XXII Congresso della Società Italiana di Analisi del Movimento in Clinica

Proceedings
SIAMOC 2022

Bari

5 Ottobre - 8 Ottobre 2022

SIAMOC

Società Italiana di Analisi del Movimento in Clinica

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Il costo di essere bipedi

Prof. Paolo Barone, Professor of Neurology, University of Salerno Chair, Department of Medical Sciences Director of Neurology Unit -University Hospital San Giovanni e Ruggi d'Aragona (Salerno)

L'essere umano ha definitivamente acquisito la posizione eretta circa 2.5 milioni di anni fa. In termini evoluzionistici il successo della funzione bipede ha richiesto la riconfigurazione non solo dell'organo muscolo-scheletrico ma soprattutto del Sistema Nervoso Centrale (SNC). In particolare il SNC del bipede uomo presenta sostanziali differenze rispetto ai primati in termini di connettività tra corteccia cerebrale, gangli della base e cervelletto, strutture anatomiche deputate al controllo del movimento. In particolare lo sviluppo del lobo frontale sembra essere strettamente correlato all'acquisizione della postura eretta ed al controllo della marcia bipede.

Altra importante modifica funzionale del SNC riguarda il sistema cardiocircolatorio, ed in particolare il controllo della pressione arteriosa che deve assicurare il continuo apporto di sangue al cervello di un corpo in postura eretta.

Le nostre conoscenze attuali di molte malattie neurodegenerative ci spinge ad ipotizzare che queste patologie, peculiari dell'essere umano, possono essere considerate difetti di adattamento del SNC nel corso dell'evoluzione verso il bipedismo. In questa sede si esamineranno alcune malattie neurologiche esemplificative di questa ipotesi, Inoltre si evidenzierà la stretta relazione tra funzione motoria e cognitività che sottostà al successo del bipedismo.

Modellistica Computazionale, Caratterizzazione Sperimentale e Controllo di Attuatori Ibridi per riabilitazione robotica

Prof. Francesco Amato, Dipartimento di Ingegneria Elettrica e Tecnologie dell'Informazione – Università degli Studi di Napoli Federico II

Questo intervento illustra un nuovo approccio per la progettazione meccatronica di un'articolazione biorobotica con compliance controllabile, per applicazioni innovative di riabilitazione robotica "assistita" mediata da un esoscheletro indossabile e morbido. L'attuazione morbida degli esoscheletri robotici può fornire alcuni vantaggi rilevanti in termini di conformità controllabile, adattabilità e sicurezza intrinseca delle prestazioni di controllo del robot durante l'interazione con il paziente. I muscoli artificiali pneumatici (PAM), che appartengono alla classe degli attuatori morbidi, possono essere disposti in configurazione antagonista al fine di sfruttare la variabilità della loro conformità meccanica per l'adattamento ottimale delle prestazioni del robot durante la terapia. L'accoppiamento di una configurazione antagonista di PAM con un meccanismo di regolazione può ottenere, con una strategia di controllo personalizzata, la regolazione ottimale della conformità meccanica dell'articolazione dell'esoscheletro in tutti i campi di pressione di attuazione e di rotazione dell'articolazione. Questo lavoro presenta un meccanismo innovativo, per la regolazione ottimale della conformità dell'articolazione biorobotica, caratterizzato da un'attuazione morbida e ibrida che sfrutta l'immagazzinamento/rilascio dell'energia elastica da parte di tralicci elastici di Von Mises bistabili. Il contributo della struttura elastica di Von Mises può migliorare sia la risposta meccanica del soffietto pneumatico morbido che aziona il meccanismo di regolazione, sia la sicurezza intrinseca dell'intero meccanismo. Qui viene presentata una serie completa di fasi di progettazione, tra cui l'ottimizzazione della geometria del soffietto pneumatico, il processo di fabbricazione attraverso la stampa 3D del meccanismo e alcuni test sperimentali dedicati alla caratterizzazione dell'attuazione morbida ibrida. I test sperimentali hanno replicato le principali condizioni operative del meccanismo di regolazione; i vantaggi derivanti dall'attuazione morbida ibrida bistabile sono stati valutati in termini di prestazioni statiche e dinamiche, ad esempio le soglie di transizione della pressione e della forza del meccanismo bistabile, la linearità e l'isteresi della risposta dell'attuatore.

Le nuove tecnologie di analisi del movimento per la Terapia Occupazionale e l'Ergonomia

Dott.ssa Monica Panigazzi, Servizio di Fisiatria Occupazionale ed Ergonomia. ICS Maugeri, IRCCS – Pavia-Montescano

Recentemente, strumenti tecnologici portatili e di facile uso, applicabili allo studio del movimento umano (soprattutto sensori indossabili, ossia IMUs, Inertial Measurement Units), hanno consentito l'adozione in ambito terapeutico e riabilitativo di tecniche valutative alternative a quelle tradizionali, rendendo disponibili a clinici e a ricercatori un'ampia mole di parametri oggettivi. La Terapia Occupazionale si avvale di tale tecnica ai fini diagnostici e terapeutici. Le caratteristiche cinematiche ricavate dai sensori possono infatti aiutare il Fisiatra e il Terapista a dettagliare il profilo funzionale del paziente e a indirizzare l'impostazione di programmi individualizzati. La fattibilità di test sul campo offre l'opportunità di valutazioni olistiche, comprendendo aspetti ambientali e individuali. I dati inerziali, analizzati attraverso tecniche statistiche di Intelligenza Artificiale (algoritmi di Machine Learning), mostrano un potere predittivo diagnostico e funzionale, e risultano inoltre associabili con classificatori ICF (Organizzazione Mondiale della Sanità). In Ergonomia l'utilizzo della sensoristica consente la caratterizzazione dei compiti lavorativi ai fini dell'aumento dei livelli di sicurezza e del miglioramento della performance del lavoratore. Le misurazioni oggettive possono offrire all'Ergonomo e al Medico del Lavoro i fondamenti per avviare interventi di prevenzione delle patologie muscolo-scheletriche e degli infortuni, o di facilitazione in attività gravose.

L’analisi del movimento come ponte fra ricerca e assistenza nella patologia ortopedica dei pazienti fragili

Prof. Biagio Moretti, Dipartimento di Scienze Mediche di Base, Neuroscienze ed Organi di Senso – Università Aldo Moro di Bari

Nel 2019-2020, il Consiglio Superiore di Sanità (CSS) ha redatto un documento su “Invecchiamento della popolazione e sostenibilità del SSN” che ha sviluppato i diversi aspetti attinenti l’invecchiamento della popolazione e, in particolare, la “Patologia ortopedica nelle condizioni di fragilità”. Oggi, a fronte di uno stato di anzianità sempre più protratta temporalmente, diventa fondamentale viverla nel miglior modo possibile ed una delle cause maggiori di decadimento è la perdita della capacità motoria che determina, tra l’altro, una situazione di disagio sociale ed una possibile condizione di depressione per chi lo vive in prima persona, oltre la difficoltà, per chi gli è vicino, di dover affrontare un’improvvisa circostanza cui non si è preparati. È stata, per tali motivi, introdotta e accettata l’esistenza di una vera e propria “sindrome da fragilità” (frailty syndrome). La definizione scientifica di fragilità identifica una condizione di vulnerabilità più o meno latente con la possibile perdita di autonomia ed aumento del rischio di disabilità e di mortalità tipica dell’anziano. Il fenotipo dell’invecchiamento muscoloscheletrico comprende quattro elementi chiave spesso concatenati: osteoporosi, artrosi, sarcopenia e fragilità. È fondamentale, pertanto, riuscire a monitorare quantitativamente in modo accurato ogni fenotipo allo scopo di identificare gli individui a maggior rischio. Una misurazione accurata del fenotipo dell’invecchiamento muscoloscheletrico deve documentare pertanto il peso di ciascun parametro, per consentire l’identificazione dei fattori che possono accelerare o ritardarne lo sviluppo o la progressione. In particolare, il passo è stato riconosciuto come un indicatore di salute e funzionalità anche negli adulti anziani fragili, e diversi parametri del passo sembrano predire esiti negativi relativi alla salute in diversi domini (dal clinico al cognitivo al fisico). I progressi nella tecnologia possono estendere la validità dell’andatura in diversi contesti clinici anche negli adulti anziani fragili, e la valutazione basata sulla tecnologia dovrebbe essere incoraggiata. La combinazione di vari parametri del passo può migliorare la previsione della fragilità e la classificazione dei diversi fenotipi di fragilità.

Tra accademia e integrazione clinica: il modello islandese e i nuovi paradigmi per la valutazione del controllo posturale

Prof. Paolo Gargiulo, Director, Inst. f. Biomed. and Neural Engineering/ Biomed. Technology Centre Reykjavik University & Landspitali – Reykjavik

Paolo Gargiulo presenterà il lavoro di ricerca e sviluppo di un nuovo paradigma per la valutazione dei meccanismi neurologici e motori associati al controllo posturale e alla cinetosi chiamato BioVRSea. In questo set up, I soggetti vengono sottoposti ad un'esperienza di realtà virtuale (VR) combinata al movimento indotto con una piattaforma mobile. La simulazione consiste in una barca in mare aperto sottoposta a onde di frequenza e ampiezza variabile. Durante l' esperimento vengono misurate CoP (center of pressure) e le attività elettriche di cuore, muscoli e cervello. L' obiettivo iniziale è stato quello di creare un database di misure da soggetti sani (300 misure già acquisite) e sviluppare un profilo multimetrico che rappresenti la risposta individuale, sana, ad uno stimolo complesso visivo e motorio che richieda adattamento ed equilibrio. La presentazione dimostrerà come questo paradigma di misura può aiutare per la classificazione e la diagnostica di disturbi posturali, di equilibrio, e come supporto alla valutazione di pazienti con problemi neurologici, come il morbo di Parkinson.

Topics

- Applicazioni dell’analisi del movimento in Teleriabilitazione e tele monitoraggio
- Applicazioni cliniche di analisi del movimento in neurologia, fisiatria, ortopedia, riabilitazione, ergonomia e medicina del lavoro
- Sistemi indossabili nell’analisi del movimento, monitoraggio domiciliare e actigrafia
- Applicazioni delle tecnologie dell’IoT nella valutazione dell’attività motoria domiciliare
- Metodi di supporto alla decisione clinica, valutazione dell’outcome
- Movimento dell’arto superiore
- L’analisi del movimento a supporto della progettazione e valutazione dei dispositivi ortesici e protesici
- Machine learning per l’analisi del movimento
- Analisi del movimento nella prevenzione delle cadute
- Analisi del movimento per il Biofeedback e l’Exergaming

Sessione 1 – Clinical applications of motion analysis
Part 1

Spine kinematics in patients with Parkinson's disease with and without Freezing of Gait

C. Palmisano [1], V. Farinelli [2], F. Camuncoli [3], A. Favata [4], I.U. Isaias [1,5], C.A. Frigo [3]
[1] University Hospital of Würzburg, Würzburg, Germany, [2] Università degli studi di Milano, Milano, Italy, [3] Politecnico di Milano, Milano, Italy, [4] Universitat Politècnica de Catalunya, Barcelona, Spain, [5] Centro Parkinson, ASST G. Pini-CTO, Milano, Italy

INTRODUCTION

Despite the importance of spine and upper limb movements in walking, most of previous studies on human locomotion focused exclusively on lower limbs [1]. Patients with Parkinson's disease (PD) are characterized by trunk postural alterations and reduced limb movements [2-3]. It is still unclear to what extent postural alterations in PD concur to, or counteract, poor balance [3]. Specifically, their contribution to the occurrence of freezing of gait (FoG), an episodic failure of forward stepping exposing patients to high risk of falls, is yet to be fully elucidated. We aimed at characterizing spine kinematics in PD patients with and without FoG during walking and standing.

METHODS

We investigated linear gait in a cohort of 14 patients with PD. They were grouped into patients with (PDF, N=6, Unified Parkinson Disease Rating Scale part III [UPDRS-III]: 35(23-49)) and without FoG (PDNF, N=7, UPDRS-III: 31(12-48)), based on their clinical history. All patients performed the experimental protocol after overnight suspension of all dopaminergic drugs (meds-off). They were instructed to perform at least three trials of barefoot walking at self-selected speed on a walkway of 8 meters. A session of quiet standing of about 60 s ended the experiment. Kinematics was monitored by means of a full body marker protocol [4]. Three markers placed on the seventh cervical vertebrae (C7), the maximum kyphosis, and a virtual marker reconstructed in correspondence of the coccyx served as reference points for the calculation of the lordosis and kyphosis spine angles. Specifically, the coccyx was reconstructed in the pelvis reference system based on previous radiography studies [5]. The distance between the C7 and the middle point between the posterior-superior iliac spines (MID-PSIS) was used to estimate the rachis length. Height of the C7 and MID-PSIS were also computed. Trunk inclination was defined as the angle between the vertical axis of the laboratory and the line connecting C7 and MID-PSIS. The shoulder-pelvis angle was computed as the angle between the line connecting the two acromion and the line connecting the anterior superior iliac spines and projected to the frontal and horizontal planes of the pelvis reference system. For the walking sessions, all variables were computed and averaged across gait cycles at steady-state velocity. For the standing sessions, variables were averaged over time. A Kruskal–Wallis test identified differences between groups for each condition (i.e., walking and standing). A Wilcoxon matched-pair test was used to compare standing and walking conditions inside each group. Threshold for statistical significance was set at 0.05.

RESULTS

No differences between groups were found in the spine variables during standing and walking. PDF showed higher values of the shoulder-pelvis angles in the frontal plane only during the standing condition. During walking, the average height of the MID-PSIS decreased with respect to standing in both groups, while C7 height decreased selectively in the PDNF group, despite a trend was present also in the PDF group. Only PDNF patients showed increased trunk inclination during walking with respect to standing.

DISCUSSION

Our analyses did not show a clear difference in the spine kinematics during gait and standing between PDF and PDNF patients. We speculate that trunk postural alterations may not be at the basis of the occurrence of FoG, but rather be compensatory (ineffective) attempts to overcome this symptom. Considering the small sample size employed in our study, further analyses on larger cohorts are warranted to confirm these preliminary results.

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Automatic identification of muscle overactivity in acute stroke patients at rest. A Validation study.

A. Merlo[1], R. Merletti [2], I. Campanini [1]

[1] LAM-Motion Analysis Laboratory, Neuromotor & Rehabilitation Department, Azienda USL-IRCCS di Reggio Emilia, Italy; [2] Laboratory for Engineering of the Neuromuscular System (LISiN), Department of Electronics and Telecommunications, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Turin, Italy

INTRODUCTION

The onset of muscle overactivity (MO) is one of the consequences of upper motor neuron lesion (UMNL) [1]. Recent literature highlights the key role of surface electromyography (sEMG) in identifying the presence or the absence of MO [2]. A custom algorithm has been recently developed by our group to automatically identify MO in the absence of any joint motion, i.e. at rest [3]. The aim of the current study was to determine its validity in detecting MO at rest from in-field sEMG measurements in acute patients.

METHODS

Study design: validation study; index test v. gold standard comparison. *Data:* Over 400 hours of data were acquired in [3] from 14 biceps brachii (BB) muscles of 10 bedridden acute neurological patients with arm plegia. Wearable sEMG probes (Mini Wave Plus, Cometa, Italy) with onboard memory and embedded 3D accelerometer were used. *Index test*: MO automatic classification (y/n) of 10s-lasting sEMG epochs. The algorithm [3] applies a preliminary set of quality controls both in frequency domain and in time domain to discard corrupted data (e.g. due to electromagnetic interferences, partial electrode detachment, artifacts). Next, the presence of muscle activity is assessed using a wavelet-based enhancement of the matched filter technique [4]. *Gold Standard:* MO visual classification (y/n) of the same epochs processed by the algorithm, performed by two expert assessors. A two-way table was prepared. Sensitivity (Se), specificity (Sp), positive and negative predictive values (PPV, NPV), and overall diagnostic accuracy were computed along with their 95% confidence intervals. *Sample size:* According to sample size calculation for diagnostic studies [5], assuming a 25% prevalence of MO [3], expected *Se*=*Sp*=80% and a $\pm$2.5% CI width, a total of 4000 epochs should be analysed.

RESULTS

Preliminary results on 704 epochs distributed among subjects are presented. Of these, 513 epochs had complete absence of movement (e.g., due to nursing activities), as detected by the accelerometer. The resulting two-way table is presented in Figure 1a. An example of data is presented in Figure 1b. Se was 87% (81-89%), Sp was 86% (81-89%), PPV was 79% (73-85%) and NPV was 91% (87-94%). The overall diagnostic accuracy was 86% (83-89%).

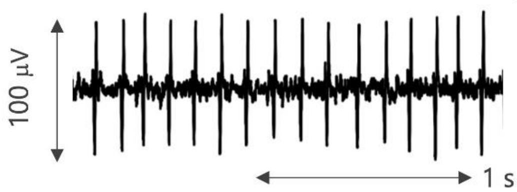
Figure 1. a) Two-way table of the validation procedure; b) an example of sEMG data with MO at rest.

a)

Recoded Data for Decision Test Statistics

	Gold Positive	Gold Negative	Total
Test Positive	173	45	218
Test Negative	27	268	295
Total	200	313	513

b)



DISCUSSION

These preliminary results support the use of wearable sEMG sensors with the developed algorithm for in-field assessment of MO at rest. False negative classifications were often due to activity staring at the end of the 10s epoch. The assessment and monitoring of MO in acute and subacute patients with UMNL could improve the quality of care by suggesting early treatments to lessen long-term complications. It is worth highlighting that the identification and quantification of MO does not provide a direct clinical diagnosis in any way. Rather, it allows assessing or monitoring a pathophysiological condition.

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Recruitment frequency of gastrocnemius lateralis in people with Parkinson's disease during locomotion

M. Romanato[1], F. Spolaor [1], D. Volpe[2], S. Fioretti[3], F. Di Nardo[3], Z. Sawacha[1,4]
[1]Department of Information Engineering Università degli Studi di Padova, Padova, Italy, [2]Fresco Parkinson Center, Villa Margherita, S. Stefano, Vicenza, Italy, [3]Department of Information Engineering, Università Politecnica delle Marche, Ancona, Italy [4]Department of Medicine Universitàdegli Studi di Padova, Padova Italy

INTRODUCTION

Motor impairments are one of the most disabling symptoms related to Parkinson's disease (PD) and negatively affect quality of life [1]. Recently aberrant motor control in this population was investigated by means of surface electromyography (sEMG) in terms of timing of muscle activation [2]. Yet, insights on the recruitment frequency during gait are still lacking. Therefore, this study aims to characterize muscle recruitment frequency in PD with respect to healthy controls during walking.

METHODS

Twenty-five people with PD (age = 64 ± 10 years; BMI =26±3) and ten able bodied subjects(age = 62±6 years; BMI =28±3) were included and underwent sEMG while walking on a 8 m walkawayat BiomovLab (University of Padova, Italy). Three bilateral strides per subject were considered (105 strides in total). Electrical activity of gastrocnemius lateralis (GL) was recorded. To identify onset and offset of the muscle activation, the wavelet-based algorithm presented in [3] was adopted. Then, eachsignal was digitized in accordance with the detected activation timing (0 = no activation detected, 1 = activation detected) and used to provide activation maps [4] for both the assessed populations.

RESULTS

The following Fig. 1 reports the activation map of GL activation for PD and control populations in function of the number of subjects of the specific population where muscular activity is observed. Horizontal bars are grey-level coded, according to the number of subjects of the population where a GL activity is detected; black = activity detected in all subjects, white = activity never detected.

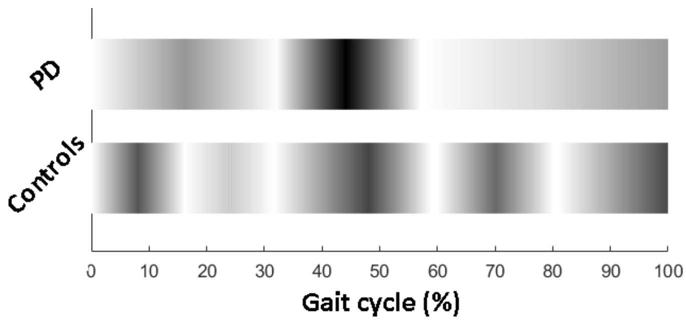

Figure 1. GL activation over PD and control populations as percentage of gait cycle (GC).

