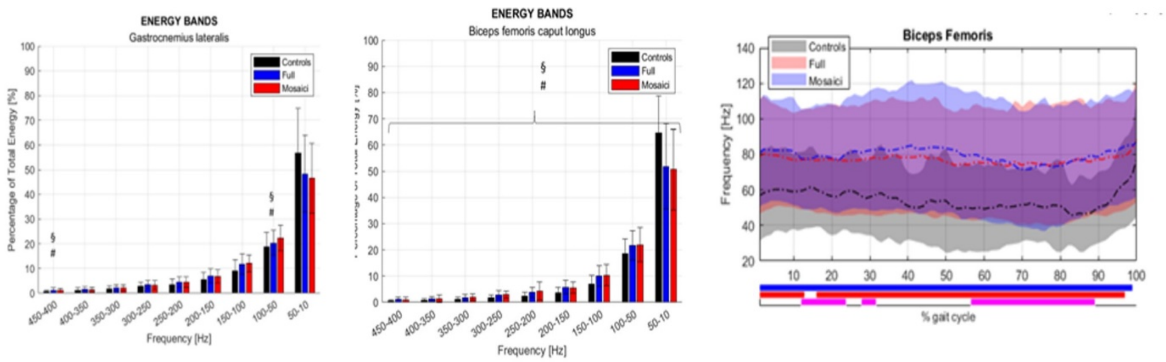

Figure 1. On the top Energy bands of Gastrocnemius Lateralis (left) and Biceps Femoris (right) and on the bottom Frequency (Hz) time series for Biceps Femoris

Discussion

These results could explain the easy fatigability observed in these children and their low participation in sports programs. For future development, these observations need to be confirmed by biopsy analysis, or metabolic tests.

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Effects of a wearable device (Q-walk) for gait retraining in Parkinson's disease

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Introduction

Parkinson's Disease (PD) is one of the most widespread neurodegenerative diseases characterized by different severity of motor disturbances [1]; gait and postural alterations are highly disabling and severely affect the quality of life of people with PD [2]. Nevertheless, these individuals do not practice sufficient physical activity [3], therefore several programs for promoting at home physical activities has become popular. The aim of this study was to test the feasibility and effectiveness of the use of a wearable device (Q-Walk QW) for gait retraining on restoring the gait of PD subjects.

Methods

16 PD individuals (BMI(Kg/m^2) 25.64±4; Age (Years):73.20±7.22) were enrolled. The protocol has been approved by the local Ethic Committee. PD individuals were randomized into two groups: G1 (Q-Walk active) and G2 (Q-Walk inactive device). As the randomisation has not been disclosed yet in the current study PD subjects will be considered altogether. Gait analysis was performed before (T0) and after (T1) 4 weeks of home-daily use of QW. Several gait cycles were collected with an 8-camera optoelectronic system (120Hz, Vicon, USA), synchronized with two force plates (960Hz, AMTI, USA) at Villa Margherita Fresco Center. The protocol described in [3] was adopted. For each subject, three left and three right gait cycles were analyzed and joint angles, moments, ground reaction forces and spatiotemporal parameters were extracted; 6 Minute walking test was also performed. The data of thirteen control healthy subjects (CS) (age=57.8±5.6years, BMI=27.3±3.9kg/m2) were used as normative bands. Statistical analysis was performed with parametric or not parametric test where appropriate ($p<0.05$) with 1D-statistical parametric mapping (SPM1d) [4].

Results

Both clinical and physical performance outcomes showed an improvement in T1 with respect to T0 (UPRS III (before QW 35.7 ±15.6; after QW 30.5±15); 6 min/walk (before QW 273.60 m±99; after QW 332.6±137). In terms of spatiotemporal parameters, subjects in T1 showed a statistically significant ($p<0.05$) increase of velocity, cadence and swing time as well as a reduction of the stance time. In terms of kinematics variables in T1 knee flexion-extension angle, trunk internal-external angle were closer to CS; this result was confirmed by the, ground reaction forces in the medio-lateral direction during midstance, knee flexion-extension moment and ankle inversion-eversion moment (p<0,05).

Discussion

These preliminary results suggest that Q-walk can be used to improve the gait of PD individuals. A larger sample subjects as well as the analysis of the results in light of the 2 groups (active vs non active) is needed in order to confirm this improvement.

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IMU-based ambulatory pre-surgical assessment of Spinal Decompressive Surgery

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Introduction

Lumbar spinal stenosis (LSS) is a common cause for chronic pain and disability, dramatically reducing quality of life. Treatment begins with conservative options, but often requires surgical treatment. Low-quality evidence is available on clinical outcomes related to treatment [1].

Given the significant clinical and economic implications associated with LSS treatment [2], methods for the quantification of functional impairment are necessary to evaluate the effectiveness of treatment options in addition to radiological and clinical assessment [1]. The aim of the present work is to present an IMU-based protocol for ambulatory assessment of the pre-surgical functional alteration of a population of LSS patients.

Methods

Thirty-eight patients (62.2±14.8 years, 1.71±0.11 m, 83.5±16.7 Kg) with a clinical and radiological diagnosis of symptomatic degenerative LSS, for whom surgical decompression was prescribed, were recruited. At hospital admission, the functional performance of patients was assessed by a physical therapist using 3 triaxial IMUs (MetamotionR, mBientLab, USA, sampling frequency and full range scale specific per task) during: Active spine mobilisation; Posture with eye open (EO) and closed (EC); Gait in normal walking (NW) and tandem (TW); 2-minute walking test (2MWT); sit to stand to sit (STS). Spine inter-segmental relative range of motion on the 3 anatomical planes was quantified from active mobilisation [3], postural parameters in the time and frequency domain [4] for EO and EC posture, temporal parameters and their variability, harmonic ratio, recurrence quantification analysis, and multi-scale entropy for NW and TW, mean velocity for 2MWT, and timing for STS. Results from LSS patients were compared to those of a reference population of healthy adults using Wilcoxon test with a level of significance of 0.05.