DISCUSSION

PD population presents a very frequent GL activity (close to 100%) between 35% and 55% of the gait cycle, as expected. A relatively poor activity is detected in the other gait cycle phases. Although GL in PD is more frequently recruited in the same gait cycle phase of controls (≈ 70%), healthy subjects displayed more homogeneous GL activity over the whole gait cycle. These outcomes seem to suggest that PD patients are characterized by a reduced ability to adapt to gait-related needs compared to age-matched control subjects.

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Assessment of muscular effort in workers performing an actual use-case manual material handling with and without the assistance of Bazar robot

T. Varrecchia[1], G. Chini[1], S. Tarbouriech[2], B. Navarro[2], A. Cherubini[2], F. Draicchio[1], M. Serrao[3], A. Ranavolo[1]
[1] INAIL, Rome, Italy, [2] LIRMM, Univ Montpellier, Montpellier, France, [2] Sapienza University of Rome, Rome, Italy

INTRODUCTION

Human-robot collaboration (HRC) technologies represent one of the new options for the prevention of work-related musculoskeletal disorders (WMDs) [1]. They share the workspace with workers, communicate with them, manage the human partner's flexibility and ergonomics and physically interact, to work together on a common goal [2]. Reconfigurable collaborative robots adapt to the workers' intentions and task variations, offloading them from external loads and keeping them in ergonomic working circumstances, to improve efficiency and quality of the task execution. Although collaborative work is a widespread method for lowering WMDs, the scientific literature reveals conflicting findings on its efficacy, due to factors affecting team capacity, autonomy, and coordination [3]. To measure motor coordination during dynamic tasks, a common approach is muscle co-activation that may become functionally unfavorable [3]. Therefore, this research aims to evaluate upper limb muscle coactivation in workers performing an industrial use case manual material handling (MMH), proposed by the SME HANKAMP (Netherlands), by comparing a scenario where the workers are helped by a dual-arm cobot BAZAR [4] with a scenario without BAZAR. This cobot BAZAR is being assessed in the context of SOPHIA (http://www.project-sophia.eu) project funded by the European Union's Horizon 2020 (grant agreement No. 871237).

METHODS

Eleven participants (5 females and 6 males; 27.73±5.99 years; BMI: 23.06±3.93 kg/m2) took part in the study carried out at the University of Montpellier in accordance with the Helsinki Declaration and authorized by the local Ethics Committee (Protocol number IRB-EM 2103A). Six bipolar electrodes (FreeEMG300 System, BTS, Italy, sampling rate at 1000 Hz) were placed on the flexors and extensors muscles of the shoulder (anterior and posterior deltoideus), elbow (biceps and triceps brachii caput longum) and wrist (flexor and extensor carpi radialis) joints. The experiments are shown in the video available at: https://youtu.be/vul8iLO0Sdw. Each participant, after being instructed, completed the task 3 times without BAZAR and 3 with BAZAR (Figure 1A). We randomly ordered the 2 conditions for each subject. Furthermore, participants performed a specific exercise twice with each muscle to obtain the isometric maximal voluntary contractions (iMVCs) [1,3]. The envelope of each task's sEMG signals was then extracted, normalized respect to the average iMVC peak value for each muscle, time-normalized and then interpolated according to the brushing sub-task duration (400 samples) [1,3]. The time-varying multi-muscle coactivation function (TMCf) [3] was estimated and the mean and maximum values were calculated. A statistical analysis was carried out to evaluate whether the help of the cobot had determined significant changes in each parameter (p-value < 0.05).

RESULTS

Figure 1B show the mean and standard deviation of mean and max values of evaluated TMCf for each condition. Significant effects of the presence of BAZAR were found for mean ($p<0.001$) and max ($p=0.001$) values of TMCf: the values significantly decrease when the task is performed with BAZAR.

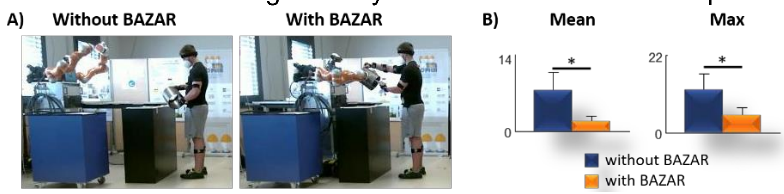

Figure 1. Task with and without BAZAR for a representative participant (A). Means, standard deviations and statistical results (*) of mean and max values of time-varying multi-muscle coactivation function (TMCf) in the two tasks (B).

DISCUSSION

The results showed a reduction in upper limb co-activation when the specific MMH was performed with BAZAR. Therefore, HRC technologies, which share the workspace with workers, not only offload workers from external loads and improve the task execution efficiency and quality. They also allow a better coordination and reduce the worker's physical effort while she/he physically interacts with the robot, and positively affect her/his physiological motor strategy.

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Postural control in Parkinsonisms during a short static sway

M. Russo[1], C. Ricciardi[1-4], M. Amboni[2], M. Picillo[2], G. Ricciardelli[3],F. Abate[2], M. F. Tepedino[2], M. C. Calabrese[3], M. Cesarelli[1-4],M. Romano[1]

[1]*Department of Electrical Engineering and Information Technologies University of Naples "Federico II", 80125 Naples, Italy*

[2]*Center for Neurodegenerative Diseases (CEMAND), Department of Medicine, Surgery and Dentistry "Scuola Medica Salernitana", University of Salerno, 84081, Baronissi, SA, Italy*

[3]*Azienda Ospedaliera Universitaria OO. RR. San Giovanni di Dio e Ruggi d'Aragona, 84131 Salerno, Italy*

[4]*Istituti Clinici Scientifici Maugeri IRCCS, Pavia, Italy*

INTRODUCTION

Neurological diseases, such as Parkinsonisms, are often associated with static postural instability. Progressive supranuclear palsy (PSP) is a rare neurodegenerative disease classified among atypical Parkinsonisms. In the earliest stages, PSP is similar to Parkinson's disease (PD) [1]. Static postural stability is an important contributor to the balance control framework and balance impairment can be quantified with a postural sway measure [2]. The main goal of our study was to compare postural sway changes in both PSP and PD subjects, using a standing single task of 5-6 seconds, in order to prove that a shorter sway time may be useful to distinguish Parkinsonisms.

METHODS

We assessed fifteen individuals with early PSP and fifteen individuals with recent diagnosis of PD (De Novo PD). Stabilometric analysis was performed for the evaluation of balance through a BTS Bioengineering system. The patient was instructed to stand on the force plate with the eyes open and measures of 5-6 seconds were taken. To find differences between the groups, univariate statistical analysis on sway data was conducted, and an alpha significance level was set to p-value < 0.05.

RESULTS

The statistical analysis showed significant differences between De Novo PD and PSP groups for Medio-Lateral (M-L) sway (p-value=0.01), M-L range (p-value=0.023) and radius (p-value=0.026); minimum oscillation from the center of gravity and area showed a statistical trend with a p-value slightly above the 0.05 (p-value=0.056 and p-value=0.061, respectively).

Table 1. Mean ± standard deviation for each group. Significance level at 0.05.

Variables	De Novo - PD	PSP	p-value
M-L sway	10,53 ± 5,95	21,96 ± 14,62	**0,010**
M-L range	6,08 ± 2,22	7,27 ± 2,14	**0,023**
Radius	2,77 ± 1,01	4,13 ± 1,85	**0,026**

DISCUSSION

Several studies have demonstrated that balance dysfunction in PD is directionally dependent [2],[3]. In agreement with our data, patients with atypical Parkinsonism show balance impairment on M-L direction as attested by augmented M-L sway, M-L range and radius. These results indicate that a short static sway of 5-6 seconds, could provide the clinician with a reliable and non-invasive tool to distinguish PSP from PD since the earliest stages.

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Preventive exercise in people with early-stage Multiple Sclerosis: preliminary results on walking

I. Carpinella[1], E. Gervasoni[1], D. Anastasi[1], R. Di Giovanni[2], A. Tacchino[3], G. Brichetto[3], P. Confalonieri[4], M. Rovaris[1], C. Solaro[2], M. Ferrarin[1], D. Cattaneo[1,5]

[1] IRCCS Fondazione Don Carlo Gnocchi, Milan, Italy, [2] CRRF Mons. L. Novarese, Moncrivello (VC), Italy, [3] Italian MS Foundation -FISM, Genoa, Italy, [4] IRCCS Foundation "Carlo Besta" Neurological Institute, Milan, Italy, [5] University of Milan, Milan, Italy

INTRODUCTION

People with Multiple Sclerosis (PwMS) suffer from mild impairments of balance and gait since the very early stages of the disease [1,2]. Nonetheless, it has been recently suggested that the prompt administration of preventive rehabilitation at the beginning of the pathology can potentially slow the MS-related functional decline [3]. The present multi-center pilot randomized controlled trial (RCT) aims at preliminarily analyze the effects of a treadmill-based exercise program on walking characteristics in early-stage non-disabled PwMS. The study was supported by FISM (grant N16/17/F14).

METHODS

Twenty-six PwMS (age: 39.4±10.4 years, Expanded Disability Status Scale <=2.5, disease duration<=5 years), not involved in regular physical activity during daily life, were randomized to experimental (EG, N=15) and control group (CG, N=11). Participants allocated to EG underwent sixteen 35-minute sessions (2-3 sessions/week) of a training based on published guidelines [4] and previous study [5]. In particular, the training included 10 minutes of aerobic exercises to increase fitness (e.g. walking at different speed and slopes) and15 minutes of task-oriented balance exercises (e.g. walking with feet in tandem). Participants in the CG were asked to continue their daily-life activity. Both groups were assessed pre- and post-training with the 6-minute Walk test (6MWT) instrumented with 3 inertial sensors (MTw, XSens, NL) on trunk and ankles. Distance walked in 6 minutes at maximum speed was provided as a clinical measure of walking endurance, while a set of instrumented metrics were computed from the inertial sensors to describe the temporal aspects (cadence, stance and double support duration) and the quality of walking (gait regularity, symmetry and local dynamic instability, see [2]). In this preliminary analysis, post-training values were compared between EG and CG using ANCOVA with pre-training scores as covariates. For each variable, the effect size (ES) was provided by computing Cohen's *d*.

RESULTS

Pre-training demographic, clinical and instrumented data were comparable between groups. After adjusting for pre-treatment score, no between-group difference was found in post-training 6MWT (mean ± SE; EG: 573 ± 8 m; CG: 571 ± 9 m, p=0.896, ES: 0.07). Instrumented metrics showed that, after the treatment, EG was characterized by lower double support time (EG: 6.1±0.6 %stride; CG: 8.5±0.6 %stride, p=0.008, ES: -1.14), increased antero-posterior gait symmetry (EG: 88.4±2.3 a.u.; CG: 81.1±2.6 a.u., p=0.049, ES: 0.86), and reduced vertical local dynamic instability (EG: 0.80±0.02 a.u.; CG: 0.88±0.03 a.u., p=0.04, ES: -0.89) compared to CG. No statistically significant difference between groups were found in the other variables.

DISCUSSION

The preliminary results of this pilot RCT on early-stage PwMS suggested that the proposed treadmill training seems to be efficacious (at least in the short term) in improving gait quality rather than walking endurance. In particular, compared to CG, EG showed after the training increased gait symmetry and improved dynamic balance, as shown by the reduction of double support time and the decrease of local dynamic instability, the latter indicating an improved ability of the locomotor system to cope with small perturbations naturally occurring during walking. Importantly, the large effect sizes (|ES|>0.8) in instrumented metrics suggested their high sensitivity in detecting subtle improvements not easily measurable with clinical scales. Future studies on larger samples should be performed to confirm the present findings and assess the long-term effects of the proposed training.

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Feasibility and usefulness of a consumer-grade device for physical activity monitoring for patients with Parkinson's disease and Parkinsonism

P. Tropea[1], E. Judica[1], A. Seregni[1], M. Caprino[1], M. Corbo[1]

[1]*Department of Neurorehabilitation Science, Casa di Cura del Policlinico, Milan, Italy*

INTRODUCTION

The identification of the best measures to improve quality of life, awareness and care management for senior users with neurodegenerative diseases, and the implementation of personalized recommendations to support the user through gamification techniques and to adopt healthy habits, to maintain a good daily routine and to follow the prescribed actions by professionals for maintaining and improving their health condition, are the main contributions of PROCare4Life, an EU funded project. In fact, by proposing an integrated scalable and interactive care ecosystem, this solution can be easily adapted to the reality of several chronic diseases.

The ability to passively track continuous ambulatory activity over time in a real-world scenario in patients with Parkinson's disease (PD) has many potential uses. Wrist-worn physical activity monitors may be a valuable tool for tracking and/or increasing physical activity among patients with Parkinson. Because of differences in technology acceptance associated with age, and variable clinical conditions, feasibility and usefulness of Fitbits may vary among these subjects.

The purpose of this study was to evaluate the patients' adherence during the period of physical activity monitoring and to analyze the correlation between steps counts and clinical parameters.

METHODS

Patients with idiopathic PD (Parkinson's disease) or Parkinsonism were recruited at Casa di Cura del Policlinico (Milan, Italy). Participants attended one assessment session at hospital with an expert neurologist. Age, gender, disease duration, falls history and medication intake were collected by an interview. Disease severity was measured using the Unified Parkinson's Disease Rating Scale (UPDRS) and stage of disease rated using Hoehn and Yahr scale (H&Y). All participants signed an informed consent. All research procedures were approved by the Local Ethics Committee.

Patients' physical activity monitoring was performed by means of the wearable sensor Fitbit Versa 2 (Fitbit Inc, San Francisco, California, USA), a small wearable activity tracker that is worn like a watch with a triaxial accelerometer and that displays step count. The activity tracker was provided to patients at the time of enrollment together with the instructions for use. Patients were asked to wear it at all times for 60 days, excluding while bathing and sleeping. Step count was recorded while participants wore the smartwatch. While no specific recommendations were given on amount of physical activity and there was no daily step target, patients were invited to follow their daily routine for the period of the monitoring. Correlation between step count data from the Fitbit, demographic indicators and clinical scales were examined using Pearson's correlation coefficient.

RESULTS

13 subjects were enrolled (73.23 ± 6.56 years; 8 males; 10 with diagnosis of PD; UDPRS at baseline: 67.92 ± 35.30; H&Y: 2.69 ± 0.75). Three of the 13 participants did not complete the study due to wristband's usability problems. Among the subjects that completed the study, the number of mean daily steps during the monitoring period was 4879.76 ± 3385.69, with individual participants' means ranging from 62.54 to 11727.86. The majority of subjects (60%) could be classified as sedentary (i.e., mean daily steps lower than 5000) [1]. Using the adherence definition of >100 steps, on average the participants wore wristband 49.80 ± 16.86 days, with an adherence of 83.00 ± 28.11% of the 60-day study period. Noteworthy, for the quasi-totality of subjects (70%) the adherence was very high (96.67 ± 5.69%), for two participants was high (68.33-75.00%) and for one participant very low (10.00%).

A significant correlation between steps taken and UPDRS (R= -0.76, p=0.010) at the end of the monitoring period was found. Removing the subjects with very low adherence and the one that never reached 5000 steps per day, a high significant correlation for steps taken and H&Y scale (R = 0.71, p = 0.047) resulted. An additional high significant correlation was found between steps taken and the differences in global score of UPDRS (R = 0.75, p = 0.031) assessed at the beginning and at the end of the monitoring period.

DISCUSSION

The preliminary results show that the use of a consumer-grade device in patients with neurodegenerative disease is feasible with reasonable adherence. The positive correlation between steps taken and modification in UPDRS scales means that higher steps correspond to a smaller worsening in UPDRS scale assessment. These preliminary results, if confirmed in large scale scenario, could be useful in the framework of the PROCare4Life project, in order to develop and validate an ICT-based integrated care ecosystem that will improve the quality of life of the users in their care delivery, and by improving social and medical services through automation and digitalisation.

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Relationship between 123I-FP-CIT-SPECT and gait impairments in drug-naïve individuals with Parkinson's disease

M. Giardini[1], I. Arcolin[1], A. Solop[2], F. Pisano[3], R. Campini[2], S. Corna[1], M. Godi[1]
[1] Department of Physical Medicine and Rehabilitation, ICS Maugeri Spa SB, IRCCS, Veruno (NO), Italy, [2] Nuclear Medicine Unit, ICS Maugeri Spa SB, IRCCS, Veruno (NO), Italy, [3] Unit of Neurorehabilitation, Policlinico San Marco, Gruppo San Donato, Zingonia, Bergamo, Italy.

INTRODUCTION

Parkinson's disease (PD) is a progressive neurodegenerative disorder characterized by loss of nigrostriatal dopaminergic neurons [1]. In addition to cardinal motor symptoms, individuals with PD suffer of gait impairment [2]. Although functional imaging is useful for the diagnosis and pathophysiological evaluation of PD, little is known about the relationship between neuroimaging findings and PD clinical features. A study found a correlation between dopamine denervation and impaired gait automaticity [3]; others reported no association between dopaminergic denervation and some gait parameters, such as stride length and velocity [4,5], assuming that deficits in nondopaminergic neurotransmitter systems played the main role in gait impairments [3]. We aimed to examine the relationship between striatal dopaminergic depletion with disease severity in motor symptoms and gait variables in drug-naïve individuals with PD, in order to find where nigrostriatal pathway mainly acts.

METHODS

A total of 18 drug-naïve individuals with PD (mean age 70.4 ± 7.4 yrs) were enrolled. Motor symptoms were evaluated using the modified Hoehn and Yahr (H&Y) stage. Seven spatiotemporal variables of gait were acquired using a GAITRite® electronic walkway under comfortable walking, of which the coefficient of variation and the asymmetry were then calculated. The extent of striatal dopaminergic depletion was evaluated by dopamine transporter imaging with single-photon emission computed tomography using 123I-FP-CIT. Correlations between H&Y stage and gait variables with the specific binding ratios (SBRs) of the striatum (separated into putamen and caudate nucleus) were assessed with the Spearman's correlation coefficients (r).

RESULTS

The mean SBRs of both the putamen and the caudate nucleus were significantly associated with the modified H&Y stage, with correlation coefficient of at least 0.60. A moderate correlation was found also between the asymmetry in the SBR of the putamen and the H&Y stage. Moreover, among the spatiotemporal gait variables, a moderate correlation was found between the mean double support duration and its asymmetry with the mean SBRs of both the putamen and the caudate nucleus (Table 1). On the contrary, stride length and velocity showed a weak correlation (below 0.30).

Table 1 Correlations between the SBR of the putamen and caudate nucleus, the modified H&Y stage and the most correlated spatiotemporal variables of gait.

	Mean putamen SBR		**Mean caudate SBR**		Putamen Asymmetry		Caudate asymmetry	
	r	***p***	***r***	***p***	***r***	***p***	***r***	***p***
Modified H&Y stage	0.63	0.005	0.60	0.008	0.49	0.04	0.13	0.61
Double support time (s)	0.49	0.04	0.61	0.008	0.17	0.50	0.11	0.68
Double support time asymmetry (%)	0.45	0.05	0.41	0.09	0.27	0.30	0.47	0.05

DISCUSSION

Our findings suggest that both disease severity and gait impairments in early PD are associated with decreased dopamine binding in the striatum. Since the double support time showed a moderate correlation with dopaminergic depletion in particular in caudate nucleus, we propose this variable as a marker of the effect of nigrostriatal denervation on gait in individuals with early PD. On the other hand, the poor correlations found between the reduction of stride length and velocity with the nigrostriatal depletion confirmed the hypothesis of a major involvement of other systems (such as the cholinergic) in the control of these variables. Our findings supported the notion that a large part of gait impairments in PD resulted from multisystem degeneration [6,7].

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Sessione 2 – Clinical applications of motion analysis
Part 2

Evaluating balance disorders with different levels of walking impairment in Multiple Sclerosis: correlation between IMU-based parameters and clinical scales

A.S. Orejel Bustos[1,2], M. Tramontano[1,2], V. Belluscio[1,2], E. Bergamini[1,2], O. Argento[1], M. Bossa[1], C. Piacentini[1], U. Nocentini[1,3], G. Vannozzi[1,2]

[1] Fondazione Santa Lucia IRCCS, Rome, Italy; [2] University of Rome "Foro Italico", Rome, Italy; [3] Tor Vergata University of Rome, Rome, Italy

INTRODUCTION

Gait and balance disorders are marked functional deficits in people with multiple sclerosis (MS) [1]. Walking limitations are frequently reported in people with MS despite the Expanded Disability Status Scale (EDSS) indicates normal walking autonomy [2]. To better identify changes due to disease severity, a combined instrumental assessment based on inertial measurement units (IMUs) and clinical scales during walking paths have been recommended [3,4]. The aim of this study is to verify the correlation between objective data extracted from IMUs during walking and scores of a routinely performed clinical scale in patients with MS with different levels of walking impairment.

METHODS

Thirty-three patients with MS (Class 1– mild disability, n=4, 2 F, 53.8±1.3 y, EDSS 0–1.5; Class 2– mild to moderate disability, n=16, 12 F, 50.5±9.7, EDSS 2.0–4.0; Class 3– moderate disability, n=13, 10 F, 49.5±10.4, EDSS 4.5–6.5) participated in this study. All participants performed a 10-meter Walk Test (10mWT) and a Figure-of-8 Walk Test (F8WT) [3] while wearing five IMUs (APDM, Opal, 128 Hz) on both lateral malleoli, pelvis, sternum, and head. Stride segmentation was performed from leg IMUs. Spatio-temporal (ST) parameters (stride frequency-SD and duration-SD) along with gait quality indices related to stability (Root Mean Square-RMS and Attenuation Coefficients-AC), symmetry (improved Harmonic Ratio-iHR), and smoothness (Spectral Arc Length-SPARC) of gait were obtained. In addition, the Mini-Balance Evaluation Systems Test (Mini-BESTest) was also administered. The correlation between biomechanical parameters and the clinical scale was investigated through Pearson's correlation analysis after verifying for normal data distribution.

RESULTS

Significant correlations (moderate to high correlations) were observed between spatio-temporal, stability, symmetry, and smoothness gait parameters and MiniBESTest, especially for patients with higher EDSS (Class 2&3) and for the F8WT (Table 1).

Parameters		MiniBESTest					
		Class 1, n=4		Class 2, n=16		Class 3, n=13	
		10mWT	F8WT	10mWT	F8WT	10mWT	F8WT
ST	SF				.605*		
	SD				-.655**		-.602*
Dynamic Stability	RMS P_AP						-.626*
	RMS P_ML	-.995**		-.571*	-.629**		
	RMS S_AP						-.708**
	RMS S_ML	-.999**		-.562*			-.607*
	RMS H_AP			-.532*	-.843**		-.607*
	RMS H_ML			-.593*	-.627**		-.638*
	AC PH_AP				.768**		
	AC PH_ML					.566*	.676**
	AC SH_AP				.784**		
	AC SH_ML						
Symmetry	iHR_AP				.722**		
	iHR_ML		-.952*				
	iHR_CC				.640**		
Smoothness	SPARC_AP	.987*			.537*		.631*
	SPARC_ML			.611*	.554*		
	SPARC_CC	.995**		.576*	.546*		.684**

Table 1. 10mWT and F8WT Pearson's correlation coefficients for each estimated parameter and clinical scale. Statistical significance is indicated by asterisks (* $p < 0.05$; ** $p < 0.01$).
AP: antero-posterior; *ML*: medio-lateral; *CC*: craniocaudal; *P*: pelvis; *S*: sternum; *H*: head.

DISCUSSION

In the clinical setting, instrumental gait analysis with IMUs is a useful tool for evaluating balance disorders in patients with MS, especially when clinical scales are not able to detect subtle impairments as in the earliest stages of the disease (Class 1,EDSS ≤ 1.5). Despite linear walking highlights several correlations between the clinical scale and dynamic gait indices, the F8WT confirms to be highly discriminant of the different levels of walking impairment since more challenging [3]. The IMU-based approach could be therefore integrated in clinical practice to quantify gait impairments when undetectable with a standard clinical measure.

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Toward the definition of a minimum input model for an emg analysis in clinics

M. Romanato[1], E. Meggiorin[1], Z. Sawacha[1,2]

[1]Department of Information Engineering Università degli Studi di Padova, Padova, Italy, [2]Department of Medicine Università degli Studi di Padova, Padova Italy

INTRODUCTION

Neuro-musculoskeletal (NMS) modeling based on electromyographic (EMG) signals allows for a better understanding of the principles of human movement [1]. Through appropriate modeling software (CEINMS) it is possible to estimate the muscular forces and joint moments calibrated on the single individual. The possibility of having highly subject-specific models allows an improvement in the treatment of a great variety of neurodegenerative diseases and can be fundamental for the general understanding of the neuro-mechanics of human locomotion.

METHODS

Fifteen walking trials of four able body subjects (mean age = 60 ± 2.16, mean BMI = 26.66 ± 4.13) were acquired with a motion capture system (BTS, 60Hz), synchronized with a force plate (Bertec, 960Hz) and a 15 channels surface electromyography (sEMG) system (FreePocketEMG, 1000Hz). The CAST protocol was adopted as marker set, while the following muscles were acquired: Gluteus Maximus, Gluteus Medius, Tensor Fasciae Latae, Sartorius, Adductor Longus, Rectus Femoris, Biceps Femoris, Semitendinosus, Vastus Lateralis, Vastus Medialis, Tibialis Anterior, Peroneus Longus, Gastrocnemius Lateralis, Gastrocnemius Medialis and Soleus. The data were processed in MatLab for the extraction of four muscle synergies by applying the ‘Non-negative Matrix Factorization’ method [2]. Then, 'Statistical Parametric Mapping' [3] and 'Cosine Similarity' were used as metrics to assign each synergy to the EMG signals of just one muscle for each different muscle groups (Ankle Plantar-flexors, Ankle Dorsi-flexors, Knee Extensors and Knee Flexors). Afterwards data were processed in OpenSim; scaling, inverse kinematics, inverse dynamics, muscle analysis were run. Finally, CEINMS was executed to calculate muscle activations and torques first by informing the model with a complete setup of experimental EMGs data then with a reduced setup (the foru EMGs that best matched with muscle synergies). Activation signals of the muscle-tendon units and the angular moments of the knee and ankle obtain from models developed by CEINMS were compared for different setup with the experimental EMG signals. Comparison was done for both different muscle setups for each subject.

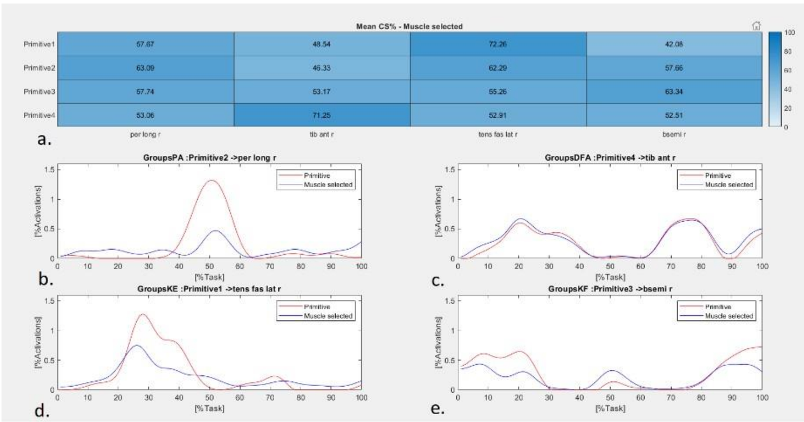

Figure 1. Results of a subject: 1a. Mean value CS% of the selected muscles for each primitive. 1b-e. Plot of primitives and sperimental activation of assigned muscles for a trial.

RESULTS

In Figure 1a are shown the values of cosine similarities of the muscles able to better approximate eachprimitive for one subject. In Figure 1b-e are displayed the pattern of primitives and the chosen experimental EMG signals for the same subject during one walking trial.

DISCUSSION

The implemented methodology allowed the analysis of the muscular forces developed during walking with an acquisition protocol that includes a reduced number of EMG signals, and a sensitivity analysis for the adoption of NMS models based on a limited number of inputs was conducted. Results seem promising but a validation on a wider sample of subjects including pathological subjects is needed.

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Assessment of trunk control and core stability in spinal cord injured subjects

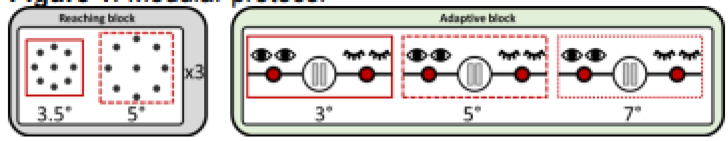
G. Marchesi[1,2], A. Bellitto[1,2], K. Torre[3], E. Quinland[3], S. Gamba[3], A. De Luca[4], A. Canessa[1,2], V. Squeri[4], A. Massone[3], M. Casadio[1,2]

[1] DIBRIS, University of Genoa, Italy; [2] Spinal Cord Italian Lab (SCIL), Santa Corona Hospital, Italy; [3] Unità Spinale Unipolare, Santa Corona Hospital, Italy; [4] Movendo Technology s.r.l., Italy.

INTRODUCTION

Objective measures for evaluating active trunk movements and postural control in sitting are important for the assessment of people with Spinal Cord Injury (SCI) and for tailoring rehabilitative interventions. However, studies addressing this issue are limited [1]. This work fills this gap by proposing a modular protocol for the kinematic and muscular quantitative assessment of trunk control, specifically designed for SCI subjects.

Figure 1. Modular protocol



METHODS

We used hunova® (Movendo Technology), a medical robotic device for the sensory-motor assessment and training of postural control in standing and sitting [2]. consisted of two different tests: a reaching (R) and an adaptive exercise (A), both performed while sitting on hunova®. The test R aims to assess the volitional component of trunk control: six reaching exercises, where subjects need to actively tilt the seat platform to move a cursor on the screen and reach targets, are alternating with two different platform inclinations: 3.5 and 5° (1° corresponds to 1 cm of cursor motion on the screen). The test A aims to assess how subjects adapt to predictable perturbations imposed by the seat platform [3]: six repetitions of an adaptive task, where subjects need to stabilize themselves while the seat platform moves following a given infinite-shape trajectory, is repeated once with eyes open (EO) and eyes close (EC), with different inclinations of the seat platform: 3, 5 and 7°. After testing the device and protocol on 18 healthy subjects, 10 SCI subjects (with different lesion level) participated in the study. Both the reaching block and the adaptive block (Figure 1) started with the easiest testing condition and gradually increases the difficulty of the exercises. This allowed all SCI subjects, with different lesion level, to participate in the assessment. Electromyography (EMG) was recorded bilaterally from the following muscles: obliquus externus abdominis, trapezius descendens, trapezius transversalis, trapezius ascendens, erector spinae longissimus, erector spinae iliocostalis, multifidus, latissimus dorsi, soleus, tibialis anterior, vastus medialis, semitendinosus, gluteus medium. The leg muscles were recorded only for SCI subjects with an incomplete lesion of the spinal cord. For each subject, we characterized postural responses in terms of kinematics and muscular activity, estimating the correspondent spatiotemporal organization of the motoneuronal activity in the spinal cord [4].

RESULTS

All subjects with an incomplete SCI could finish the whole protocol. This was not the case for subjects with a complete lesion. Only one subject (lesion level D12) completed both blocks and had movement performance like SCI subjects with an incomplete lesion. The other subjects (two with lesion level D6 and one D3) performed few repetitions of R as they found difficult to control the seat platform, and the tasks with 3 and 5° of inclination for A. Concerning the performance, for R all subjects, independently on their type of lesion, reached a greater number of targets across repetitions. During A, all subjects had a bigger trunk sway for higher inclinations of the seat platform, with higher values in the repetitions with EC. Each SCI subject used his/her own muscular strategy for reaching the different targets and also for adapting to the seat motion, despite it was continuous and predictable. This assessment highlighted the differences in the muscular control among subjects, also due to the different lesions.

DISCUSSION

This modular protocol evaluated in a quantitative, objective, repeatable, and comprehensive manner the kinematic and muscular strategies adopted by SCI subjects when performing dynamic tasks while sitting. The device hunova® allowed us to evaluate different aspects related to trunk control, the volitional and the feedforward control of balance while adapting to predictable and continuous perturbations. The results of this assessment will be used to tailor specific rehabilitative interventions.

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Robotic telerehabilitation: a feasibility study in patients with stroke.

I. Aprile[1], M. Gallotti[1], M. Schirru[1], S. Insalaco[1], M. Germanotta[1], F. Scotto di Luzio[2], L. Vollero[2], L. Zollo[2]
[1]IRCCS Fondazione Don Carlo Gnocchi, Florence, Italy, [2] Campus Biomedico University, Rome, Italy

INTRODUCTION

Stroke is the world's second leading cause of death and the leading cause of disability. Robotic therapy is a well-established approach for the rehabilitation of the upper limb, as a way to increase the amount and intensity of the therapy and standardize the treatment [1]. The coronavirus pandemic has required a reorganization of rehabilitation services but also an enhancement of technology as a tool in the rehabilitation field that can allow treatment in compliance with social distancing [2]. Many scientific works have confirmed the usefulness of these approaches to overcome the limits imposed by the pandemic, in particular for the treatment of stroke patients [3]. The proposed study aimed to test the feasibility of rehabilitation treatment in a home setting using a system of teleconsultation, telemonitoring and robotic telerehabilitation with the use of the robot Icone and integrated sensors, to overcome the limits imposed by the COVID-19 pandemic in a cohort of patients with stroke.

METHODS

For the study, 18 stroke patients were recruited. Patients underwent robotic telerehabilitation treatment, carried out at home, directly supervised by a caregiver and, remotely (using three webcams), by a multidisciplinary team. A total of 20 treatment sessions were provided. Patients underwent an initial (T0) and final (T1) evaluation through clinical scales (Fugl-Meyer Assessment Upper Extremity, FMA-UE, and Numerical Rating Scale for pain, NRS) and instrumental evaluations (based on the sensors present in the robot and additional sensors for the evaluation of joint kinematics, the galvanic response of the skin and the ECG signal) during kinematic and kinetic tasks. The clinical and instrumental evaluation was also performed remotely, to assess its reliability. Finally, the subjective perception of the treatment by the patient and the therapist were evaluated in terms of usability, acceptability and satisfaction.

RESULTS

The main results related to the instrumental evaluation through the sensors embedded in the robot are reported in Table 1. Six over ten robotic indices were responsive to the treatment, while eight indices showed excellent reliability in the remote assessment. Clinical scales confirmed the effectiveness and the safety of the treatment, and the FMA showed excellent reliability when performed online. (ICC>0.75). Finally, the subjective perception of the treatment in both patients and therapists was high.

Table 1. Robotic indices at baseline (T0) and after telerehabilitation (T1), compared with the Wilcoxon test;reliability of the remote assessment through the Intraclass Correlation Coefficient (ICC).

Task	Indices	T0 Mean (SD)	T1 Mean (SD)	P	ICC (remote assessment)
Circle drawings	Independence	0.443 (0.211)	0.687 (0.230)	0.023	0.735
Circle drawings	Area [m^2]	0.029 (0.016)	0.044 (0.018)	0.041	0.776
Point to point	Path error [m]	0.015 (0.013)	0.012 (0.005)	0.477	0.874
Point to point	Reach error [m]	0.027 (0.027)	0.013 (0.008)	0.091	0.766
Point to point	Smoothness	0.515 (0.097)	0.449 (0.044)	0.013	0.732
Point to point	Peak speed [m/s]	0.128 (0.021)	0.140 (0.009)	0.075	0.667
Point to point	Mean speed [m/s]	0.065 (0.013)	0.063 (0.007)	0.722	0.784
Point to point	Movement duration [s]	5.218 (2.833)	2.774 (2.237)	0.040	0.872
Playback static	Hold [m]	0.086 (0.042)	0.049 (0.036)	0.013	0.267
Round Dynamic	Displacement [m]	0.096 (0.042)	0.120 (0.041)	0.013	0.972

DISCUSSION

Our preliminary results suggest that the proposed treatment is feasible, effective and well tolerated by patients, and that remote clinical and instrumental evaluation is a reliable way to assess patients. Then, the proposed approach can represent an effective way to ensure the continuum of care for patients with disabilities, even in situations such as the current pandemic.

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Added value of the instrumented Timed-Up and Go test (iTUG) in the long-term assessment of PD patients with bilateral subthalamic nucleus deep brain stimulation (STN-DBS)

I. Campanini [1], F. Cavallieri [2], B. Damiano [1], S. Scaltriti [1], V. Fioravanti [2], N. Guagnano [1], G. Vannozzi [3], E. Bergamini [3], A. Gessani [4], C. Budriesi [4], F. Antonelli [4], V. Rispoli [4], M. Lusuardi [5], F. Valzania [2], A. Merlo [1]

[1] LAM-Motion Analysis Laboratory, Neuromotor & Rehabilitation Department, Azienda USL-IRCCS di Reggio Emilia, Italy; [2] Neurology Unit, Neuromotor & Rehabilitation Department, Azienda USL-IRCCS di Reggio Emilia, Italy; [3] University of Rome "Foro Italico", Roma, Italy; [4] Neurology Unit, Department of Neuroscience, Azienda Ospedaliero-Universitaria di Modena, Modena, Italy; [5] Neuromotor & Rehabilitation Department, Azienda USL-IRCCS di Reggio Emilia, Italy

INTRODUCTION

STN-DBS is an effective long-term treatment in PD, improving a broad spectrum of symptoms, including tremor, rigidity, and bradykinesia (Figure 1a) together with dopaminergic treatment. Among axial symptoms, gait disorders are common in PD. This study examines the long-term effects of different combinations of these two treatments in a cohort of advanced PD patients by means of the iTUG.

METHODS

Observational study on consecutive PD patients previously treated with bilateral STN-DBS. Disease severity was assessed using the UPDRS part III. Accelerometric data were acquired using an inertial sensor (G-WALK, BTS Bioengineering). Three iTUG trials were recorded in each of four stimulation and drug conditions: on-stimulation/off-medication, off-stimulation/off-medication, on-stimulation/on-medication and while preforming a cognitive task (counting backward, DUAL TASK) with both stimulation and medication on. Data were segmented into six phases (e.g., rising from chair, walking) as in [1]. A set of indices was computed including durations, RMS amplitudes, peak accelerations, peak angular velocities, indices of symmetry (improved Harmonic Ratio) and smoothness (Spectral Arc) [1]. A one-way non-parametric ANOVA was carried out, with the condition as a factor, followed by paired comparisons when appropriated. Statistical significance was set at 5% for all analyses.

RESULTS

Twenty-five patients were re-evaluated 3 to 7 years after STN-DBS surgery, with a mean five-year postoperative follow-up. Clinical characteristics were age 64(5) y, 8/17 F/M, PD duration 16(5) y, distance from STN-DBS intervention 5(1) y, median (IQR) UPDRS-III 12(12), WHS 5(1), FAC 5(2). Most patients were able to perform the test in all conditions. Both STN-DBS alone and the combination of STN-DBS and medications led to an improvement of clinical motor scores and most iTUG parameters ($p<0.001$). In particular: 1) the elevation/sitting gestures and the turn phases differently improved in the different conditions; 2) on average, the effect of the DUAL TASK condition led to indices similar to those in the off-off condition 3) data from the DUAL TASK condition suggest the existence of two subgroups of patients, whose performance is either affected or not affected by the cognitive task (Figure 1).

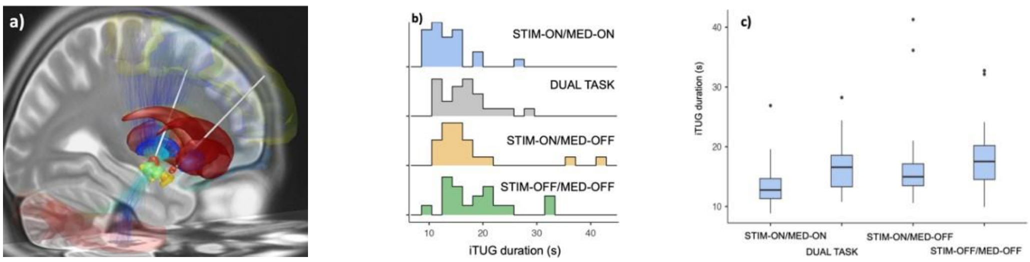

Figure 1. a) bilateral STN-DBS, b) distribution, and c) box plots of iTUG duration.

DISCUSSION

The protocol resulted feasible. Our results indicate that both STN-DBS and levodopa can improve walking ability even in the long-term after surgery. Results during DUAL TASK suggest the use of attentional strategies in the rehabilitation of selected patients, as indicated in the EU physiotherapy guidelines for PD [2]. A rehabilitative intervention should be strongly recommended in those patients whose performance in DUAL TASK becomes so impaired as in the STIM-OFF/MED-OFF, as measured by the iTUG. In conclusion, the iTUG test could be used in PD patients with STN-DBS to support the selection of tailored rehabilitative interventions and to identify patients whose performance is highly affected during cognitive tasks.