Results

LSS patients exhibited significant ROM reduction, decreased mean velocity, and alteration of STS timing, as well as an alteration of postural and control parameters as reported in Figure.

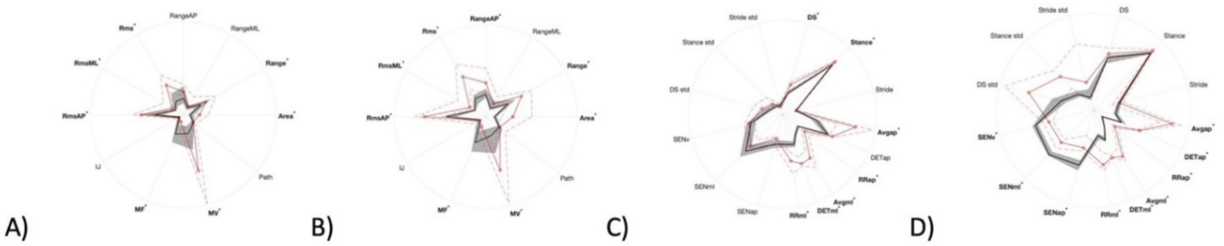

Figure 1. Polar plot of median values (solid red line for LSS, solid black for healthy subjects) and 25th-75th percentile range (dashed red for LSS patients, gray band for healthy subjects) of postura metrics for posture EO (**A**) and EC (**B**), NW (**C**), and TW (**D**).

Discussion

The proposed ambulatory protocol allowed to quantify, by means of a 15-minute set of tests, significant coherent functional alterations in LSS patients: reduced ROM, increased sway area, range, RMS, mean frequency, and velocity in EO and EC posture; increased stride duration and recurrence parameters in NW; reduced entropy and increased recurrence in TW. These alterations quantify the reduced fast postural control, as well as a reduction of complexity in motor control. The post-intervention re-assessment will allow to quantitatively characterise functional recovery in the follow-up.

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From development to deployment: introducing MobGap, the open-source tool for mobility assessment with wearable devices by Mobilise-D

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Introduction

Mobilise-D is the largest project on digital mobility assessment [1]. One of its goals is to provide an analytical pipeline for extracting clinically relevant digital mobility outcomes (DMOs), such as real-world walking speed. To this end, the Mobilise-D consortium has developed and validated a set of algorithms in Python and Matlab (The Mathworks, Inc.) for the quantification of DMOs using a lower-back-mounted wearable device [2,3]. To bridge the gap between development of mobility assessment tools and their deployment to users, Mobilise-D has recently released the alpha version of MobGap [4], the open-source full-Python implementation of the Mobilise-D algorithms. This study provides a preliminary overview of the agreement between the MATLAB and Python implementations, by comparing their outputs in gait sequence detection and initial contacts detection.

Methods

Comparison was done with the example data available in MogGap, including data from one healthy adult and one multiple sclerosis patient. Each subject's data included acceleration and angular velocity from two short walking trials (≈10 s) and one longer trial (≈3 min) recorded with McRoberts Dynaport MM+ (fs: 100 Hz). Data were processed with both implementations to detect gait sequences [5] and initial contacts [6]. Finally, gait sequences and initial contacts estimated by the Python implementation were matched to those estimated by the MATLAB implementation, considered as the reference (Figure 1). Agreement was evaluated in terms of F1-score, precision, and recall.

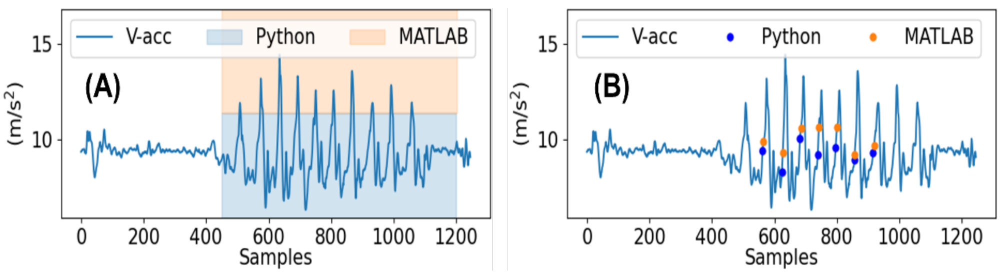

Figure 1. Gait sequence (**A**) and initial contacts (**B**) estimated by the two implementations for a short walking trial of the healthy subject. V-acc: vertical acceleration.

Results

In total, 21 gait sequences and 172 initial contacts were analyzed. On average, F1-score, precision, and recall were 86.0%, 79.7%, 94.1% for gait sequence samples, and 99.1%, 98.8%, 99.4% for initial contacts, respectively.

Discussion

Based on this preliminary analysis, results obtained with the Python implementation strongly agreed with those from the MATLAB implementation, although the new implementation resulted in some missed gait sequence samples with respect to the original one. Future work will include re-validating the new implementation on the larger dataset used for the Mobilise-D technical validation study [2,3]. Moving from a licensed software (MATLAB) to an open-source package improves access to the developed mobility analysis tools, allowing researchers, industrial partners, and users worldwide to contribute to and benefit from the project's advancements. MobGap's ability to bring real-world gait detection to a broader audience is crucial for providing equitable and personalized care. By accurately reflecting patients' true mobility capabilities in their daily environments, MobGap can enhance clinical assessments and interventions, ensuring advanced mobility analysis is accessible to all healthcare providers.

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Real-world gait detection with a head-worn inertial unit and features-based machine learning

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Introduction

Detecting gait in real-world conditions is challenging but crucial to assessing digital mobility outcomes [1]. A head-worn Inertial Measurement Unit (H-IMU) offers potential benefits due to its integration with commercial devices (e.g., glasses, hearing aids) [2], yet it has not been validated in real-world settings. This study investigates shallow machine learning for real-world gait sequence detection using features from a single H-IMU.