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Characteristics of landings, rotations, and impacts of real-world falls captured by wearable sensors in older persons

L. Palmerini[1], I. D'Ascanio[1], L. Chiari[1], J. Klenk[2], S. Robinovitch[3], C. Becker[2]

[1] *Dept. of Electrical, Electronic, and Information Engineering "Guglielmo Marconi", Bologna, Italy*

[2] *Dept. for Clinical Gerontology, Robert-Bosch-Hospital, Stuttgart, Germany*

[3] *Dept. of Biomedical Physiology and Kinesiology, Simon Fraser University, Burnaby, Canada*

INTRODUCTION

Falls are a significant health problem. Approximately 30% of adults 65 and older fall each year. Understanding the characteristics of fall patterns, including landing, impact, and related injuries, is of paramount importance to understand why and when injuries happen and implement adequate interventions to reduce the risk of adverse consequences. We analyzed real-world falls of older persons living in different settings to characterize the landing positions, related impacts, and injuries.

METHODS

We analyzed real-world falls from the Farseeing dataset [1], recorded by a wearable sensor worn on the lower back. We selected only those falls with a clear upright pre-fall position. We processed Accelerations and angular velocities to estimate landing positions and the amount of rotation during the descent phase. We computed the prevalence of different types of landings and associated these quantitative characteristics with the reported injuries. Finally, we estimated the impact force using the body mass of the subject and the maximum value of the acceleration norm.

RESULTS

We analyzed 92 falls in total. The landing positions were divided into backwards (BW), forwards (FW), and sideways (SW). The majority of falls were BW (67%), followed by SW (25%) and FW (8%), in accordance with [2]. BW falls were the ones with fewer injuries in percentage, also in accordance with [2]. Only two serious injuries happened, one in FW and one in SW. The highest rotation was found around the vertical direction V (see Figure 1.a)). Estimated impact forces were between 1000 and 5000 Newton, with a slightly higher impact force for falls with backward landing.

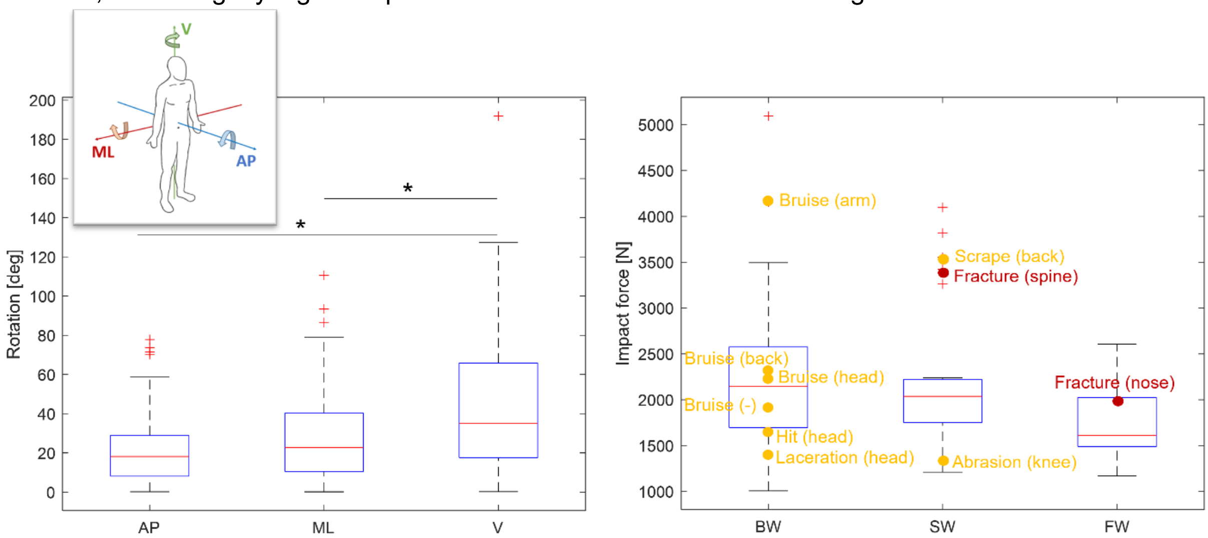

Figure 1. a) Degrees of rotation during falls around the mediolateral (ML), anteroposterior (AP), and vertical (V) axes, b) Impact forces and injuries

DISCUSSION

Through automatic analysis of wearable sensor data, it was possible to identify different patterns of real-world falls of older people, getting novel insights about the prevalence of different landing positions, associated injuries, movements during descent (i.e., rotations), and fall impact forces. The backward landing was the most frequent landing position, with the lowest relative number of associated injuries (both minor and serious injuries).

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Clinical relevance and methodological framework of feedback in robot-assisted upper limb rehabilitation in people with Multiple Sclerosis

F. Galletti[1,2], M. Gandolfi[3], G. Morone[4], M. Iosa[5,6], N. Smania[3], S. Mazzoleni[7,8]

[1]Master in Riabilitazione Neurologica, University of Verona, Italy; [2]Dipartimento di Scienze Neuroriabilitative, Istituto Auxologico Italiano, IRCCS, Milano; [3]Department of Neurosciences Biomedicine and Movement Sciences Neuromotor and Cognitive Rehabilitation Research Centre (CRRNC), University of Verona, Italy; [4]Department of Life, Health and Environmental Sciences, University of L'Aquila, Italy; [5]Department of Psychology, University Sapienza of Rome, Italy; [6]Smart Lab, IRCCS Santa Lucia Foundation, Rome, Italy; [7]Department of Electrical and Information Engineering, Politecnico di Bari, Italy; [8]The BioRobotics Institute, Scuola Superiore Sant'Anna, Pisa, Italy

INTRODUCTION

Upper limb functional impairments are prevalent and disabling outcomes in patients with Multiple Sclerosis (PwMS). Electromechanical and robotic devices are increasingly used in neurorehabilitation. However, few studies have been conducted in PwMS with high clinical heterogeneity of treatment programs and the variety of robot devices [1]. Feedback is a critical component in motor control and, hence, is involved in motor and cognitive rehabilitation with technological devices [2]. However, clinicians give little attention to the different types of feedback on movement control performance and motor learning provided by technological devices. This review systematically reports the rehabilitation protocols used in the upper limb rehabilitation in PwMS, focusing on the feedback taxonomy and serious game features.

METHODS

PubMed/MEDLINE, the Cochrane Library, and the Physiotherapy Evidence Database (PEDro) databases were systematically searched from inception to March 2021 including the following keywords: “multiple sclerosis” and “robot” and “upper limb”. Two reviewers (F.G., M.G.) independently screened for inclusion based on the title and abstract of all the ten potentially relevant studies identified. Data on the rehabilitation protocols intervention were retrieved according to the feedback features taxonomy proposed by Morone et al. (2021) [2]. According to Vieira et al., the features belonging to game genre, game nature, game development strategy were extracted from the selected studies [3].

RESULTS

Nine studies were included. Overall, 161 PwMS (EDSS 4.5-8) were included in the clinical studies. Seven of the nine studies employ end-effector robots. In all studies, continuously augmented feedbacks were used for therapy given in real-time [2]. Visual feedback is always present; haptic feedback was used in 7/9 studies, while auditory feedback is present in 5/9. Seven studies present feedback in a multimodal way, while only two studies use feedback in a single modality. A score of success was shown five out of nine. Performance feedback is present in two studies. Four studies use neutral feedback, three showing the position and one the trajectory The other three studies present feedback with positive or negative valence, while the last two valences of the feedback are not reported.

DISCUSSION

Clinical evidence regarding the relative effectiveness of different robotic therapy controllers suggests that some control strategies are more effective than others [4]. In contrast, there is a lack of evidence in the literature about which kind of feedback and elements of the serious game can help to achieve the best clinical results. In all works included in the present review, robotics training protocols are based on augmented feedback provided in continuous real-time. Most of the devices and exergames considered have been designed to rehabilitate stroke survivors. These findings emphasize the need for careful customization of rehabilitation devices in both hardware and software components, considering motor, sensory, and cognitive impairments in PwMS.

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Virtual coaching system for continuity of care and rehabilitation in patients with stroke. Results of the pilot study in the home scenario.

A. Seregni[1], P. Tropea[1], R. Re[1], V. Biscaro[2], M. Caprino[1], E. Judica[1], M. Corbo[1]

[1]Department of Neurorehabilitation Sciences, Casa di Cura del Policlinico, Milan, Italy; [2]Fondazione NEED Institute, Milan, Italy

INTRODUCTION

With the purpose of supporting self-care at home and health management as secondary prevention, the lack of continuity of care for patients with stroke requires innovative approaches that embed the home-rehabilitation into the clinical-care-chain. vCare, a European multicenter project (EU's Horizon2020 - https://vcare-project.eu), proposes a new ICT-based concept offering personalized home rehabilitation solutions and care pathways through a Virtual Coach (VC) that integrates machine learning technologies with coaching and clinical pathway services. Coaching at home can help these patients to proceed with a personalized form of rehabilitation and the VC can be a key technology to ensure continuity of care, reinforce self-management, enhance adherence to the care plan and risk prevention and ultimately empower patients. From the technical point of view, vCare integrates a set of technologies in a single platform. The VC provides the patient with a number of services clustered into:
1) coaching services such as physical training based on motion tracking and cognitive training; 2) supporting services such as reminders; 3) clinical pathways services allowing the seamless configuration of the VC [1, 2]. The aim of this study was to evaluate the health status (EQ-5D), the reduction of risk factors and the adherence to the prescribed care plan in patients with stroke, who experienced home rehabilitation, either mediated by the virtual coach (experimental group – EG) or conventional (control group – CG).

METHODS

Patients with stroke were enrolled among those who were hospitalized at the Casa di Cura del Policlinico (Milan, Italy). For a period of 30-60 days in their own home, patients experienced rehabilitation treatments and activities based on the neurologist, physiotherapist and neuropsychologist's clinical indications, provided at the discharge after the hospital care. All participants signed an informed consent. All research procedures were approved by the Local Ethics Committee. The patients in the CG performed motor and cognitive exercises suggested by therapists during the first visit. For the EG, personalized treatments and activities were suggested by the VC through a tablet, following the therapists' predefined schedule. The rehabilitation plan consisted mainly in motor and cognitive serious games executed in a virtual reality environment realized in the patient's home through a 3D depth camera and a monitor for the motor games, and the tablet for the cognitive ones. Additional risk factor–related activities (e.g.: e-learning session) were also foreseen and suggested. Every day the VC proposed videos with different contents; the patient could evaluate them, allowing the VC to refine the choice of videos and increase the patient's satisfaction. Moreover, based on the monitoring of patient's physical activity by means of an activity tracker wristband, the VC counseled additional exercise or leisure activities. The EQ-5D descriptive system and the EQ-5D visual analogue scale (EQ-VAS) were used as measure of health status for both patients belonging to the EG and CG.

PRELIMINARY RESULTS

All the enrolled participants (N=20; 71.9±10.2 years old; 13 males; 16 ischemic) completed the experimental protocol and no adverse events were encountered during the treatment period. Subjects showed mild impairment as documented by median NIHSS of 2.5 (IQR 2.0–4.8), and median FIM score of 115 (IQR 101.3–121.8). Preliminary results on the experimental group showed, for each week of treatment, an average of: 3.07±1.76 accesses to the VC's platform, 3.60±2.07 e-learning videos viewed, 12.69±10.75 active interactions of patients with the VC (i.e., feedback, reminders, questionnaires). In addition, results showed that patients worn the activity tracker 28.6 ± 7.7% of days of monitoring.

DISCUSSION

Data-analysis and interpretations on potential benefits (quality of life, reduction of risk factors, adherence to the care plan) related to both groups (i.e., experimental and control) will be presented during SIAMOC 2022. Considering: the preliminary results related to the activities performed by the experimental group, the state of the art regarding the adherence to conventional cares and the data already obtained in a clinical home-like scenario during the previous testing phase [3], we expect to demonstrate that the vCare solution is promising in educating and empowering patients to adhere and to pursue personalized physical and cognitive rehabilitation programmes, with the final aim of regaining independence and a better quality of life through a consistent healthier lifestyle.

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Sessione 3 – Upper limb movements analysis

Characterization of Parkinson's Disease using spectral features of kinetic tremor: correlationof on-line digitized handwriting and classical motor scales

S. Starita [1], A. Miladinovic [1], M. Guerra [2], L. Pascazio [2], A. Accardo [1]
[1] *Department of Engineering and Architecture, University of Trieste, Trieste, Italy*
[2] *Geriatric unit, Department of Medicine, Surgery and Health Sciences – Trieste University Hospital Trieste, ITALIA*

INTRODUCTION

Tremor is one of the motor impairments of Parkinson's disease (PD). To date, kinetic tremor in PD is barely examined and there is lack of information on the relation between its severity and scales relatedto specific motor deficits [1]. In this study, we aimed at investigating the correlation between handwriting-related kinetic tremor and motor score measures by motor part of Unified Parkinson's Disease Rating Scale (UPDRS-III) [2], using a digitizing tablet.

METHODS

In this preliminary study, eight PD patients (7M/1F; age 74.5±8 years) draw an accurate Archimedes' Spiral (AS) and fast, overlapped Circles (C) for a duration of 15 seconds. All patients underwent motor deficit assessment using UPDRS-III. Power Spectral Density of both velocity and acceleration profilesin their horizontal, vertical, and curvilinear components was estimated by using Welch's method, with a Hamming window on intervals of 5s and a 50% overlap. To analyze the power distribution related to different movement-associated phenomena, the ratio between two frequency bands (B_{ME}/B_T) and theB_T bandwidth (BW) were calculated for each subject. B_{ME} is the band of voluntary Movement Execution required by the task, ranging from 0.2 to 4 Hz, and B_T is the band associated with involuntary Tremor, ranging from 4.0 to 12 Hz [3]. Normalized Jerk, a classic kinematic feature representing handwriting fluidity, was also estimated. The correlation between the parameters and UPDRS-III scores were assessed using Spearman's rank correlation coefficients. All the evaluations were conducted in the pharmacological *on* state of PD patients.

RESULTS

A positive correlation was found between Jerk and UPDRS-III scores (Table 1). On the contrary B_{ME}/B_T correlates negatively with motor scale scores in horizontal and vertical velocities (Vx, Vy) for both tasks, vertical and curvilinear acceleration (Ay, Ac) for AS task, horizontal and vertical acceleration (Ax, Ay) for C task. Only Ay of C task shows correlation with motor scores.

Table 1. Spearman's rank correlation coefficients (rho) and corresponding p-values of UPDRS-III and handwriting spectral/kinematic features (in bold italic the p-value<0.05)

		Spectral Features												Kinematic Feature
		V_x		V_y		V_C		A_x		A_y		A_C		Jerk
		B_{ME}/B_T	BW(Hz)	B_{ME}/B_T	BW(Hz)	B_{ME}/B_T	BW(Hz)	B_{ME}/B_T	BW(Hz)	B_{ME}/B_T	BW(Hz)	B_{ME}/B_T	BW(Hz)	
AS	rho	-0.886	-0.314	-0.886	-0.600	-0.829	0.029	-0.771	-0.152	-0.886	-0.696	-0.886	0.200	0.886
	P	***0.033***	0.564	***0.033***	0.242	0.058	0.983	0.103	0.833	***0.033***	0.144	***0.033***	0.714	***0.033***
C	rho	-0.874	0.180	-0.778	0.000	-0.120	0.067	-0.886	-0.380	-0.886	-0.946	0.084	-0.036	0.850
	p	***0.007***	0.673	***0.029***	1.000	0.781	0.886	***0.006***	0.354	***0.006***	***0.001***	0.849	0.936	***0.011***

DISCUSSION

The results highlight that the severity of motor deficits in PD patients, as assessed by a widely employed motor scale, correlates with the outcomes of spectral and kinematic analysis of handwriting that indicate a loss of fluency, an increased power at BT level and a thinning of the spectral peak of B_T. This suggests that handwriting assessment of parkinsonian dysgraphia can be used to implement clinical evaluation and represents a non-invasive, low-cost method for the identification of objective and reproducible biomarkers of kinetic tremor.

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An ISB-consistent upper limb model based on the Denavit-Hartenberg convention for joint angle estimation during prolonged rehabilitation exercises.

M. Caruso [1,2], L. Gastaldi [1], S. Pastorelli [1], A. Cereatti [1], E. Digo [1]
[1] Politecnico di Torino, Torino, Italy, [2] University of Sassari, Sassari, Italy

INTRODUCTION

An accurate and robust joint kinematics description is a crucial prerequisite for the development of tele-rehabilitation applications. Miniaturized wearable sensors (IMUs), along with the use of efficient sensor fusion algorithms, represent a suitable solution. However, orientation drift can affect real-time joint kinematics over prolonged acquisition. In this work, we proposed an optimization kinematics framework which exploits a Denavit-Hartenberg (DH) model of the upper limbs, compliant with the guidelines of the International Society of Biomechanics. The accuracy of the estimated 3D shoulder and elbow kinematics was evaluated using data recorded by two IMUs attached to a robotic arm during a 20-minute planar exercise and compared with the errors obtained using a model-free approach.

METHODS

The upper limb was modelled as a three-segment chain including trunk, upper arm (UA), and the forearm (FA). Shoulder and elbow joints were modelled with three (φ_1, φ_2, φ_3) and two degrees of freedom (φ_4, φ_6), respectively. The carrying angle (φ_5) was introduced as a fixed subject-specific parameter to describe the physiological abduction of the FA with respect to the UA. The joint angles were computed in an optimization process which minimizes at each time step the difference between the orientation predicted using the DH model and the corresponding orientation estimated by a sensor fusion algorithm without the magnetometer [1]. In addition, joint angle constraints were set based on the maximum angular velocity, the physiological angular limits, and the specific range of movement when known *a-priori*. To validate the methods, two IMUs (Xsens – MTw) were attached to the UA and FA of a robotic arm (Kinova – Jaco2) programmed to mimic a shoulder flexion-extension (φ1, φ2, φ3), an elbow flexion-extension (φ4), and a forearm prono-supination (φ6), simultaneously, for 20 minutes (~150 cycles) [3]. The φ_5 was equal to zero for the robot. IMU and reference data were collected at 100 Hz. The gyroscope offset was computed during a preliminary acquisition and then subtracted from the measurements. The accuracy was evaluated in terms of root mean square difference (RMSD) between the model-based optimized and robot reference joint angles. Furthermore, the RMSD corresponding to the Euler inversion of the FA-to-UA relative orientation (model-free) was also computed.

RESULTS

The RMSD (deg) for the joint angles obtained with the optimization (model-free) process amounted to 1 (10.2), 0.4 (0.2), 0.9 (1.4), 3.0 (3.1), 0 (8.2), and 1 (6) for φ_1, φ_2, φ_3, φ_4, φ_5, φ_6, respectively.

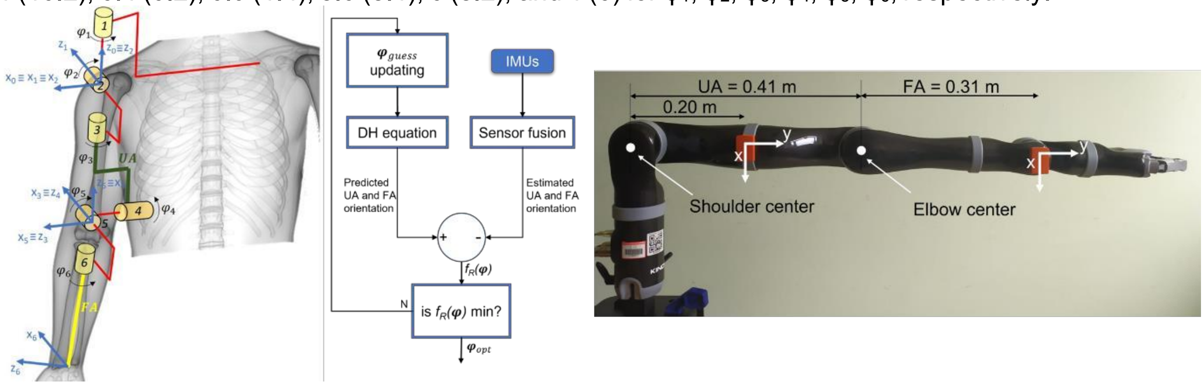

Figure 1. The DH upper limb model (left), the optimization framework at each time step (center), and the robot setup (right).

DISCUSSION

The proposed methods allowed to reduce joint angles errors of almost a factor 10 over long period compared to model-free approach (1.1 vs 8.9 deg on average). These results if further confirmed on human experiments can contribute to the design of tele-rehabilitation applications relying on the accurate upper limb joint kinematics estimates. Funded by Sardegna Ricerche (POR FESR 2014/2020).

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Does unilateral adhesive capsulitis also affect the healthy shoulder? Bilateral evaluation of shoulder kinematics and pain sensitivity using IMU sensors and algometer

S. Starita[1], M. Deodato[2], M. Martini[2], L. Murena[2], A. Accardo[1]

[1] DIA, University of Trieste, Trieste, Italy [2] DSM, University of Trieste, Trieste, Italy

INTRODUCTION

Adhesive capsulitis (AC) is a generally unilateral condition caused by a pathological retraction of the capsule and ligaments of the glenohumeral joint. This results in progressive pain with a decrease of Pain Pressure Threshold (PPT), and in gradual loss of range of motion (ROM) in all planes of space [1]. The effectiveness of physical therapy treatments depends on the appropriate clinical management strategies, for this reason, the objective evaluation and treatment remain challenging [2]. In this observational study, clinical and kinematic differences between healthy and capsulitis shoulder before and after a conservative physiotherapy protocol are enquired.

METHODS

Humeral flexion/abduction motions of 10 patients with unilateral AC were investigated with inertial and magnetic (IMU) sensors. Specifically, ISEO protocol was used to assess the differences in humeral ROM between the pathological and healthy shoulder [3], and pain sensitivity was assessed by means of algometer. The acquisitions were performed, on both capsulitis (cS) and healthy shoulder (hS), twice: at the baseline (T0), and after 20 one-hour individual sessions of physiotherapy protocol (T1) [4].

RESULTS

Significant differences in the humeral ROM during both motion exercises were detected between cS and hS at T0 but not after physical therapy treatment (Figure 1a). On the contrary PPT increased significatively at the cS level (not shown) and at the hS level (Figure 1b).

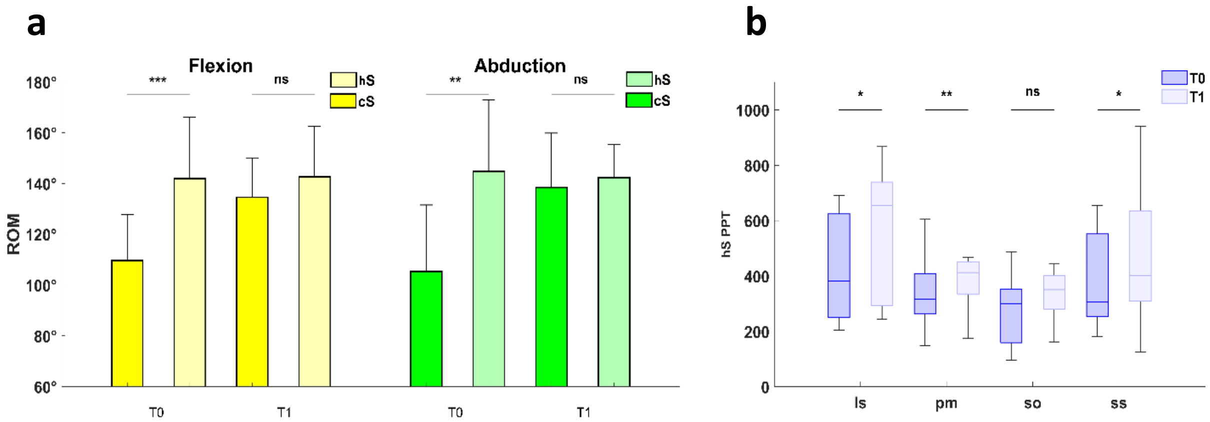

Figure 1. a - ROM of both shoulders before and after treatment. **b** - PPT of healthy shoulder muscles before and after treatment (so *suboccipitalis*, ls *levator scapulae*, ss *subscapularis*, pm *pectoralis minor*). Statistical analysis by means of Wilcoxon rank sum test for paired data (* = p<0.05; ** = p<0.01; *** = p<0.001).

DISCUSSION

To date, no previous study has investigated the quality of movement with IMU sensors nor the differences between hS and cS in patients with AC. This study reveals that ISEO protocol is an efficient approach for quantitative evaluation of physical therapy efficacy in AC. Moreover, while physical therapy does not improve ROM in hS, it does ameliorate significantly bilateral patients' pain sensitivity: since unilateral AC alters motor programs not only of the affected shoulder but also of dorsal and cervical elements [5], physical therapies treating and mobilitating these areas have a bilateral biomechanical effect that allows a reduction of pain sensitivity also at the level of hS.

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Multi-user myoelectric pattern recognition for shoulder motion intent detection

M. Scattolini[1], A. Tigrini[1], A. Mengarelli[1], S. Fioretti[1], L. Burattini[1], M. Morettini[1], F. Verdini[1]
[1] *Department of Information Engineering, Università Politecnica delle Marche, Ancona, Italy*

INTRODUCTION

Myoelectric interfaces have a large range of applications in rehabilitation and prosthetic fields. The electromyographic signal (EMG) generates different patterns of activations according to a specific motion activity allowing the extraction of task-discriminant features, and leading to an efficient external device control [1]. The application of such methodologies in the motion intention detection (MID) is challenging, since this requires to predict the subjects' intentions while attempting to generate a certain movement [2]. Despite good results have been obtained for the intra-subject scenario [3], the inter-subject generalization still remains an issue. The aim of this work was to investigate myoelectric interfaces for multi-user application on data relative to the shoulder MID.

METHODS

The dataset was composed by eight subjects performing six shoulder movements [4]. The signals were segmented into 150 ms windows with an overlap of 75 ms and four time-domain features were extracted. The feature matrix was split into a calibration and testing subsets. The spectral regression (SR) was used to reduce the dimension of the feature space and with the canonical correlation analysis (CCA) the reduced feature set was projected into a new space, where data related to different subjects are maximally correlated. The obtained projection coefficients were then used on the testing subset. The SVM classifier was trained on the projected calibration subset of a user A and the projected testing subset of a user B was used for testing. In this way, the classifier was trained on data belonging to a certain subject, and then tested on unseen data of a different person.

RESULTS

Outcomes demonstrated that the presented approach boosted the classification performance, even if only one trial was used for the training session, with respect to the case in which neither the SR nor the CCA were applied. Indeed, the F1-score increased from 28% up to 53%. It can be also appreciated that increasing the number of repetitions for the calibration subset, the F1-score was further improved, up to 70% already with two repetitions. The accuracy presented a similar behaviour (Figure 1).

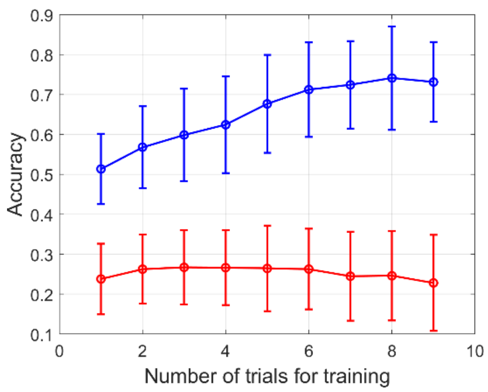

Figure 1. Mean values (dots) and standard deviations (vertical bars) of the accuracy as a function of the number of trials used for calibration. Very low classification accuracy was obtained without the application of the framework SR-CCA (red), whereas higher values were reached when the SR and CCA were employed (blue).

DISCUSSION

The coupling between SR and CCA proved to be reliable for the multi-user oriented shoulder MID. In MID problems, the movement recognition is performed relying on features extracted from a very short time period and on a transient epoch of the EMG signal, before the movement was fully achieved. For this challenging task, the present architecture proved to be reliable in an inter-subject scenario. Indeed, it provided high classification performances training on one subject and then testing on an unseen one, hence supporting the use of CCA for the development of subject-independent myoelectric interfaces.

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Upper limb movement during locomotion in patients with neurological disorders: a wearable-based approach

M. De Angelis [1], V. Belluscio [1,2], A. Orejel-Bustos [1,2], M. Tramontano [1,2], G. Vannozzi [1,2], E. Bergamini [1,2]

1 University of Rome "Foro Italico", Rome, Italy, 2 IRCCS Santa Lucia Foundation, Rome, Italy

INTRODUCTION

The contribution of upper limbs during walking is crucial in maintaining balance and stability: humans, in fact, swing each upper limb in phase with contra-lateral lower limb at their comfortable walking speed, with a ratio of 1:1 [1], thus counteracting the angular momentum, reducing the energy expenditure, and improving the overall gait efficiency [2,3]. In people who suffer from neurological disorders, like Multiple Sclerosis (MS) or Traumatic Brain Injury (TBI), upper limb function is often impaired, resulting in differences in arm swing frequency, amplitude, symmetry, as well as in the ratio between step and arm swing frequency, compared to healthy people [2]. Although it is known that a neurological rehabilitation program should focus on the recovery of a proper gait also emphasizing the contribution of upper limbs [1], few studies analyzed the contribution of the upper arms during locomotion in people with neurological disorders. The aim of this study is to explore a wearable sensor-based protocol for the assessment of the upper limb movement in patients with MS and TBI compared to healthy participants.

METHODS

Thirty-three patients suffering from MS (24 F; 49.8±9.3 y; EDSS 4.0±1.6), 8 patients suffering from TBI (2 F; 32.3±14.1 y; DGI 18.3±5.9), and 20 healthy adults (HC) (9 F; 37.0±19.9 y) were enrolled in this study (CE/PROG.700). Each participant performed a 10-meter Walking Test (10mWT) while wearing 5 synchronized inertial measurement units (IMUs) located at sternum, both wrists and distal tibiae level. Stride segmentation was performed using tibiae-mounted IMUs and the following parameters were estimated from wrist- and sternum-mounted IMUs [4]: arm oscillation frequency, peak and range of the angular velocity norm, as well as step to arm oscillation frequency ratio for the right (RW) and left (LW) wrists (freq, gyro peak, gyro range, Step-freq ratio). The range of the sternum cranio-caudal angular velocity was also obtained (sternum gyro range), together with a measure of symmetry (Symmetry Index [5]) between RW and LW angular velocity ranges. After checking for data normality, a one-way ANOVA was used to test for significant differences among MS, TBI, and HC. Post-hoc analysis was performed using Bonferroni-Holmes correction for multiple comparisons.

RESULTS

Results are depicted in Fig.1 (the larger the spider, the better the performance). Significant differences were found in frequency, symmetry, and angular velocity parameters among the MS, TBI, and HC. Patients with TBI seem to be characterized by a reduced performance with respect to MS, except for the step to arm swing ratio.

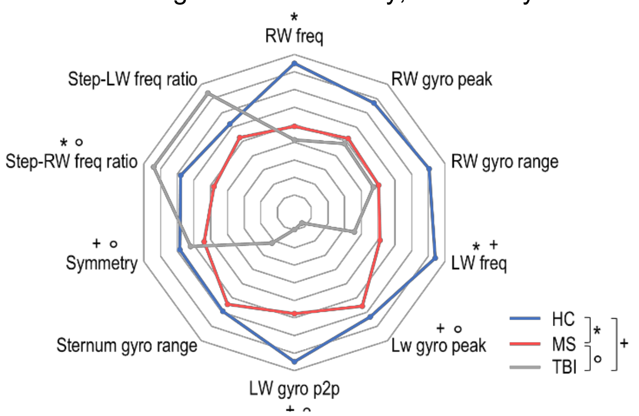

Figure 1. Radar plot of the estimated parameters for MS, TBI and HC.

DISCUSSION

The proposed assessment protocol demonstrates a potential clinical value in discriminating not only patients with neurological disorders from HC, but also patients with MS from TBI, who showed significant differences in terms of swing frequency, angular velocity range, and symmetry. This information could be useful in tailoring rehabilitation treatments involving the upper limbs during gait exercises [1]. Although in the present study, no significant difference was found among the three populations walking speed, the effect of the latter on the proposed metrics should be better investigated in further studies.

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Sessione Methodological Poster 1

Kinematic analysis of ankle joint during gait in drop foot patients wearing passive Ankle-Foot Orthosis.[2]

A. Coccia[1,2], F. Amitrano[1,2], G. Pagano[2], L. Dileo[2], V. Marsico[2], G. Tombolini[3], G. D'Addio[2]
[1]Department of Information Technologies and Electrical Engineering, University 'Federico II', Naples, Italy
[2] Scientific Clinical Institutes ICS Maugeri SPA SB, Pavia, Italy
[3]Officine Ortopediche Tombolini, Taranto, Italy

INTRODUCTION

The term 'drop-foot' refers to an uncommon presentation of degenerative diseases, derived from neurological, muscular or anatomical complications, resulting in difficulties in performing foot dorsiflexion. This causes an abnormal gait pattern, characterized by two complications: the 'foot slap' at the initial contact with the ground, and the 'toe-drag' during the swing phase. In order to support gait, a common non-surgical treatment is the use of lightweight 'L' shaped ankle-foot orthosis (AFO). In this study we combine gait analysis and biomechanical modeling tools to analyse the kinematics of ankle joint in gait with and without the support of a passive AFO, namely the 'Codivilla' spring.

METHODS

The study was conducted on a population of eighteen adult subjects suffering from unilateral drop-foot (7 females, age 58.1 ± 14.5 years, BMI 23.4 ± 4.60). The infrared multicamera system SMART DX by BTS Bioengineering (Milan, Italy), was used to acquire data relating the 3D position of 22 markers placed on patient's body, following the Davis protocol, during walking trials performed in two conditions: barefoot and with the AFO mounted on the affected limb. Data were then imported in OpenSim (SimTK software) and used to solve an inverse kinematic problem in order to reproduce walking and compute the evolution of body joints angles. Ankle dorsiflexion and subtalar inversion signals were analysed using MATLAB (2022a) to compute the following metrics for each angle: Range of Motion (RoM), angle at Heel Strike (HS) and angle at Toe Off (TO). The two-way ANOVA statistical test was used to analyse the effects of two factors: walking condition (with versus without AFO) and limb (affected versus contralateral). The interaction factor (condition*limb) was also analysed.

RESULTS

Figure 1 shows the evolution over the gait cycle of the ankle and subtalar angles in the two walking conditions for each foot. Solid lines are obtained as the mean value of subjects' averaged step. Shaded areas represent the variability among subjects. Table 1 reports the results of the two-way ANOVA test in terms of p-value.

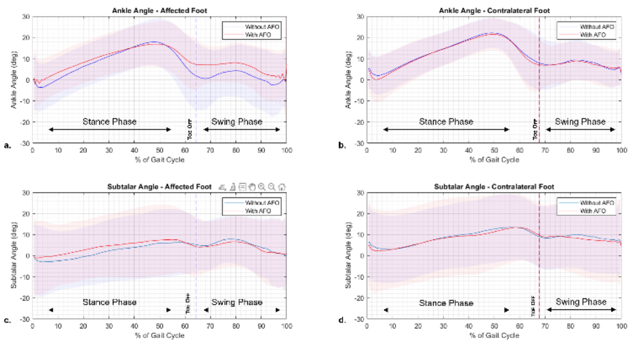

Figure 1. Comparative plots of ankle and subtalar angles with AFO/without AFO. Positive values in ankle angle represent dorsiflexion, positive values in subtalar angle represent inversion.

Table 1. Statistical results of two-way ANOVA. The p-value are organized for parameters and factors. Red values represent statistically significant differences for the considered factor (p-value<0.05).

ANOVA p-value	Condition	Limb	Condition *Limb
RoM Ankle Angle	<0.01**	0.4505	<0.01**
Ankle Angle at HS	0.8583	<0.05*	0.4598
Ankle Angle at TO	0.2340	0.3074	0.2036
RoM Subtalar Angle	0.2044	0.6866	0.6846
Subtalar Angle at HS	0.8179	<0.01**	0.6685
Subtalar Angle at TO	0.3116	0.2846	0.6617

DISCUSSION

Results show that the AFO 'Codivilla' spring acts on the kinematics of ankle by reducing the RoM during walking, as it limits the plantar flexion of drop foot. However, it does not significantly affect the ankle angle at HS and TO, although the first is lower in the affected foot. Results also show that the evolution of subtalar angle in the affected foot is altered, not in the RoM, rather in values, in particular at the initial phases of gait cycle. However, the considered orthosis does not produce improvements in the kinematics of subtalar angle. This is probably due to the L-shape of the device, which does not limit ankle inversion/eversion. In conclusion our study confirms the alterations of the drop foot in the kinematics of the ankle joint, particularly at Heel Strike in which both the ankle and the subtalar angle are altered compared to the contralateral foot. The use of Codivilla spring results in a more physiological dorsiflexion of the ankle but has no significant effect on the kinematics of the subtalar joint.

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

Study of Gait and Posture Kinematic Indices for the Evaluation of Ankle-Foot Orthoses[1]

F. Amitrano[1,2], A.Coccia[1,2], G.Pagano[1], L. Dileo[1],E. Losavio[1], G. Tombolini[3], G. D'Addio[2]
[1] Department of Information Technologies and Electrical Engineering, University of Naples 'Federico II', Naples, Italy
[2] Scientific Clinical Institutes ICS Maugeri SPA SB, Pavia, Italy
[3] Officine Ortopediche Tombolini, Taranto, Italy

INTRODUCTION

Motor disabilities resulting from pathologies such as brain injuries, strokes, spinal cord injuries and other neurological diseases usually lead to deficits in locomotion. One such problem is Drop Foot (DF), which can severely impair walking function. To cope with this pathology, ankle-foot orthoses (AFOs) can be used, which allow the patient to improve ankle dorsiflexion during the swing phase of the foot.
The aim of this research work is to evaluate the impact of the use of a passive AFO orthosis on gait by studying the kinematic indices of gait in patients with DF. The study was conducted on a population of 19 patients at the IRCCS Istituti Clinici Maugeri in Bari.

METHODS

Ninteen subjects (12 males, 7 females), with unilateral DF syndrome, were involved in this research. The experimental data collection procedures consisted of gait analysis sessions performed with the Mobility Lab system by APDM (APDM Inc, Portland, OR, USA, http://apdm.com). In this test subjects wore 3 IMUs (low back and dorsal surface of the feet) and are instructed to stand quietly for 30s and then asked to walk over a 7 meters walkway, turn around a pivot and walk back to the starting point. Each subject performed two sessions in two different gait conditions: (i) unconstrained gait (without any AFO); (ii) gait with an AFO attached to the participant's affected limb. The median value of each parameter among the three selected trials was extracted and considered for the analysis. We focused on the following set of spatio-temporal parameters, which have clinical relevance in patients with DF: Elevation at Midswing (cm) (EMS), Gait Cycle Time (s) (GCT), Stride Length (m) (SL). These metrics were statistically analysed with two-way ANOVA test to explore the effects produced by the variables 'Condition' (With/Without AFO), 'Limb' (Affected/Contralateral) and the interaction between these two factors. Statistical analyses were performed using R version 4.0.3 (R Foundation, Vienna, Austria).

RESULTS

Table 1 presents the results of the statistical test, reporting p-values when a significant difference was obtained ($p-value < 0.05$). Otherwise the absence of statistical significance is reported (ns). The level of statistical significance is specified by a different number of stars ($*$): the higher number of stars, the lower α value threshold for the $p - value$. Figure 1 shows the boxplots representing the distribution of the analysed data.

Table 1. Results of statistical analyses.

	Condition	Limb	Condition*Limb
EMS	ns	$*$	ns
GCT	$***$	ns	ns
SL	ns	ns	ns

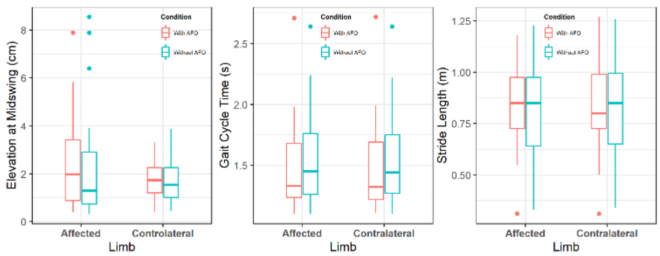

Figure 1. Each plot presents the distribution of data of the three examined parameters, divided per condition and limb. The box boundaries represent the 25-th (Q1) and 75-th percentile (Q3).