Methods

Fifteen young participants (7 females, 26±3 years old) underwent indoor trials at three self-selected speeds, and a 2.5-hour real-world acquisition. Each participant wore an H-IMU on the left side of the head (fs: 100 Hz), alongside the INDIP system [3] as a reference. Acceleration and angular velocity data were segmented into 50% overlapped 2-s windows, yielding 203 time-based and frequency-based features per window, labelled using the INDIP [4]. Correlation-based feature selection [5] was employed to reduce dataset dimensionality. Five machine learning classifiers were trained to assess the predictive power of the selected features for gait sequence detection: Multilayer Perceptron (MLP), Random Forest, k-Nearest Neighbors (KNN), Support Vector Classifier (SVC), and Logistic Regression. Models were trained with data of ten participants and tested with the remaining five. Classification performance was evaluated using F1-score, recall, and precision.

Results

Selected features derived from acceleration components (anteroposterior root mean square (RMS) to norm RMS ratio; sum of wavelet coefficients of vertical; skewness of mediolateral; anteroposterior RMS; maximum of mediolateral; sum of squared high-frequency spectral coefficients of mediolateral, and low-frequency coefficients of vertical), acceleration norm (entropy, variance, skewness, RMS, 2nd dominant frequency, peak spectral coefficient), and angular velocity norm (RMS, maximum). Table 1 shows the classification performance achieved by each model on the test set.

Table 1. Classification performance of the trained models on the test set.

(%)	MLP	Random forest	KNN	SVC	Logistic
F1-score	92.2	91.2	89.3	88.4	88.0
Recall	91.5	88.9	89.4	84.8	84.6
Precision	92.9	93.6	89.2	92.2	91.8

Discussion

The most relevant features were those derived from acceleration, which is crucial as it could reduce battery consumption by minimizing reliance on other on-board sensors (e.g., gyroscope). Among those, the number of frequency-based features (6) was equal to that of time-based features (6), highlighting the importance of both domains for walking recognition. High classification performance across models (F1-score > 88.0%) indicates the significant discriminative potential of selected features for real-world gait detection. To the authors' knowledge, this is the first study that investigates the use of a H-IMU for real-world gait detection. Our findings provide insights on the use of H-IMU to extract domain-specific features for gait sequence detection, suggesting its potential to enhance the development of robust algorithms for real-world gait assessment.

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Approximate bayesian computation and intermittent control model of balance maintenance: an attempt to "open the box" of neuromuscular control strategy in diabetic subjects with and without neuropathy

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Introduction

The intermittent control paradigm represents a well-established physical description of the active role that central nervous system (CNS) plays in balance maintenance [1]. Indeed, the inherently unstable nature of stance mechanics, modeled with an inverted pendulum, requires an active modulation played by CNS to counteract the gravitational toppling torque in an energetically efficient way [1-3]. Thus, the model presented in [1] serves as a useful simulator for the center of mass (COM) time course in the anterior-posterior direction, suggesting the possibility to combine data and model to infer controller parameters with physiological significance. Approximate Bayesian Computation (ABC) approaches appeared to be the only feasible methods for obtaining posterior probability density functions of each parameter of the model [2,3]. In the present study, a Sequential Monte Carlo ABC (SMC-ABC) approach was used to investigate potential changes in control strategies under the intermittent paradigm among diabetic patients with and without neuropathy [4].

Methods

The COM of 15 neuropathic (N) and 15 non-neuropathic (NN) subjects were estimated from their center of pressure timeseries resulting in signals of 60 seconds sampled at 100 Hz [2,4]. Then, summary statistics vectors were extracted for each subject as described in [2]. The SMC-ABC inference procedure was used with the intermittent control model proposed in [1,3] to obtain posterior distribution of the model parameters for each subject. A SMC-ABC approach with a total of 5000 particles sampled the parameter hyperspace for a total of 10 runs [2]. Weighted medians of the posterior distributions were considered as the estimated parameters. Comparison between groups was performed through Wilcoxon rank-sum test with significance set at 0.05.

Results

Table 1 shows average inferred parameters for the two groups. Significant differences were obtained in time delay Δ and in the variance of postural noise σ.

Table 1.

Group	P [Nm/rad]	D [Nm s/rad]	Δ [s]	ρ	σ [N m]
N	275.02±15.37	111.06±15.53	**0.35+0.02***	0.63±0.01	**2.51±0.04***
NN	271.67±19.21	117.61±20.54	**0.32±0.03***	0.66±0.10	**2.46±0.06***

Discussion

Differently to healthy subjects, both diabetic groups showed a higher delay, i.e. $\Delta>0.2$ [1]. Notably, the N group's higher delay suggests neuropathy affecting nerve conduction [4,5]. Additionally, the N group exhibited increased postural noise likely due to deteriorated foot sole receptors [5]. Interestingly, derivative (D) coefficient and the intermittent ratio (ρ) remained comparable to healthy subjects [1], while proportional (P) coefficient assumes only relatively larger values [1]. This implies diabetes may affect the feedback loop, not the control policy itself. Future studies with different center of mass (COM) summary statistics might be beneficial for enhancing present results [3].

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Does cortical activation pattern during treadmill walking change with a head stabilization task? An observational cross-sectional study in healthy subjects

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Introduction

To date, studies only investigated changes in cortical activity before and after rehabilitation [1]. To study mechanisms of action during a task-oriented rehabilitation session the functional Near Infrared Spectroscopy (fNIRS) combined with Inertial Measurement Units (IMU) can be used [2,3]. This study aims at assessing brain cortical activity and head stability during a task-oriented exercise in real-time such as walking on a treadmill by modulating task difficulty and the presence of biofeedback in healthy subjects.

Methods

So far, ten healthy subjects (5 females, 32.2±11.4 years) were asked to walk on a treadmill at 3 km/h under 4 different task conditions (block design, 40s task and 40s standing): (1) walking, (2) walking with laser, (3) walking with laser (easy-task), and (4) walking with laser (difficult-task). The laser was used as biofeedback and was mounted on a pair of eyeglasses worn by the subjects, with the laser projecting head movements onto the wall in front of the subject. Both the easy and the difficult tasks required the participants to hold the laser between two horizontal bars that were placed on the wall; the task difficulty was modulated by decreasing the distance between the two bars. Cortical activation, in terms of HbO concentration, was assessed with fNIRS (Artinis Brite MKII) with 22 standard (inter-optode distance: 3 cm) and 2 short channels (8 mm) covering the frontal cortex. The fNIRS had an integrated IMU to assess head movements. After fNIRS signal pre-processing and artefact removal, the average change in HbO concentration was used to identify active channels.

Results

Five channels, located in right and left Brodmann Area (BA)46, right and left BA9 and left BA44, were statistically significantly active during the tasks($p<0.05$). In these channels the cortical activation was modulated by the tasks, specifically the HbO concentration during the walking condition was lower than in the other conditions. Similarly, the head stability was modulated by the conditions. The head sway in the walking condition was different when compared to the easy and difficult task. ($p<0.05$). The average sway in the sagittal plane was 1.69±0.79° during walking, 1.28±0.63° during laser, 0.78±0.24° during easy-task, and 0.69±0.21° during difficult-task.

Discussion

Both cortical activity and head stability were modulated by the presence of the biofeedback. Unexpectedly, task difficulty did not modulate either cortical activation or head stability. However, these results should be confirmed on a wider sample of healthy subjects, and then the experimental setting could be tested on people with Multiple Sclerosis [4].

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Optimized Gait Classification in Hereditary Cerebellar Ataxia via AI-Driven Data Balancing Methods

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Introduction

The interpretability of gait analysis studies in people with rare diseases, such as those with primary hereditary cerebellar ataxia (pwCA), is frequently limited by the small sample sizes and unbalanced datasets [1]. The purpose of this study was to assess the effectiveness of data balancing and generative artificial intelligence (AI) algorithms in generating synthetic data reflecting the actual gait abnormalities of pwCA.

Methods

Gait data of 30 pwCA (age: 51.6 ± 12.2 years; 13 females, 17 males) and 100 healthy subjects (age: 57.1± 10.4; 60 females, 40 males) were collected at the lumbar level with an inertial measurement unit. Subsampling, Oversampling, Synthetic Minority Oversampling, Generative Adversarial Network, and Conditional Tabular Generative Adversarial Network (ctGAN) were applied to generate datasets to be trained and tested according to input to a random forest classifier-based machine learning model [2]. Consistency and explainability metrics were also calculated to assess the coherence of the generated dataset with known gait abnormalities of pwCA. In particular, the use of Kolmogorov-Smirnov analysis and methods such as SHAP can improve the clarity and interpretability of metrics generated by machine learning applications, enabling clinicians to better understand the classification process and translate the results into clinical decisions.

Results e Discussion

The results revealed that ctGANs was an effective method for balancing tabular datasets from rare disease populations due to their ability to improve diagnostic models with consistent explainability. Specifically, by augmenting an a priori computed size of 200 samples, ctGAN significantly improved the classification performance of the machine learning model, increasing accuracy, precision, recall, and F1 score, compared with the original dataset and traditional data balancing strategies as shown in table 1. The superior performance of ctGANs can be attributed to their ability to generate more realistic synthetic data, as they incorporate conditional constraints that better capture the distribution of the underlying data. The ctGAN generated dataset reflected the characteristics of the original samples, just as the impact of the variables in the classification model reflected the evidence from the literature on gait analysis based on trunk acceleration in pwCA, with pelvic rotation, Harmonic Ratio Antero-Posterior, and CV stride length showing the greatest importance in discriminating between pwCA and HS [3].

Through this research, we aim to pave the way for more effective diagnostic tools and interventions for pwCA individuals. Future research should investigate the use of ctGANs in other rare disorders, as well as long-term clinical outcomes, to validate these preliminary findings.

Table 1. Overall classification performance.

Method	Accuracy	Recall	F1-Score	Log loss	ROC AUC
Unbalanced	*0.79 (0.2)*	*0.79 (0.1)*	*0.75 (0.3)*	*0.42 (0.3)*	*0.87 (0.2)*
Under Sampling	*0.77 (0.4)*	*0.77 (0.3)*	*0.78 (0.2)*	*0.49 (0.3)*	*0.89 (0.1)*
Over Sampling	*0.83 (0.3)*	*0.82 (0.4)*	*0.83 (0.4)*	*0.38 (0.2)*	*0.89 (0.2)*
SMOTE N=200	*0.80 (0.1)*	*0.80 (0.2)*	*0.79 (0.1)*	*0.40 (0.1)*	*0.87 (0.2)*
SMOTE N=1000	*0.75 (0.2)*	*0.74 (0.1)*	*0.75 (0.2)*	*0.42 (0.2)*	*0.86 (0.1)*
GAN N=200	*0.83 (0.1)*	*0.83 (0.2)*	*0.79 (0.1)*	*0.42 (0.2)*	*0.83 (0.4)*
GAN N=1000	*0.82 (0.2)*	*0.83 (0.1)*	*0.81 (0.3)*	*0.44 (0.1)*	*0.86 (0.2)*
ctGAN N=200	*0.90 (0.1)*	*0.88 (0.2)*	*0.88 (0.2)*	*0.35 (0.1)*	*0.90 (0.1)*
ctGAN N=1000	*0.81 (0.3)*	*0.80 (0.1)*	*0.79 (0.1)*	*0.40 (0.2)*	*0.85 (0.2)*

SMOTE, synthetic minority oversampling technique; GAN, generative adversarial network; ctGAN, conditional tabular generative adversarial network; N, sample size after balancing strategy implementation.