DISCUSSION

This paper presented a clinical study regarding the impact of using a solid plastic AFO on spatio-temporal gait metrics of 19 patients with DF syndrome. Our analysis pointed out that EMS is generally higher in affected limb than in contralateral limb, as the patient compensates for difficulties in lifting the front part of the foot by increasing foot elevation during swing. However the use of the AFO has no significant effects on either foot. On the contrary, the GCT is reduced when the AFO is worn by the patient demonstrating higher confidence in step execution. The use of the AFO also tends to improve the stride length of both feet, however this difference is not statistically significant. In future studies, it would be better to evaluate changes in gait metrics on a longer walking trial, to carry out the assessment on a larger number of steps.

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

Gait performance in patients operated for soft tissue sarcoma measured through instrumental gait analysis and surface EMG.

M. Germanotta[1], F. Falchini[1], S. Valeri[2], C. Pagnoni[2], B. Vincenzi[2], A. Gronchi[3] and I. Aprile[1]
[1] *IRCCS Fondazione Don Carlo Gnocchi, Florence, Italy;* [2] *Università Campus Biomedico, Rome, Italy;*
[3] *Fondazione IRCCS Istituto Nazionale dei Tumori, Milan, Italy.*

INTRODUCTION

Soft tissue sarcomas (STS) are a group of rare and heterogeneous tumors that includes about 1% of all adult malignant neoplasms occurring in the trunk, retroperitoneum or limbs [1]. Surgery is the mainstay of treatment, and microscopic negative margins need to be achieved in order to improve disease local control. Considering the heterogeneity of the clinical picture after the treatments in patients with STS, a quantitative and specific evaluation of the motor impairment should be added to clinical assessment for planning a tailored rehabilitation program. Sarcoma specific tools to measure patients' outcome after rehabilitation are lacking, while the need to achieve comprehensive knowledge on this specific topic is always more and more felt by the sarcoma community [2]. In this perspective, instrumental tools can be useful to evaluate the impact of surgery and neoadjuvant treatments on the kinematics of the upper and lower limbs. Here, we hypothesize that a comprehensive assessment of patients after preoperative neoadjuvant treatments and surgery, will allow us to characterize patients' deficit and personalize rehabilitation

METHODS

In this preliminary study, we analyzed gait patterns after surgery in 7 subjects with lower limb or retroperitoneal/pelvic STS, with different clinical characteristics, through an optoelectronic system (Smart D500, BTS, Italy) and two force platforms (P6000, BTS, Italy). Subjects were asked to walk at a comfortable, self-selected pace, along a 10 m pathway. Each patient performed 10 gait trials. Muscle activity was measured bilaterally through surface EMG (sEMG) (Free1000, BTS, Italy) from four muscles (rectus femoris, biceps femoris, tibialis anterior, and lateral gastrocnemius), and the envelopes of the rectified sEMG signals were averaged across trials to obtain the mean activation pattern profiles.

RESULTS

Figure 1A shows a radar plot representing gait impairment patterns in seven patients operated for lower limb sarcoma, standardized to healthy data (z-scores), while the sEMG profiles averaged across the gait cycles related to the operated side (upper row) and the contralateral side (lower row) are reported in Figure 1B.

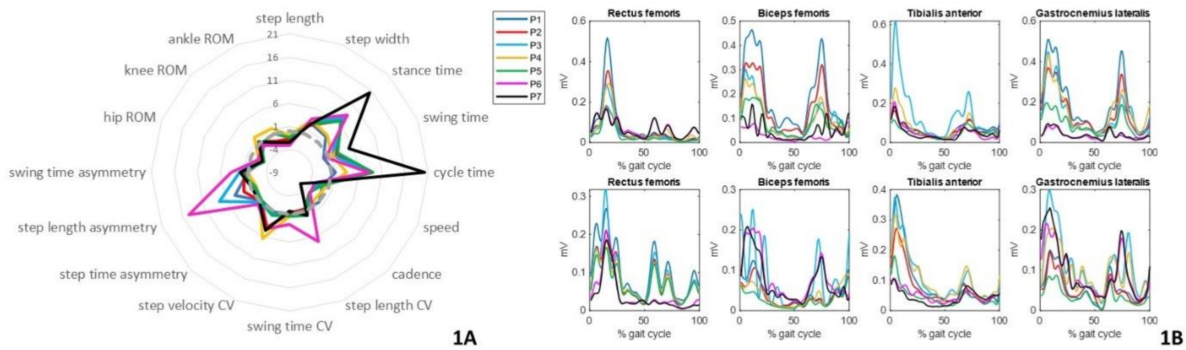

Figure 1 – (A) Gait variables in seven patients (P1 to P7) operated for lower limb sarcoma, standardized to healthy data (z-scores); (B) sEMG profiles in the operated (upper row) and the contralateral side (lower row).

DISCUSSION

These early findings support the feasibility of using instrumental gait analysis and surface EMG to identify movement patterns in patients operated for STS or RPS and, therefore, to quantify the different gait strategies that patients develop as a result of tumor location and surgical approach.

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Stride detection in running using foot-mounted magneto-inertial sensors: a preliminary investigation for different running paces

E. Dipalma [1], R. Rossanigo [2], M. Caruso [1,2], R. Nicola [1], G. Martinez [2], M. Morrone [2], M. Meloni [2], T. Vieira [1], A. Cereatti [1]

[1] *Politecnico di Torino, Torino, Italy,* [2] *Dipartimento di Scienze Biomediche, Università degli Studi di Sassari, Sassari, Italy*

INTRODUCTION

The analysis of running biomechanics could help understanding the mechanics underlying running-related injuries and optimizing running efficiency [1]. As running has increasingly become a popular leisure and competitive activity, the demand for low-expense and easy-to-use equipment for in-field assessment has increased, and magneto-inertial sensors (MIMUs) represent the most adopted solution [2,3]. The aim of this study was to compare the performances of three methods for initial contact (IC) detection on a wide running speed range (10–32 km/h).

METHODS

Five amateur runners were asked to run on a running track at 10 km/h for 3 min, and five elite runners were asked to run along an 80m-straight running track at 70%, 85% and 100% of their maximal speed. Each participant was instrumented with two MIMUs [4] (fs = 100 Hz), fixed to the shoelaces of both feet. Three different algorithms for the detection of ICs were implemented: 1) the method proposed by Schmidt et al. [2] for sprints (21-32 km/h), based on the vertical accelerations and the slope of the medio-lateral angular velocities; 2) the method proposed by Benson et al. [3], based on the norm of the acceleration and tested for 10 km/h running; 3) a novel method which exploits the periodicity of the antero-posterior projection of the magnetic field, related to changes in foot inclination, to define a stride duration-dependent search window within which the IC is identified as the minimum in the acceleration norm after the first peak in the filtered acceleration norm (low-pass Butterworth, cutoff 5 Hz). Due to the lack of a gold standard for IC detection, the three methods were evaluated in terms of missed and extra strides detected, based on video comparison, whereas the agreement among them was assessed computing stride-by-stride differences between different methods.

RESULTS

Table 1 shows differences in the stride durations estimation obtained by the three methods over the amateur runners (analyzed strides = 1316) vs. the sprinters (analyzed strides = 771). Methods 2) and 3) provided a mean percentage of missed and extra IC events below 5%, whereas missed strides for the sprinters dataset amounted to 32.3% with Method 1). The correct strides number was only achieved by Benson et al. in all the 10 km/h trials and by the proposed method in all the sprint trials.

Table 1. Mean absolute differences (MAD) and 95% limits of agreement interval (LoA) between the stride durations computed from the IC obtained using the three implemented methods.

	Method 1 – Method 2		Method 2 – Method 3		Method1 – Method 3	
	MAD (ms)	LoA 95% (ms)	MAD (ms)	LoA 95% (ms)	MAD (ms)	LoA 95% (ms)
Amateurs	45	366	33	277	42	374
Sprinters	109	620	108	626	23	156

DISCUSSION

As expected, the implemented methods for IC detection led to different results according to the running speed. Method 2) and Method 3) enabled the best performances in terms of missed and extra events for trials at 10 km/h and sprints, respectively. Analyzing the differences between stride duration estimates with different methods and populations, the highest agreement was reached between Methods 1) and 3) for high-speed running. In conclusion, the novel method appears more suitable for running at higher speeds. Current work is focused on the development of a speed-adapting method for running events detection, its validation against instrumented insoles, and the increase of the sampling frequency.

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A Framework for the Simultaneous Acquisition and Analysis of Gait and Clinical Data

N. Balletti [1,2], **A. Ciccotelli** [3], **G. Laudato** [2], **R. Oliveto** [2,3]
[1] *Italian Joint Veteran Defense Center, Rome, Italy*
[2] *University of Molise, Pesche (IS), Italy* – [3] *Datasound srl, Pesche (IS), Italy*

INTRODUCTION

Machine Learning (ML) has shown significant effectiveness in Gait Analysis (GA) applications to automatically recognize pathological conditions, such as abnormal gaits [1], Parkinson's disease [2], or for assessing the deviations from normal gaits [3] or measuring the balance ability in leading a walk [4] in post-stroke patients. Promising results have been also achieved in the treatment of abnormal neurological conditions, such as Traumatic Brain Injuries, by providing quality indices to gaits [5], or a complete and structured methodology for the assessment and analysis of gait [6]. Albeit promising, all those models are built from different tools and acquisition settings, often with differences even in the gait characteristics considered and without considering clinical biomarkers. Such a scenario makes the adoption of ML in GA applications in real contexts quite challenging.

METHODS

Our goal is to propose a framework to facilitate the adoption of ML in GA applications in real contexts. The framework, called EDAM (*Explainable DiAgnosis recoMmender*), allows the acquisition of gait and clinical data from different sensors. Collected data are stored in a standardized format facilitating the definition of ML-based modules for automatic data analysis.

RESULTS

Figure 1 depicts the EDAM framework. The *Database Management* component oversees the storing of data. A relational DB is used to store the medical record, while gait and clinical data acquired through sensors are stored in a NoSQL DB. The *Data Acquisition* component allows the acquisition of gait data and of the following clinical data: heart rate, EEG, and EMG. This module is *device agnostic*: Any device can be used through a dedicated driver. Currently, EDAM provides drivers for the acquisition of gait data from Vicon and Azure Kinect DK, heart rate from Polar H10, EEG from DSI-7, and EMG from Cometa Mini Wave. The *Decision Support System* (DSS) component allows the automatic analysis of data. Through a standardized API (Application Programming Interface) is possible to add to the DSS new ML models depending on the analysis to be performed. Currently, EDAM provides two ML models for the analysis of deviations from normal gaits and for the Parkinson's disease, respectively. Thanks to the XAI (*eXplainable Artificial Intelligence*) module, the DSS also provides the rationale – in natural language – behind the prediction. This means that the support to the medical personnel is provided not only in terms of a classification outcome but also providing a pre-report that highlights the main factors that lead to the prediction.

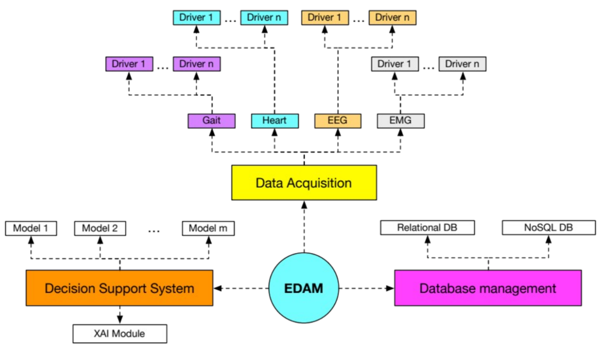

Figure 1. *The EDAM framework.*

DISCUSSION

EDAM allows to collect gait and clinical data from (potentially) any device. The data are stored in standardized format and dedicated API allows the definition of ML-based module for the automatic analysis of both clinical and gait data. EDAM is designed to overcome the limitations of many GA systems, by providing a unique framework that is at the same time *device agnostic*, *extensible*, *multi-prediction*, and *XAI-based.*

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Relevance of RMS of gait analysis wearable data in evaluating gait asymmetry: a case study.

M. Barbalace [1], A.S. Orejel Bustos [2], V. Belluscio [2], T. Sciarra [3], F. Rizzo [3], C. Damiano [1], F. Martelli[1], V. Camomilla [2], C. Giacomozzi [1]

[1] *Istituto Superiore di Sanità, Rome, Italy,* [2] *University of Rome "Foro Italico", Rome, Italy,* [3] *Joint Veterans Defence Center, Rome, Italy*

INTRODUCTION

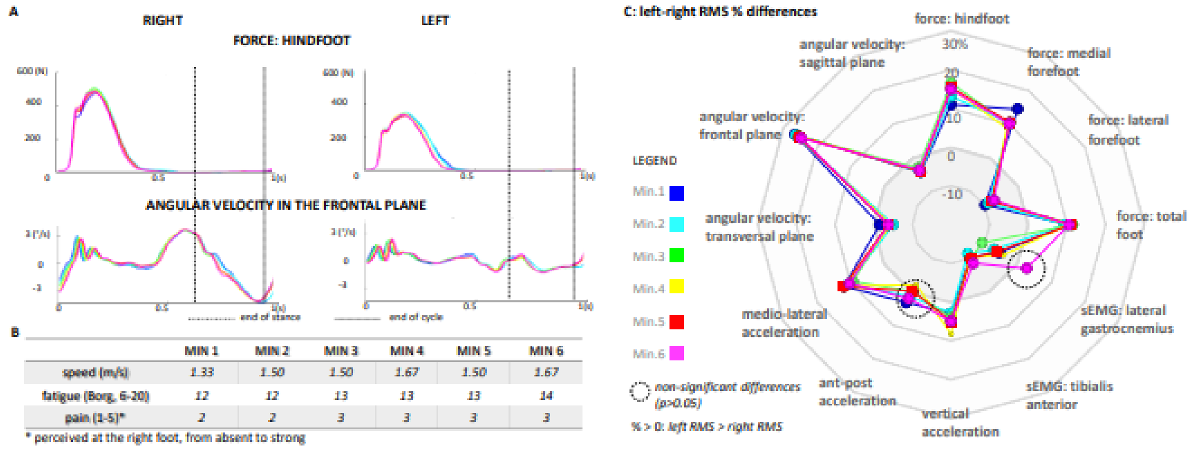
High levels of lower-limb functional asymmetry represent a major risk for musculoskeletal injuries in athletes. Its examination can support decision-making of coaches and sports medicine professionals [1]. This case study aims at investigating the feasibility and potentiality of assessing it using RMS values of kinematic, kinetic and EMG data [2].

METHODS

Within the MOVIDA Project [3], a wearable kit was used, made of load insoles (INS) (Loadsol, novelGmbH, 100Hz, vertical force at hindfoot, medial and lateral forefoot, and total foot), MIMUs (Opal, APDM, 128Hz, 2 at the ankles and 1 on the pelvis) and sEMG probes (DueLite, OTBioelettronica, 2048Hz, lateral gastrocnemius and tibialis anterior). Participants performed the 6MWT on a magnetic treadmill (Power Mag, Toorx). At each minute they were asked for fatigue (6-20 Borg scale) and pain (5-levels Likert scale) perception. Signals were resampled, synchronized, filtered and processed: 20N-threshold (INS); 4th-order Butteworth filter (sEMG: 5-450Hz; MIMUs: <20Hz); rectification and enveloping (sEMG); rigid transformation (MIMUs); average removal (sEMG, MIMUs). RMS was calculated for each cycle, segmented on the basis of total force, and normalized to its maximum (INS, MIMUs) or to a modified MVC test (sEMG) (Matlab v2018b). Right and left RMSs were compared for each signal and minute (Wilcoxon independent tests, $p<0.05$).

CASE-STUDY RESULTS

A professional runner (F, 25yrs, BMI 21.9), with previous (2020) stress-related micro-fracture at both navicular bones and unresolved right plantar fasciitis, performed a 6MWT maintaining a self-selected speed in the range 1.3-1.7m/s, walking 540m. Perceived fatigue and pain (right foot) ranged 12-14 and 2-3 respectively. Left-right RMSs were significantly different for all signals and minutes, with the exception for ant-post acceleration. Angular velocity in the frontal plane, had much higher RMS on the left, decreasing during the test from 27 to 25%. Lateral foot was about 10% more loaded on the right while all other force RMSs were significantly higher on the left (Fig 1).



	MIN 1	MIN 2	MIN 3	MIN 4	MIN 5	MIN 6
speed (m/s)	1.33	1.50	1.50	1.67	1.50	1.67
fatigue (Borg, 6-20)	12	12	13	13	13	14
pain (1-5)*	2	2	3	3	3	3

* perceived at the right foot, from absent to strong

Figure 1. A. For each 6MWT minute, median hindfoot force (top) and frontal plane angular velocity (bottom). B. Fatigue and pain perception. C. Left - right RMS % differences for each signal from wearables, at each minute.

DISCUSSION

Normalized RMS seems a valuable metric to analyze and interpret signals from wearables. It reveals kinematic, kinetic and EMG variables mostly affected by gait asymmetries. In the case-study, heel pain caused a 27% reduction of frontal plane foot motion, with a 10% less effective foot-ground interaction.

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Motor control of the lower limbs while walking with the TWIN exoskeleton operated by TWINActa in healthy subjects

T. Lencioni [1], M. Semprini [2], V. Bandini [1], J. Jonsdottir [1], S. Maludrottu [2], A. Marzegan [1], S. Scarpetta [2], C. Vassallo [2], L. De Michieli [2], M. Ferrarin [1]

[1] IRCCS Fondazione Don Carlo Gnocchi, Milano, Italy, [2] Istituto Italiano di Tecnologia, Genova, Italy

INTRODUCTION

Lower limb exoskeletons are medical devices used in the rehabilitation to provide physical therapy to individuals with neurological disorders [1]. These robotic devices were originally designed and developed for spinal cord injury subjects, who do not have any residual walking abilities, and are therefore mainly based on an assistive approach. To successfully use these machines in subjects with residual capacities such as persons post stroke, the control system must be adapted to an assist-as-needed control scheme. This approach requires the subject active participation to stimulate the voluntary muscle contraction of the paretic limb and manage the somatosensory feedbacks subsequent to the action. For these reasons, we have developed TWINActa, a control suite for gait training following stroke, that provide asymmetric assistance to the user. The assistance-as-needed can be provided in the following modes: (i) support during the toe-off phase of the non-paretic leg; (ii) pelvic tilt damping during stance phase; (iii) stabilization of the knee joint of the supporting leg during the double support phases; and (iv) hip extension support of paretic leg during the stance phase. This study was aimed at verifying if motor control during a walking task performed with an exoskeleton, operated by TwinActa, is similar to the physiological control of walking in healthy subjects.

METHODS

Five healthy volunteers were asked to perform motor tasks (i.e., overground walking, stairs ascending and stair descending) wearing the TWIN exoskeleton [2] operated by TWINActa control system. During the task EMG signals were acquired from 12 muscles (10 placed on the lower limb and 2 on the upper limbs per side) and movement data were recorded from 2 IMUs placed on the shanks. Non-negative matrix factorization was carried out on the EMG recorded signal to identify muscle synergies [3]. The EMG activity patterns were also mapped onto the rostro-caudal location of ipsilateral motoneurons pools in the human spinal cord [4]. Based on the Kendall myotomal charts of segmental localization [5], we reconstructed the sacral (S1-S2) and lumbard (L2-L5) motor pool activation profiles. Pearson's correlation coefficient was used to evaluate the similarity degree of 1) muscle synergies and 2) sacral and lumbar motor pool activation profiles of walking with exoskeleton with respect to the normative reference (without device) provided by Eurobench project (Pepato scenario).

RESULTS

Four muscle synergies accounted for a R2 > 0.85 for all participants during overground walking. A strong degree of similarity (correlation) of activation of sacral and lumbar motor pools with respect to the reference group was found (mean ± SD, 0.77 ± 0.06 and 0.78 ± 0.11, for sacral and lumbar spinal output respectively). Also the mean similarly of the muscle synergies activation profiles was strong (mean ± SD, 0.70 ± 0.14) with respect to the four physiological muscle synergies involved in gait control [6].