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Automated video-based General Movements analysis: sensitivity analysis of metrics in a population of very preterm infants

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Introduction

General Movement Assessment (GMA) is a non-invasive method for early detection of infants' neuro-developmental disorders, based on observation and scoring of spontaneous motions [1]. GMA widespread use is limited by the need for licensed evaluators, degree of subjectivity in the assessment, and time requirement [2]. Several preliminary methods have been proposed to implement automated, video-based GMA, exploiting body segment tracking, different evaluation metrics, and motion classification [3]. Still, the lack of standardization in measurement and processing protocols and of reliability assessment prevents clinical applicability. The work aims at comparing reliability of the different metrics proposed and analyzing their sensitivity to acquisition and preprocessing specifications (i.e. frame-rate, track interpolation, filtering) in a population of very preterm infants.

Methods

Clinical staff recorded GM videos (GoPro Hero 9, 240fps, 1920x1080p) from 33 very preterm infants (gestational age <32 weeks and/or weight at birth <1500g) at 40 weeks and 3 months of corrected age. Anatomical landmark trajectories were extracted using DeepLabCut (14-point model, 20 training-frames per video, k-means) and processed in MATLAB. Intervals where the infant was on the side and/or limbs were out of the image plane or hidden were automatically excluded. 15 metrics for GMA (Table 1), identified from literature review, were implemented and calculated on raw data, linear interpolation over 120, 240, and 1200 frames, down-sampling at 30 and 60 Hz, and with filtering at 5 and 10 Hz. Percentage variation of each metric relative to raw data was calculated.

Results

Unlabelled frames per video averaged 17.89% (median=14.00%, IQR=15.53%). Missing frames were 7.15% (median=0.96%, IQR=4.07%) due to infants being on their side, 0.31% (median=0.00%, IQR=0.14%) to body parts out of frame, and 1.06% (median=0.61%, IQR=0.81%) to hidden body parts. Mean of COM coordinates (x and y) exhibited the lowest variation among the protocol factors analysed. All other metrics showed mean or IQR percentage variations greater than 10% for at least one of the factors. Specifically, Lateral Mobility Index, Area Out of Standard Deviation, and Periodicity were the least reliable, being highly dependent on interpolation, down-sampling, and filtering procedures. The results for each metric are detailed in Table 1.

Table 1. Extracted metrics and relative median and IQR percentage variation (%) with Interpolation, Down-sampling and Filtering

Extracted metrics	Interpolation		Down-sampling		Filtering	
	Median	IQR	Median	IQR	Median	IQR
Mean of centroid of motion (COM) x coordinate	0.23	1.05	0.09	0.47	0.24	1.28
Mean of COM y coordinate	-0.11	1.09	-0.07	0.68	-0.19	1.16
Standard deviation of COM velocity	-1.90	5.44	47.08	99.19	-75.31	16.54
Mean of COM velocity	-5.81	6.47	-13.04	48.41	-88.29	5.28
Minimum of COM velocity	0.00	0.00	-1.30	41.33	-46.85	33.07
Standard deviation of COM acceleration	0.08	6.75	43.03	101.71	-83.93	12.42
Lateral mobility index	-96.89	209.95	-78.47	184.06	-103.33	291.75
Mean hull area percentage	-1.82	3.18	-3.93	13.63	-13.26	18.05
Mean orientation	-1.17	16.64	-1.97	14.22	-1.50	21.58
Area out of standard deviation	-85.06	13.41	10.10	101.39	-85.28	12.08
Periodicity	-80.95	20.38	-44.37	61.15	-84.83	13.80
Correlation coefficient	-3.83	39.97	0.09	33.53	-2.86	44.08
Mean of power spectral density	0.00	122.93	-62.50	65.16	95.82	226.72
Standard deviation of power spectral density	24.83	129.07	-68.27	61.02	95.65	247.89

Discussion

Results highlight the need for a better definition of acquisition and processing protocols to ensure metrics' reliability, which is fundamental for subsequent motion classification. Once reliable metrics will be identified, future work will analyse the relationship between proposed metrics and clinical evaluation of a larger group of enrolled infants.

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One step towards gait-based Parkinson's disease classification

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Introduction

The diagnosis of Parkinson's disease (PD) is very challenging, as it is commonly based on signs and symptoms that often overlap with other neurodegenerative diseases (1). Therefore, there is a need to identify methods and characteristics that can support this diagnosis. Movement disorders are among the most evident manifestations of PD. During walking, various movement characteristics such as trajectories, speeds, and coordination can be observed. The latter has recently been studied through network theory, which, by measuring the synchronization between different elements (e.g., parts of the body) that make up a system (e.g., the body in motion), has allowed us to create very informative matrices that we have called kinectomes (2). Our hypothesis is that the level of information from these objects may be more effective than that offered by simple movement trajectories or spatiotemporal walking parameters when attempting to classify PD in comparison to healthy individuals. Therefore, we tested the classification performance achievable using support vector machines (SVM) by analyzing a single gait cycle with the aforementioned approaches.

Methods

We analyzed a single gait cycle in 23 patients with PD and 23 healthy controls matched for age, sex, education, and walking speed. We used a multiclass SVM model with 5-fold cross-validation to classify patients and controls. The analysis was conducted using three separate sets of features: the kinectomes, the three-dimensional trajectories of different body parts, and the spatiotemporal walking parameters. For the latter two parameters, principal component analysis was performed, and components up to explaining 95% of the original data were used as features. The analysis was repeated 100 times, randomizing the cross-validation each time.