DISCUSSION

The four muscle synergies involved in the gait control [6] were found while walking with the exoskeleton operated by TWINActa in neurologically intact subjects. We found also a strong degree of similarity between the motor pools wearing the exoskeleton with respect to the normative reference of walking without the device. Since the spinal motor pools are associated with functional grouping of motoneurons of the lower limb muscles, our findings suggest that the Twin exoskeleton operated by TWINActa can be used as rehabilitation device to enhance the recovery of the physiological motor control in persons with residual ability. Further studies need to be conducted to verify this finding in subjects with neurological diseases.

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E-Textile smart socks for gait analysis: a preliminary validation study.

F. Amitrano[1], M. Macagno[2], S. Rossotti[2], D. Viganò[2], M. Cesarelli[1], G. D'Addio[3]

[1] Department of Information Technologies and Electrical Engineering, University 'Federico II', Naples, Italy
[2] Sensoria Health Inc, Redmond, United States
[3] Scientific Clinical Institutes ICS Maugeri SPA SB, Pavia, Italy

INTRODUCTION

In the last years wearable technologies and smart fabrics are arousing a great deal of interest in the healthcare field. The possibility to directly interact with the body, along with the comfort of fabrics, represent great opportunities to develop interesting applications. Smart sensing socks, able to collect kinematic and/or foot pressure signals, are attractive solutions to perform gait analysis also outside clinical laboratories, e.g., in the home environment for remote continuous monitoring of patients. In this study we analyse the performance of Sensoria smart socks (Sensoria Health Inc. Seattle, WA, USA) in detecting the major spatio-temporal gait analysis metrics. We validate the results provided by the system in comparison with those of the IMU-based gait analysis system OPAL Mobility Lab by APDM (APDM Inc, Portland, OR, USA).

METHODS

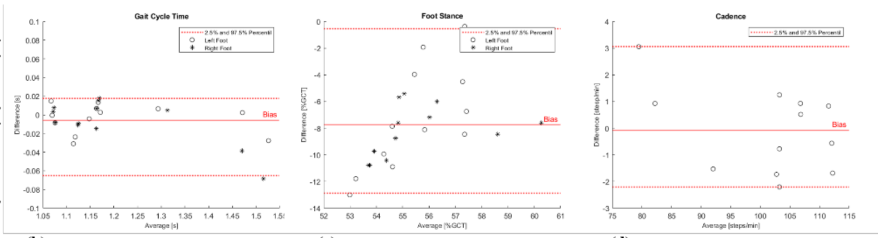
Three textile pressure sensors are embedded in the Sensoria Sock to monitor plantar pressure, while the hardware unit is connected on the lateral part of the ankle to measure kinematic signals and transmit data to a smartphone. Twelve records were acquired on five healthy subjects (2 women). Each subject wore the sensing Sensoria smart socks and three OPAL Inertial Measurement Units (two on the feet and one in lumbar position), in order to perform simultaneous recording of the walking. The trial consisted of walking 10 metres, turning and returning to the starting point at preferred speed. The following resulting gait metrics were considered from the two systems and compared: Gait Cycle Time (GCT) [s], Stance Phase [%GCT], Cadence [steps/min]. Statistical comparison was performed by means of Bland-Altman test.

RESULTS

Figure 1 shows the results of the statistical analysis. Figure 1a presents the principal statistics of the considered metrics for the two systems. The table in Figure 1a also reports the numeric results of Bland-Altman test, expressed as the average bias (Sensoria minus OPAL) and its 95% Confidence Interval (CI) (Lower Bound LB – Upper Bound UB). Figure 1b, 1c and 1d respectively represent the Bland-Altman Plots for GCT, Stance Phase and Cadence.

	GCT	Stance	Cadence
OPAL	1.20±0.15	59.4±1.7	101±11
SENSORIA	1.20±0.14	51.6±2.9	101±11
	Bland-Altman Test		
Bias	-0.00593	-7.75	-0.0820
Bias CI LB	-0.0455	-13.8	-3.18
Bias CI UB	0.0336	-1.73	3.01

(a)



(b) (c) (d)

Figure 1. Results of Bland-Altman Test: a. Statistics and numeric Bland-Altman results in the comparison of the two systems; b. Bland-Altman plot of GCT measures; c. Bland-Altman plot of Stance Phase measures; d. Bland-Altman plot of Cadence measures.

DISCUSSION

In this preliminary study we investigate the performances of the wearable Sensoria smart socks in evaluating the major temporal gait metrics. Results underline a general agreement in measuring GCT ($bias = -0.00593s$) and Cadence ($bias = -0.0820 steps/min$). The confidence interval of bias includes the zero for both metrics, indicating that the differences randomly occur and are not systematic. The Bland-Altman plot for Stance Phase metric shows a significant difference between the measures provided by the two systems: Sensoria smart socks underestimate the foot stance phase duration with respect to the reference system OPAL Mobility Lab. In this case the average bias is -7.75 % and its confidence interval does not include zero. The agreement in GCT values and the simultaneous disagreement of stance phase demonstrate discrepancies between the two systems in the detection of intermediate gait events (initial and terminal contact). In conclusion, smart socks performance in the detection of GCT and cadence are satisfactory, however improvements are needed in order to assess more specific gait metrics. In future studies, we aim to test the socks on a larger population and in the assessment of other temporal and spatial gait metrics.

Biomechanics of planned and unplanned change of direction in subjects with and without anterior cruciate ligament reconstruction: a case study

C.Bosio [1,2], A. Baldazzi [2], L. Rum [2], H. Pillet [1], E. Bergamini [2]
[1] Arts et Métiers ParisTech, Paris, France, [2] University of Rome "Foro Italico", Rome, Italy

INTRODUCTION

Anterior cruciate ligament (ACL) rupture is one of the most recurrent knee injuries in soccer players [1]. Commonly, global performance measures like jumping/hopping distance or time to perform agility test and side-cutting manoeuvres are used as criteria to determine readiness to return to sport after ACL reconstruction (ACLR) [1]. However, athletes may pass these criteria despite ongoing biomechanical deficits while performing the tests. Although ACL injury commonly occurs during change of direction (COD) [2], little is known about how athletes execute COD after ACLR and how they compare to healthy athletes. Also, few studies have investigated the influence of planned Vs unplanned COD on biomechanical parameters related to ACL injury risk. The aim of this preliminary study is to contribute filling this gap, quantifying a set of relevant biomechanical parameters in a healthy and ACLR soccer players during both planned and unplanned COD.

METHODS

Two male soccer athletes (Tegner Activity Score ≥ 6) participated in the study, one healthy (HS) and one with ACLR (12 months before the test; injured limb: left). They performed three maximal 90□ planned (COD-P) and unplanned (COD-U) CODs after standardized warm-up. For the COD-U, speed gates (Microgate, WittySem) were used to indicate the COD direction, which was selected randomly. Ground reaction forces (GRFs) of the foot performing the COD were measured by two force plates (AMTI, 1000 Hz). The start line was 5 meters from the force plates [1] and full foot contact with the force plates had to be made for a valid trial. The 3D trajectories of 52 markers located according to [3] were simultaneously measured by an optoelectronic system (Vicon, 200 Hz). Foot-force plates contacts were identified setting a threshold of 20 N on the vertical GRF (vGRF) [1]. A set of ACL injury risk-related parameters were then extracted from GRFs and marker trajectories [4]: ground contact time (GC_{time}), knee flexion and knee valgus angles at initial contact (KflexIC, KvalgIC), peak vGRF ($vGRF_{peak}$), GRF impulse (J), and peak knee abduction moment ($KMabd_{peak}$). Mean and standard deviation values over the three trials were calculated for each parameter and each COD type.

RESULTS

The value of each estimated parameter is reported in Table 1. In COD-U, ACLR subject showed - 774% KvalgIC and +123% KMabdpeak in the injured/non-dominant limb compared to the dominant, while smaller asymmetry was reported in HS (non-dominant vs dominant: -440% and +93%, respectively). Overall, COD-P has lower asymmetry percentages than COD-U.

Table 1. Grey cells: injured limb for the ACLR participant. Bold font: dominant limb. BW : body weight.

			GCtime [s]	KvalgIC [°]	KflexIC [°]	vGRFpeak [N/kg/BW]	J [N·s/kg/BW]	KMabdpeak [N·m/kg/BW]
ACLR	COD-U	**R**	**0.33±0.05**	**30.2±9.1**	**64.8±8.7**	**19.3±2.7**	**6.4±1.6**	**1.3±0.3**
		L	0.46±0.04	3.9±1.6	51.5±2.1	20.3±1.8	9.0±0.4	1.6±0.2
	COD-P	**R**	**0.49±0.06**	**18.5±0.7**	**58.5±6.4**	**16.0±0.2**	**7.8±1.1**	**1.1±0.1**
		L	0.41±0.02	4.0±1.4	53.5±0.7	19.3±0.4	7.9±0.6	1.4±0.1
HS	COD-U	R	0.49	-1.0	38.0	15.8	7.7	1.5
		L	**0.41±0.05**	**4.4±5.4**	**34.8±7.6**	**17.0±0.8**	**7.1±0.4**	**1.4±0.6**
	COD-P	R	0.45±0.02	0.9±1.7	28.7±5.1	19.8±2.9	8.8±1.6	2.0±0.4
		L	**0.45±0.01**	**1.9±0.5**	**31.5±2.1**	**15.3±1.4**	**6.8±0.4**	**1.0±0.3**

DISCUSSION

The results of this preliminary study suggest that different strategies were implemented by the two subjects in both COD-U and COD-P. As expected, due to the small sample size, a clear trend in terms of between-limb and COD type comparison can be hardly identified. The results about the knee kinematics suggest that a higher degree of asymmetry exists in the ACLR subject with respect to HS. A similar consideration can be drawn for kinetic results, where greater knee abduction moment and force impulse are displayed for the injured limb in the ACLR subject. The implemented methodology proved to be robust and can be applied to a larger sample size to strengthen the present results.

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Sensor based characterization of fine motor control in school children

M.C. Bisi[1], A. Masini[2], S. Toselli[2], S. Marini[2], L. Bragonzoni[3], A. Ceciliani[3], M. Lanari[4], A. Sansavini[5], A. Tessari[5], D. Gori[2], L. Dallolio[2], R. Stagni[1]

[1] Department of Electrical, Electronic and Information Engineering "G. Marconi", University of Bologna, Italy, [2] Department of Biomedical and Neuromotor Science, University of Bologna, Italy, [3] Department of Life Quality Studies, University of Bologna, Italy, [4] Department of Medical and Surgical Sciences; University of Bologna, Italy, [5] Department of Psychology "Renzo Canestrari", University of Bologna, Italy

INTRODUCTION

Assessment of motor development as a part of the overall neuropsychological, and developmental examinations is fundamental to predict developmental delays and disorders [1]; fine motor skills are a fundamental domain of motor control [1]. Several tests have been proposed for the characterization of fine motor control, although their evaluation is mainly based on qualitative observation, limiting quantitative assessment to the measure of test durations. Among the many available tests, the placing bricks test (PB), part of the Test of Motor Competence [1], was proposed to assess fine motor competences from infancy to old age. In its standard assessment, participants are requested to attach eighteen square-shaped Duplo™ bricks on a board (3 × 6 bricks size) as fast as possible [1]; PB performance measure is time to completion in seconds [1]. The instrumentation of the PB test using wearable inertial sensors can provide a more detailed, reliable, and quantitative characterization of the motor performance. The approach presented in this work exploit parameters, extracted from sensor data, describing temporal performance and its variability, associated to peripheral realization of movement patterns, and nonlinear metrics, characterizing the underlying motor control [2]. By using the instrumented version of the PB test, the present study aims at characterizing fine motor performance of primary school children; effect of sex, handedness, and age will be considered.

METHODS

59 I grade (6YO, 6y, 28F/31M) and 71 III grade (9YO, 9y, 31F/40M) primary school children performed the PB test [1] once, while wearing 2 tri-axial inertial sensors (OPALS, Apdm, USA, sf=128Hz), one per wrist; both hands were tested. An ad-hoc algorithm was developed to identify task events on 3D wrist angular velocity: peaks corresponded to flight phases, minima before and after peaks to brick grasping and brick placing, with an approach similar to that of one of the most reliable algorithm for gait event detection [3]. The following temporal parameters were estimated from task events: i) cycle duration (CD); ii) brick to board flight time (Br2Bo%, expressed in %CD); iii) board to brick flight time (Bo2Br%, %CD). Variability of temporal parameters was calculated using Poicaré plots (SD1, short-term, SD2, long-term variability). Nonlinear metrics (recurrence quantification analysis, RQA, and multiscale entropy, MSE) were calculated [2] on 3D wrist acceleration to estimate regularity and complexity of movement pattern. A Kruskal Wallis test (significance level 5%) was used to test the effect of i) sex; ii) dominant (D) vs non dominant (ND) hand, iii) and age (6YO vs 9YO), on the calculated parameters.

RESULTS

i) No difference was found between male and female participants for all the estimated parameters.

ii) With ND hand, CD, and SD1 and SD2 of Bo2Br% were higher than with D hand in both groups. No differences in nonlinear metrics were found.

iii) 6YO showed significant longer CD and Br2Bo% than 9YO; when analyzing D hand, SD1 and SD2 were higher in 6YO for both Br2Bo% and Bo2Br% than in 9YO, while with the ND hand, variability was higher only for Br2Bo% phase. 6YO showed higher RQA parameters and lower MSE values than 9YO.

DISCUSSION

No difference between male and female participants was highlighted and motor performance with the D hand was more rapid and less variable, as expected. Older children showed shorter and less variable cycle duration than younger children: these results can be related to the expected maturation and the fine motor skills training during school years. Older children showed also less regular and more complex movement patterns: their motor control allow the exploration of more flexible movements [2]. PB instrumentation allowed characterizing fine motor control performance of school-children, highlighting the advantages of sensor-based assessment and of nonlinear metrics for its characterization.

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The role of robotic assisted gait trainer in pd: model-based evaluation of the tratment outcomes

M. Romanato[1], F. Fichera[2], E. Pegolo[1], F. Spolaor[1], D. Volpe[2], Z. Sawacha[1]

[1]Department of Information Engineering Università degli Studi di Padova, Padova, Italy; [2]Fresco Parkinson Center, Villa Margherita, S. Stefano, Vicenza, Italy; [3]Department of Medicine Università degli Studi di Padova, Padova, Italy

INTRODUCTION

Physical training has shown to have a positive effect on the quality of life of people with Parkinson's disease (PPD) [1]. Overground robotic gait training (ORGT) might promote neuroplasticity and restore functional gait due to cyclical movement [2]. The goal of the study is to provide model-based estimated variables, *i.e.*, muscle forces, to quantify participants' neuromotor profile after ORGT.

METHODS

Five PPD (age=66.0±5.3 years, BMI=25.7±3.7 kg/m^2) were enrolled (ClinicalTrials.gov NCT04778852) to undergo a 4-weeks ORGT. Gait analysis was performed before (BT) and after (AT) therapy. Walking trials were collected with an 8-cameras optoelectronic system (120Hz, Vicon), synchronized with two force plates (960Hz, AMTI) and an 8-channel electromyographic system (960Hz, Cometa); the protocol described in [3] was adopted. Four lower-limb muscles (Biceps Femoris, Rectus Femoris, Gastrocnemius Lateralis, Tibialis Anterior) were selected to record their electrical activity. Joint moments and moment arms were computed using a muscle-optimized scaled model in OpenSim [4]. CEINMS was adopted to estimate muscle forces informing the model throughout the subject-specific experimental excitations. Muscle forces time series were arranged to form anterior and posterior kinetic chains, and compared BT and AT, and with respect to a cohort of healthy controls (13 people, age=57.8±5.6years, BMI=27.3±3.9kg/m^2) through one-dimensional statistical parametric mapping [5].

RESULTS

Figure 1 displays the results.

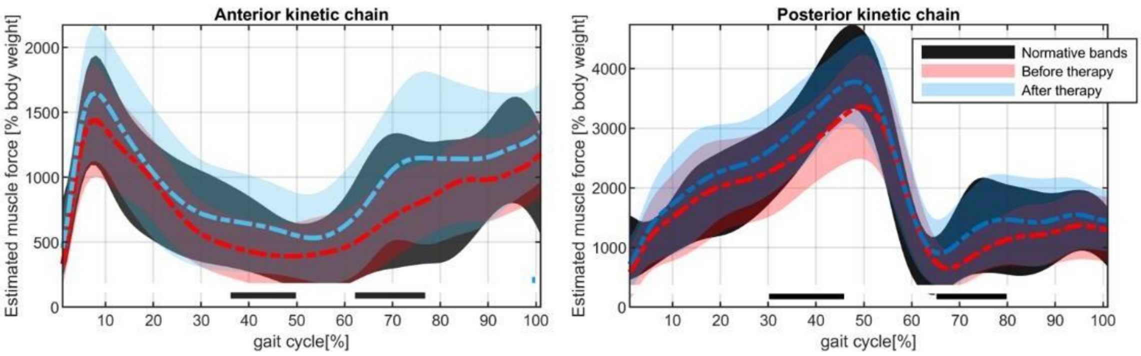

Figure 1. Muscle forces forming anterior (left) and posterior (right) kinetic chains. BT (red) and AT (blue): mean (solid-dashed line) ± standard deviation (shaded area). Normative bands in black. Bars in the lower part of the figure represent the statistical significance ($p<0.05$): BT vs AT in in black.

DISCUSSION

Energy-efficient walking might be achieved by adopting a stable kinetic chain of multiple limb segments [6]. Differences BT and AT in PPD were detected in the terminal stance, a crucial phase for stability, where a single limb support is required. AT an improvement was detected as the muscle force profile of the posterior kinetic chain was found in the same range of the controls. The results are still preliminary and sample size needs to be increased. Future study could explore if the improvement assessed AT could be linked to an improvement of the upright stability and correlates with the clinical scales.

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Test-retest reliability of inertial-based joint kinematics estimation during rehabilitation exercises in a control group.

G. Molè [1], M. Caruso [1], S. Bertuletti [2], D. Balta [1], A. Zedda [3], E. Gusai [3], S. Spanu [3], A. Pibiri [3], M. Monticone [3], D. Pani [3], A. Cereatti [1]

[1] *Politecnico di Torino, Turin, Italy* [2] *University of Sassari, Sassari, Italy* [3] *University of Cagliari, Cagliari, Italy*

INTRODUCTION

DoMoMEA is a home-based neuromotor telerehabilitation system for mild-impaired stroke patients which implements a full-body rehabilitation protocol consisting of 15 exercises. Real-time joint kinematics is estimated using a network of wearable inertial sensors (IMUs), and a set of biomechanical parameters, among which the range of motion (ROM), are extracted to monitor patients' progress over time. However, it is acknowledged that the reliability of the estimated biomechanical parameters could be affected by several inaccuracy factors associated to the anatomical calibration procedure, the presence of soft tissues artefacts and errors due to the IMU orientation reconstruction. In this work, we investigated the reliability of the ROM in terms of absolute agreement during a test-retest session of nine planar rehabilitation exercises by means of the intraclass correlation coefficient (ICC).

METHODS

The experiments involved five young healthy subjects tested during two recording sessions, one week apart. Each subject was equipped with eight IMUs applied with elastic straps on the body segments and 49 markers (Davis protocol) to provide the reference joint kinematics with a stereophotogrammetric system (SP). Exercises included the flex/extension (FE) of the elbow, wrist, knee, hip, ankle and trunk, the ab/adduction of the shoulder, and the trunk rotation around both the vertical and the antero-posterior axes. For both test and retest sessions, subjects were asked to perform twenty repetitions of each exercise, while seated (but for the trunk FE), at their maximum ROM, defined as the difference between the maximum and minimum joint angle values. Twenty ROM values were then averaged and employed to compute the ICC(3,k) suitable when evaluating test-retest absolute agreement based on mean of multiple measurements taken by an instrument under the same experimental conditions [2].

RESULTS

The ICC values of the IMU and SP systems for each exercise were reported in Table 1.

Table 1: AA = ab/adduction, FE = flex/ext, Rot = rotation, V = vertical axis, AP = antero-posterior axis. ICC Intervals: <0.5 poor reliability, >0.5 & <0.75 moderate, >0.75 & <0.9 good, >0.9 excellent [2].