Results

The kinectomes showed an accuracy of 79% (Figure 1) with 81% true negatives (TN) and 76% true positives (TP). The spatiotemporal parameters showed an accuracy of 49% with 32% true negatives (TN) and 65% true positives (TP). Finally, the trajectories showed an accuracy of 59% with 71% true negatives (TN) and 47% true positives (TP).

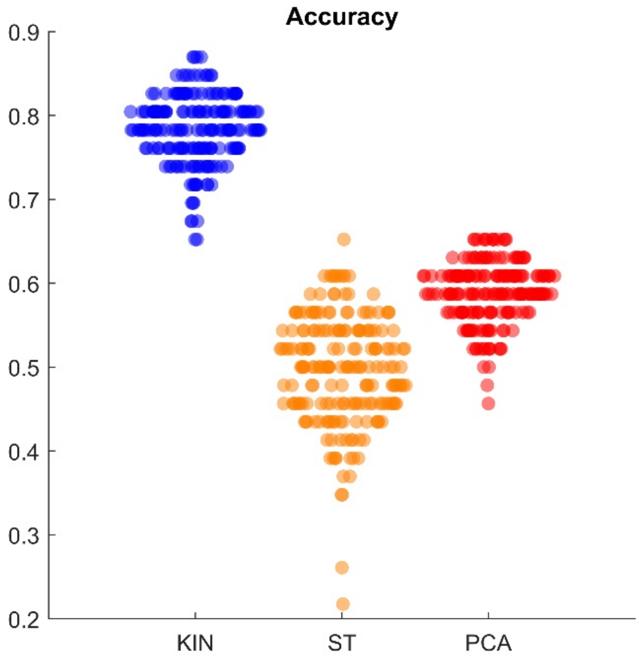

Figure 1. Swarm plot showing the accuracy of the cross-validated classification using kinectomes (KIN), spatiotemporal parameters (ST), and kinematic trajectories reduced with principal component analysis (PCA). Each dot represents a random split of the sample.

Discussion

Surprisingly, the spatiotemporal parameters, which are often successfully used in PD classification, showed the worst performance. The trajectories, which constitute the origin of the movement data, were slightly better, although the classification of PD did not reach useful percentages. The kinectomes, which contain more complex information on whole-body kinematic interactions, outperformed the other measures and emerge as an important candidate for future investigations.

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Muscle activation during Action Observation: experimental insights

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Introduction

It is known that during Action Observation (AO) specific motor-related brain areas are activated in the same way as during actual execution [1,2]. OA has been shown to enhance motor learning [3]. The central mechanisms of neuroplasticity related to AO are widely studied, whereas the involvement of muscles during AO has not been conclusively documented [4]. This study aims to investigate the presence of modification in basal EMG activity during the observation of a task involving fine control of the upper limb. Three machine learning models commonly used in myoelectric pattern recognition were employed to determine if muscular activity during AO differs from that observed during the resting state.

Methods

Eight healthy subjects were enrolled for the experiment. Surface EMG activity from the Opponens Pollicis, Flexor Carpi Radialis, and Biceps Brachialis of the dominant arm was recorded (sampling frequency of 1 kHz. Each participant sat with their dominant forearm resting on a tabletop and observed an operator while, for 5 times, grasped a tri-axial accelerometer, (sampling frequency: 100 Hz) and moved it to the homolateral shoulder, with a rotation and a bending of the forearm on the arm. EMG activity was recorded by the same muscles in a relaxed posture for 25 seconds (REST condition) without any visual stimulus. Three trials were conducted for each subject in AO and REST condition respectively. The EMG signals were band-pass filtered (20-500Hz) and segmented based on accelerometer data. Feature extraction involving 90 and 30 features respectively in time and frequency domains was performed on the segmented data using a sliding window of 200ms with 50ms of overlap [5]. Relief-based feature reduction was performed to select non-redundant features, then data were randomly split 80%-20% for training-validation and testing. In the training-validation step, a 5-fold cross validation approach was implemented over the first percentage of data to train KNN, SVM and LDA models. The are used in testing to distinguish between AO and REST.

Results

The feature reduction algorithm identified a subset of 29 relevant features (20 in the time domain and 9 in the frequency domain). This subset has been used to fed the three models and in table 1, the accuracy, the specificity, and the F1 score obtained in testing for all the classifiers are reported. The KNN model exhibited the best performance.

Table 1. Metrics obtained during testing for each model (AO versus REST comparison).

	KNN	LDA	SVM
Accuracy (%)	90.0	64.1	65.2
Precision (%)	89.4	64.6	65.6
F1 score (%)	90.0	65.5	66.6

Discussion

The results of this study confirm that the electromyographic activity during an action observation task differs from that observed during a resting state. Notably, a select set of features derived from the portions of the EMG signals, temporally aligned with the intervals when the observed action is executed, retains discriminative information between the resting state and action observation.

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Upper limb joint kinematics resulting from a model conceived for the analysis of SHAP motor tasks performed by trans-radial amputees: discrepancies with the Vicon upper limb model joint kinematics

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Introduction

Trans-radial amputees often rely on compensatory movements for their daily activities. Numerous studies have explored upper limb kinematics using optoelectronic systems and biomechanical models to evaluate these compensations [1]. This study aims to develop a novel upper limb kinematic model (adapted from [2]) suitable for trans-radial myoelectric prosthesis users. As a preliminary investigation, this model was compared with an existing commercial upper extremity model in a healthy population. The proposed model is not intended to describe forearm prono-supination, which will require further investigation.

Methods

Eight healthy individuals (3 females; age: 39±11 years) performed three repetitions of four manual tasks extracted from the South Hampton Assessment Procedure (SHAP): lifting a light object, carton pouring, lateral grip, supine extension grip. A 10-camera optoelectronic system (Vicon, UK) was used to reconstruct the proposed unilateral upper extremity 4-segment model using a 20-marker set: on the thorax (4), shoulder (3), arm (6), forearm (5), and hand (2). Arm and forearm segments included 2 calibration markers each. To estimate shoulder joint kinematics, the glenohumeral joint center is determined using a functional method (SCoRE) [3]. Reference systems and kinematics definitions were based on the International Society of Biomechanics guidelines [4]. Comparisons between the upper limb joint kinematics obtained from the proposed biomechanical model and those from the Vicon Upper Limb model [5] were conducted. For both models, Range of Motion (ROM) for each joint degrees of freedom (DOF) was calculated during the reaching phase of each task, and the comparisons were performed using the Bland-Altman analysis.

Results

The two models showed very good agreement, with the absolute mean difference in ROMs being ≤2° across all DOFs and tasks, and the limits of agreement of up to ~5° (Table 1). The lowest level of agreement was found in the shoulder intra/extra-rotation during the lateral grip task, where limits of agreement ranged between -8° and 7°.

Table 1. ROM mean differences [95% Limits of Agreement] between the two models averaged across participants per each motor task.

	Shoulder Flex/Ext (°)	Shoulder Ab/Add (°)	Shoulder Intra/Extra (°)	Elbow Flex/Ext (°)	Wrist Flex/Ext (°)	Wrist Deviation (°)
Carton Pouring	-2 [-5, 1]	0 [-4, 5]	1 [-4, 5]	0 [-2, 3]	-1 [-4, 3]	0 [-5, 5]
Lift Object	-2 [-5, 2]	1 [-2, 4]	-1 [-6, 5]	0 [-3, 4]	-1 [-3, 2]	2 [0, 4]
Lateral Grip	-1 [-6, 3]	1 [-4, 6]	0 [-8, 7]	0 [-5, 5]	0 [-3, 3]	0 [-3, 3]
Sup. Extension	1 [-3, 4]	0 [-2, 3]	-1 [-3, 2]	-2 [-4, 1]	0 [-3, 4]	1 [-3, 5]

Discussion

The current findings show a high degree of similarity between the two upper limb models when comparing overall kinematic parameters such as ROM during manual tasks in healthy individuals. In the proposed model, marker calibration is performed to facilitate the application of the kinematic model to trans-radial amputees, addressing the challenges of placing markers on prosthetic parts that resemble anatomical landmarks, especially during dynamic tasks. Future developments will focus on acquiring kinematic data from amputees to refine the model.

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Enhancing Motion Analysis in Medical Diagnostics through Explainable Artificial Intelligence

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Introduction

Studying walking and gait dynamics can provide automatic, non-invasive insights into general health, cognitive decline, and longevity [1]. While Machine Learning (ML) techniques analyze gait and posture data for disease prediction, their results often appear as "black magic" to specialists. The EDAM (Explainable Diagnosis Recommender) system addresses this limitation by using Explainable Artificial Intelligence (XAI) to offer both predictive insights—such as predicting Parkinson's disease, classifying walking types, and estimating gait quality—and understandable explanations for specialists.

Methods

The EDAM system employs a multi-faceted methodology to generate explainable predictions, using SHapley Additive exPlanations (SHAP) for explainability [2]. SHAP values help understand each feature contribution to the model predictions. This approach handles complex models and provides local and global interpretability, suiting the diverse ML models in EDAM. The XAI module processes high-dimensional data, including Gait Energy Images (GEI) and Skeleton Energy Images (SEI), crucial for diagnosing Parkinson's disease and classifying walking patterns. EDAM also uses Natural Language Processing (NLP) to generate textual explanations, ensuring coherence and systematic structure.

Results

The SHAP-based XAI module in EDAM (see Figure 1) has yielded significant results. EDAM identifies key features impacting the predictions of various ML models, including deep neural networks and random forests. SHAP enables the identification of critical gait features that distinguish between Parkinsonian and non-Parkinsonian walking patterns. Locally, SHAP values highlight specific features contributing to individual predictions, such as deviations in specific gait parameters from normative data. EDAM uses advanced visualization techniques, such as image plots for analyzing GEI and SEI images, illustrating the areas influencing predictions the most. Additionally, force plots show each feature impact on the model prediction, with arrows indicating the direction and magnitude of each feature effect. Combining these plots with textual explanations is crucial for medical professionals to understand the system recommendations.

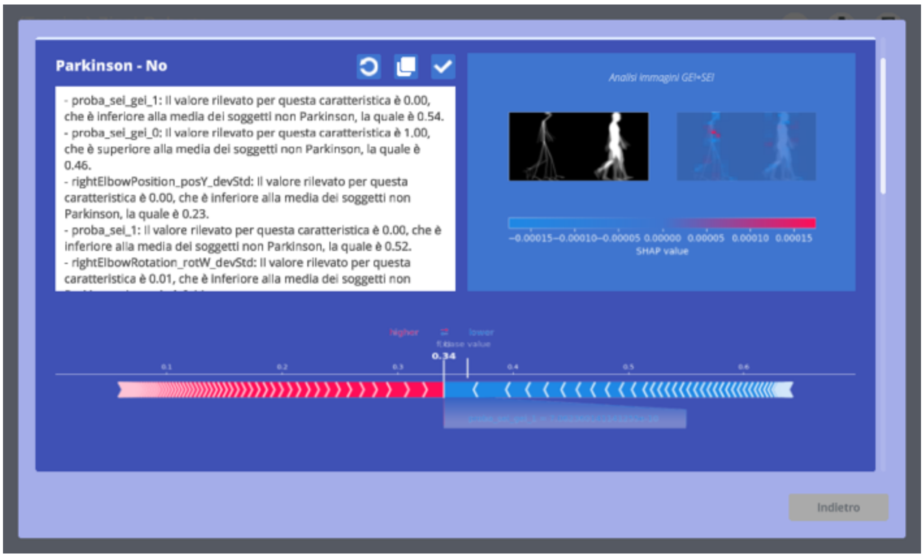

Figure 14. Example of an Explainable Prediction in EDAM.

Discussion

The XAI module of EDAM meets medical diagnostic needs by providing transparent and interpretable predictions. EDAM bridges the gap between complex ML models and clinical usability, enhancing the diagnostic process with comprehensive pre-reports that explain feature importance and compare normative values. This transparency aids in early detection and builds trust in AI-driven recommendations. Future work will expand the capabilities of the system to cover more conditions and improve the text generation process for higher-quality pre-reports.

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Comparison of knee joint kinematics between generic and sport-specific agility tests in youth basketball players

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Introduction

Basketball is a popular sport, characterized by short and rapid changes of direction (COD), such as dribbling movements. The majority of agility tests used in basketball players focused only on kinematic analysis of generic agility skills. However, these tests do not assess the kinematics during sport-specific movements, which are highly present during matches and training sessions. Thus, the aim of this study was to compare the COD kinematics between a generic and sport-specific agility test in basketball players under 13 years old.

Methods

A total of 21 basketball players (mean age 12.2 ± 0.3 years) were enrolled in this study. All players were tested on the same day after a proper 10-minute warm-up. Each player performed two agility tests: a V-cut dribbling test without a ball (generic agility test) and with a ball (sport-specific agility test). The tests consisted of a 25-meter sprint with 4 CODs of 45° every 5 meters. The kinematic data were collected using a set of 17 inertial sensors (Xsens MTw Awinda). The kinematic parameters analyzed were the minimum and maximum peaks, and the range of motion (ROM) of adduction-abduction (AA), flexion-extension (FE), and internal-external rotations (IE) of the knee joint. In the analysis, the term "pivot leg" refers to the leg responsible for pivoting, while "non-pivot leg" refers to the contralateral leg. All the kinematic variables were compared between the tests using a paired T-test. A p-value lower than 0.05 was considered statistically significant.

Results

The basketball players showed no differences in the knee ROM of each kinematic parameter of the pivot leg between the generic and sport-specific agility tests ($p>0.05$). The non-pivot leg showed the same results except for the flexion-extension ROM, which was higher in the agility test performed without the ball ($p<0.01$). In addition, during the COD, the non-pivot knee showed higher extension peaks in the agility tests without the ball ($p<0.05$).

Discussions

The findings of this study indicate that the presence of a ball during agility tests does not significantly affect the knee ROM of the pivot leg in young (under 13 years) basketball players. However, the non-pivot leg exhibits greater flexion-extension ROM and higher extension peaks when performing agility tests without the ball.

Softball players with shoulder injuries exhibit upper-body compensatory strategies compared to healthy controls: a wearable inertial sensors study

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Introduction

Softball is a sport gaining popularity in Europe and United States, with slow-pitch being more popular than fast-pitch softball [1]. Injuries related to throwing movement are common in softball players and mostly affect shoulder and elbow joints [2–4]. The aim of the study was to assess the kinematic differences in the upper limb and trunk during the throwing movement between healthy softball field players and those who had experienced a previous shoulder injury.

Methods

11 first-division softball players were enrolled in this study. Among them, 5 reported experiencing a shoulder injury that required surgery. The players completed 10 trials (throwing the ball to a target player positioned 10 meters away). The three with the highest spin velocity were retained for further analysis. Upper-body kinematics were assessed using a set of 11 wearable inertial sensors (Xsens MTw Awinda). For the analysis, the motor task was divided into 2 phases: Pickup, which starts from ball grabbing to reaching the throw position; Pass, which covers the motion from the hand far back to the completion of the throw.

The phases were extracted from the data and normalized using 3 points of interest (0% frame = beginning of the stance; 50% = frame of the stance; 100% frame = endpoint of the stance). For each phase, the peak angle kinematics defined as the maximum rotation value, the minimum rotation value, and the range of motion (ROM) for the shoulder, elbow, wrist, head, pelvis, and trunk joint were computed. However, only the data for the shoulder, elbow, and trunk were kept for the study.

Results

In the Pickup phase, the shoulder showed a higher internal-/external rotation ROM in healthy players than in injured ones ($p<0.001$). The same results were observed for the elbow flex-/extension ROM ($p<0.01$). Moreover, healthy players showed a higher tilt ROM of trunk than the injured ones ($p<0.01$). Similarly, during the Pass phase (Tab. 1), the shoulder internal/external rotation and flex-/extension ROMs of healthy players were wider than the injured ones ($p<0.001$).

Table 1. Joints ROM kinematic comparison between healthy and injured players during the pass phase

		Healthy	Injured	P-value
Trunk	Abd-Add	29.3 ± 6.7	24.0 ± 7.9	n.s.
	Flex-Ext	31.4 ± 9.7	28.1 ± 9.4	n.s.
	Ext-Int	39.1 ± 11.1	39.4 ± 6.2	n.s.
Shoulder	Abd-Add	79.2 ± 16.9	61.9 ± 28.8	n.s.
	Flex-Ext	162.1 ± 43.1	87.2 ± 32.4	<0.01
	Ext-Int	162.4 ± 69.5	80.4 ± 33.4	<0.01
Elbow	Abd-Add	75.9 ± 17.1	61.9 ± 25.7	n.s.
	Flex-Ext	157.9 ± 43.0	133.9 ± 55.0	n.s.
	Ext-Int	118.8 ± 48.0	81.7 ± 38.2	n.s.

Note: Abd-Add: abduction-adduction, Flex-Ext: flexion-extension, Ext-Int: external-internal rotation.

Discussion

The shoulder-injured players exhibited less ROM than their healthy counterparts during a standard throw, a movement commonly performed during practice and matches. Hence, injured players may voluntarily or unconsciously execute the motor task in a more conservative manner than healthy players. Coaches and trainers should focus on minimizing compensatory movements and provide guidance for the return-to-sport process following shoulder injuries.

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