	Shoulder	Wrist	Elbow	Knee	Hip	Ankle	Trunk		
	AA	FE	FE	FE	FE	FE	FE	Rot (V)	Rot (AP)
IMU	0.73	0.89	0.40	0.85	0.49	0.70	0.69	0.45	0.97
SP	0.66	0.85	0.41	0.86	0.89	0.62	0.62	0.50	0.94

DISCUSSION

These preliminary results suggested a moderate to excellent reliability of the IMU-based measurements for exercises of the shoulder, wrist, knee, ankle, and trunk (FE and AP) with ICC values ranging between 0.70 and 0.97. On the contrary, despite highly repeatable within session, the IMU-based ROM for both elbow and hip exercises was characterized by a poor reliability being the ICC lower than 0.5. This could be explained by considering the elastic strap movement caused by muscle contractions, wobbling of soft tissues, and skin stretching/sliding [3]. Poor elbow ROM reliability was also observed for the SP measurements, probably due to the different position of the shoulder joint center for each subject. Lastly, for the trunk rotation around the vertical axis, low ICC values were found for both systems despite the highly repeatable and consistent intra-session ROM values. This could be justified by the fact that, as the trunk movement is weakly constrained, its amplitude is difficult to control and to reproduce between sessions. Future investigations on stroke survivors in *ad hoc* clinical trial will be performed. This project was funded by Sardegna Ricerche (POR FESR 2014/2020).

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Instrumented Smart Crutches: Force and Orientation Sensing for Gait Monitoring

V. Arcobelli[1], M. Zauli[1], G. Galteri[2], L. Cristofolini[2], L. Chiari[1], A.Cappello[1], L. De Marchi[1], S. Mellone[1]

[1]*Department of Electrical, Electronic and Information Engineering (DEI), University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy*

[2]*Department of Industrial Engineering (DIN), University of Bologna, Viale Risorgimento 2, 40136 Bologna, Italy*

INTRODUCTION

Crutches are one of the most common walking aids [1]. Recent studies have focused on how instrumented crutches could help therapists and patients correct any improper use by the patient in terms of body weight applied and position/orientation [2]. This study aims to develop and test a set of smart crutches that can be connected and used through a smartphone.

METHODS

A pair of smart crutches for measuring the amount of body weight applied to the crutch and its orientation, namely pitch and roll angles. Each crutch comprises a Load Cell sensor (FX29 Te Connectivity®) mounted at the crutch's tip through a custom-made mechanical structure in aluminum and Teflon with a sensitivity of 20mV/V. The Load Cell is interfaced to an Arduino Nano RP2040 Connect® which is also embedded with a 6-axis Inertial Measurements Unit (IMU - ST LSM6DSOX) featured by 0.122 mg/LSB at FS = ±4 g and 70mdps/LSB at FS = ±2000 dps of sensitivity for accelerometer and gyroscope respectively. Electronic boards and the battery are embedded into the crutch's handle. Furthermore, each Arduino is equipped with a WiFi Module (U-blox® Nina W102), which oversees connecting to an Android smartphone (Mi9T Pro, Android operating system version 10Q, Xiaomi co, China) intended as a host device for visualizing and storing data by means a custom Android Application developed using Android Studio IDE. Four Kistler force platforms have been used as gold standard. Smart crutches have a 100Hz sampling frequency, while the force platform has a 1000Hz sampling frequency. Signals are processed using Matlab® R2021b and Python.

RESULTS

Multiple tests walking with the crutches on the force platforms have been performed; an example is shown in Figure 1.a, resulting in an RMSE<5N. Figure 1.b shows the crutch orientation (pitch and roll) during a 3-minutes gait recording. Figure 1.c shows the user interface of the Android App.

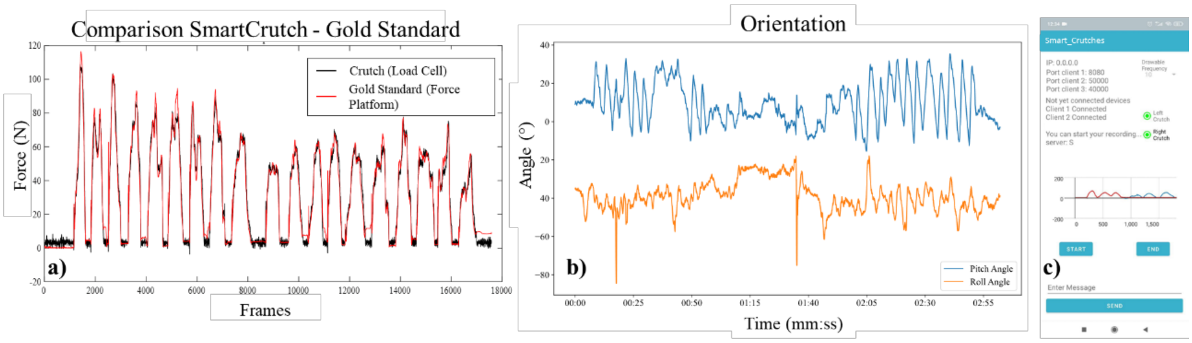

Figure 1. a) Comparison between Gold Standard (Force Platform) and Load Cell (Smart Crutch); b) Estimated pitch and roll angles in a 3-minutes walk; c) Smart crutches Android App.

DISCUSSION

Based on the preliminary results, our prototype measures the applied body weight with a good accuracy and can stream the crutch orientation and the applied load on a smartphone. The device is designed to be a standalone and portable tool. The next developments will be the calibration and validation of the pitch and roll estimates and the development of biofeedback-based applications on the smartphone.

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Design of a multi-modal and multi-user Augmented Reality biofeedback system for motor rehabilitation

G.L. Cerone [1], A. Farsi [1], A. Giangrande [1,2], A. Botter [1], D. Falla [3], M. Gazzoni [1]

[1] Politecnico di Torino - *LISiN, Dip. di Elettronica e Telecomunicazioni, Italia;* [2] *Univ. of Jyväskylä, Faculty of Sports and Health Science, Finland* [3] *Univ. of Birmingham, School of Sport, Exercise and Rehabilitation Sciences, United Kingdom*

INTRODUCTION

Augmented Reality (AR) allows to superimpose virtual contents over real-world scenes. Although AR has been proven to be effective in several biomedical applications [1][2], its use as a biofeedback tool in the field of motor rehabilitation is largely unexplored due to the lack of suitable technology allowing to integrate AR feedback systems (e.g. smartglasses) with bioinstrumentation used for movement analysis. This work aims to describe the design and development of an AR-based biofeedback framework for the visualization and monitoring of information related to the degree of muscle activity, its anatomy and the resulting movement.

METHODS

Figure 1 shows the System Architecture. A set of wireless acquisition systems (Sensor Unit - SU), forming a wireless Body Sensor Network (wBSN), can be combined in a custom way to collect information about muscle activity (bipolar and High-Density sEMG (HD-sEMG) sensors) and movement kinematics (Magneto-Inertial (IMU) sensors). A monochromatic marker is attached on the detection system (e.g. electrodes) for each SU. Collected signals are streamed to a PC or Mobile Device (Signal Processing Unit - SPU). The SPU transmits elaborated data (e.g. RMS of sEMG signals, quaternion vector etc.) to one or more Feedback Units (FUs – e.g. tablet or Microsoft HoloLens smartglasses). FUs recognize the markers and provide the *augmented* information by coloring the electrode detection area according to the muscle activation level (color map in case of HD-sEMG) and eventually displaying an avatar reproducing the orientation of user's body segments through IMUs. The feedback is provided both to patients and clinicians, allowing the latter to guide and follow the patient's muscle activity and movement in real-time.

RESULTS

The system was designed and tested in use-case scenarios implying different configurations of the wBSN and different types of signals and FUs. The biofeedback system validation is ongoing and aims to prove its applicability in two use-case scenarios: (i) training to balance knee extensor muscle activity in people with anterior knee pain and (ii) real-time visual feedback of the spatial distribution of muscle activity and body kinematics for the treatment of low back pain.

DISCUSSION AND CONCLUSION

An augmented reality system visualizing the information about muscle activity and body segment's kinematics has been developed and tested. Its innovative system architecture allows to provide multi-modal and multi-user feedback, opening new perspectives for the application of AR-based biofeedback in motor rehabilitation.

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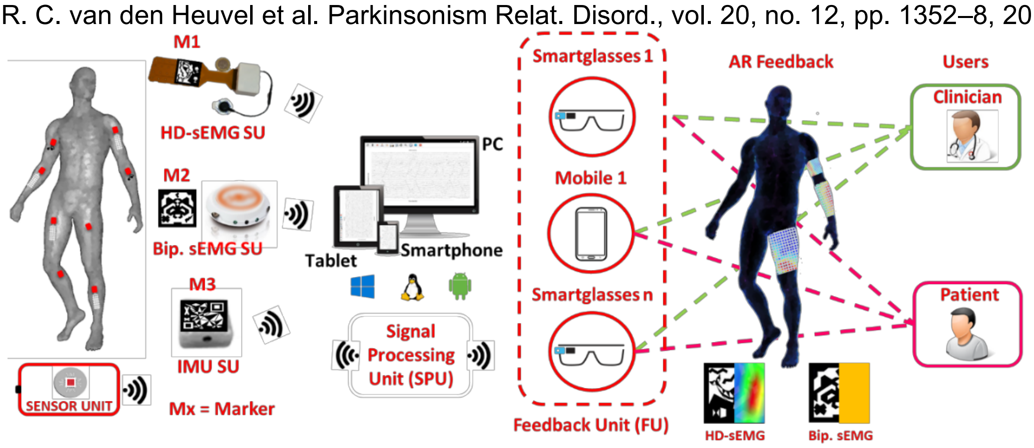

Figure 1. System architecture. A wBSN collects and transmits data to the SPU. The SPU elaborates signals and drives the FU, which provides an augmented reality feedback to multiple users.

Muscle synergy patterns in the Box and Block Task execution

E. Colamarino[12], V. de Seta[12], J. Toppi[12], F. Pichiorri[2], G. Morone[3], I. Conforti[1], I. Mileti[4], E. Palermo[1], D. Mattia[2], F. Cincotti[12]
[1] *Sapienza University of Rome, Rome, Italy,* [2] *IRCCS Fondazione Santa Lucia, Rome, Italy,*
[3] *University of L'Aquila, L'Aquila, Italy,* [4] *University Niccolò Cusano, Rome, Italy.*

INTRODUCTION

Box and Block Test (BBT) is one of the most used clinical tests to assess motor function performance. Despite its affordability and quickness, it returns limited information about the mechanisms contributing to the impaired movement. Kinematics analysis of movements and the electromyographic (EMG) technique have been validated as powerful tools to assess the main features of movements. This study aims at exploring for the first time muscle synergies in healthy participants while executing the BBT task in a daily-living activity context, contributing so to the objective characterization of the BBT movement.

METHODS

Twelve healthy volunteers were enrolled in the study (Prot. CE/PROG.752). EMG signals were acquired from 16 muscles of the upper limbs and trunk (8 per side): extensor digitorum, flexor digitorum superficialis, lateral head of the triceps, long head of the biceps brachii, anterior deltoid, lateral deltoid, pectoralis major and upper trapezius muscles (Pico EMG sensors & Wave Plus 16 channels amplifier, Cometa S.r.l., Italy). Kinematic data were collected by means 8 IMUs (MTw Awinda, Xsens Technologies, The Netherlands), placed on the hand, mid forearm, mid arm of both upper limbs, over the clavicular notch and at the lumbar vertebrae level. Participants were instructed to perform the BBT task (20 times) at self-paced velocity with both upper limbs separately collected. EMG data were pre-processed, rectified and low-pass filtered at 10 Hz (Butterworth filter, 7^{th} order) to extract envelope [1]. The envelope segmentation in trials and in the three phases of the task (reaching, transfer, return) was performed by means the biomechanical model results (IMU data). The non-negative matrix factorization (NMF) algorithm was applied to extract muscle synergies according the procedure reported in [2]. All analyses were performed considering both the whole task and each phase of the task separately.

RESULTS

Table 1 shows the average number of synergies extracted for each side analyzing both the whole task and each phase of the task separately. As for the whole task analysis, the dominant and non-dominant upper limb did not exhibit differences in term of average number of synergies (1.3 ± 0.5). As for the 3 distinctive task phases, we found that (i) the number of synergies for each phase and side was higher than that for the whole task analysis, (ii) the transfer phase resulted as the most demanding phase (2.8 ± 0.7 and 2.7 ± 0.8 synergies for R and L task, respectively).

Table 1- Average number of synergies across participants (N=12) during the BBT task with the right (R) and left (L) upper limb. For each side muscle synergies have been extracted considering the whole task and the task in its phases: reaching, transfer and return.

Participant	**Whole task**		**Single Phase**					
	R	L	Reaching R	Transfer R	Return R	Reaching L	Transfer L	Return L
Average (SD)	1.3 (0.5)	1.3 (0.5)	2 (0.7)	2.8 (0.7)	2.3 (0.9)	2.3 (0.8)	2.7 (0.8)	2 (0.7)

DISCUSSION

To our knowledge, this is the first study applying a multimodal (EMG and kinematics) approach to describe the Box and Block Test task performance in healthy volunteers. The results showed the BBT task can be globally described by two synergies at most. Considering the task in its single phases showed different results from the whole task, pointing out (i) the complexity of the transfer phase with respect to the other phases, (ii) the need to consider the single phase in the description of the BBT task to capture abnormal synergies that occur in pathological conditions (e.g. stroke).

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EMG-data driven model for wrist motion estimation

F. Verdini[1], A. Tigrini[1], M. Scattolini[1], S. Fioretti[1], G. Verde[1], L. Burattini[1], M. Morettini[1], A. Mengarelli [1]

[1] *Department of Information Engineering, Università Politecnica delle Marche, Ancona, Italy*

INTRODUCTION

In the last years active prostheses, driven by surface electromyography (sEMG), took advantage by patter recognition methods to control simple on/off motions or to discriminate hand gestures and then to facilitate an effective motion control strategy. Contrary to the classification methods that provide an event related control strategy [1], regression-based approach has been recently implemented to estimate joint kinematics thus allowing a simultaneous and proportional control in all the degree of freedom in more a physiological way. In this context, conventional machine learning techniques (ML) that mainly rely on handcraft features extraction and deep-learning techniques, as for instance convolutional neural networks (CNN), for which features are derived from raw data through a feature-learning process, are reported in literature [1,2,3]. In this study, ML and CNN approaches are applied to data from a wearable and consumer device (OYMotion, GforcePro+) to obtain an estimation of the angular execution of the wrist through a regression-based approach.

METHODS

Eight EMG sensors of the armband allowed to capture data from the forearm muscles during two sequences of wrist movement, each 7 minute long, the first of flexion/extension and the second of ab/adduction. During the test, inertial sensor measurements obtained by the IMU positioned over the dorsal part of the hand were collected to obtain angular excursions. Three males and three females were enrolled. A set of time- and frequency-domain features [4] was extracted by the sequences of the windowed EMG signal (200ms long with an overlap of 20ms). The 90% of whole amount of data was used to train ML models and the remaining 10% was used for testing. The handcraft feature approach was evaluated with respect to a signal-driven approach using a CNN composed by 1 input layer, 8 convolution and 5 average pooling layers, 1 fully connected layer, and last a regression layer [3]. R^2 and Root Mean Square Error (RMSE) were calculated as regressors performance metrics.

RESULTS

Both the methods used for the angle estimation allowed to obtain reliable temporal excursions of the wrist flexion/extension and ab-adduction without any smoothing post-processing of the regression results. The performance metrics (table 1) showed better performance for CNN with respect to RF in both the wrist movements.

Table 1. Average (±SD) regression performances metrics on testing data for both RF and CNN.

	Flexion-Extension		Abduction-Adduction	
	R^2(%)	RMSE (deg)	R^2(%)	RMSE (deg)
RF	73 ± 12	16 ± 4	78 ± 10	10 ± 2
CNN	83 ± 8	12 ± 4	82 ± 14	9 ± 2

DISCUSSION

Results obtained in this preliminary study confirms the usability of consumer device to capture reliable EMG signals for applications with myoelectric interfaces. Since both RF and CNN provided angular trajectories that reproduce the kinematics as confirmed by the variance captured from the testing data i.e. R^2 not lower than 70% in both ML methods. Despite the CNN better performed with respect to RF in terms of all the metrics evaluated, its use requires a huge amount of training data in order to provide a generalized model. Thus, the use of handcraft feature methods appears to be still valid in practical scenario, where a long training session can be uncomfortable for the patient.

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Assessment of corticomuscular coupling during cross-country skiing using wearable EEG-sEMG: a pilot study

A. Giangrande[1-2], G.L. Cerone[1], M. Gazzoni[1], K. Ruotsalainen[2], M. Karczewska-Lindinger[3], S. Lindinger[4], J.M. Piirainen[2], H. Piitulainen[2], A. Botter[1]
[1]LISiN, Dip. di Elettronica e Telecomunicazioni, Politecnico di Torino, Torino, Italy, [2]Univ. of Jyväskylä, Faculty of Sports and Health Science, Jyväskylä, Finland, [3]Istituto Alberti Di Bormio, Lab. di Biomeccanica dello Sci (LaBiS), Bormio, Italy, [4]Center for Health and Performance at the Dep. of Food and Nutrition and Sport Science, Univ. of Gothenburg, Gothenburg, Sweden

INTRODUCTION
The interactions between cortical drive and muscle activation (i.e. cortico-muscular coupling, CMC) can be evaluated through simultaneous recordings of electroencephalograms (EEG) and electromyograms (EMG). However, due to the lack of biomedical instrumentation suitable to detect high quality EEGs in dynamic conditions, the majority of EEG-EMG studies was conducted during well-controlled and quasi-static conditions. For instance, little is known about CMC in sports, which could be relevant to improve the understanding of motor control during highly dynamic and skilled tasks. In this pilot study we test the suitability of a wearable Body Sensor Network (wBSN) to quantify CMC during cross-country skiing.

METHODS
A professional skier performed three minutes of simulated cross-country skiing on a treadmill (V2 technique, 10 km/h, 2° uphill). The used wBSN is composed of different wireless sensors developed by our group, allowing to record: (i) 30 EEG signals [2], (ii) bipolar sEMG from three muscles (right SOL, TA and GM), (iii) right ankle acceleration, (iv) 2D ground reaction forces from both skies. We applied Independent Component Analysis on EEG signals to identify the artifactual components e.g. related to eye blinks, muscular activity or electrodes relative movements. EEG-EMG coupling was finally assessed through coherence analyses on the gliding phases (n=78) from the whole recording [3].

RESULTS
Figure 1 shows three seconds of the collected signals and the results from the coherence analyses during all the gliding phases of the skating cycles. Significant coherence for the soleus muscle was found, as expected, in the Cz electrode located over the leg motor area (CMC peak at 22 Hz: 0.004).

DISCUSSION AND COCNCLUSION
Although preliminary, these results show the great potentiality of using our wBSN-based devices to simultaneously record multiple signals, and to quantify the CMC during challenging dynamic activities, such as cross-country skiing.

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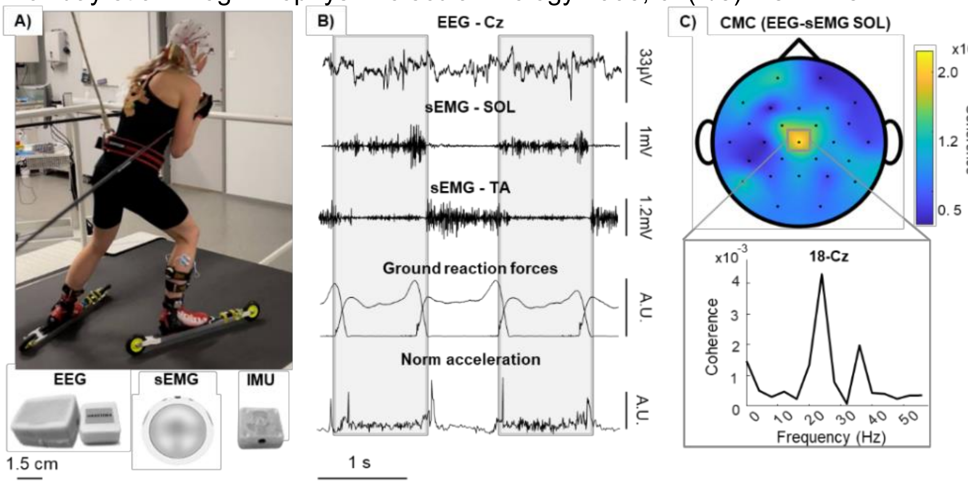


Figure 1. A) Experimental Setup and wireless instrumentation used. B) From top to bottom: Cz-EEG signal, sEMG signals from SOL and TA, right/left ground force reactions, ankle norm acceleration. Two gliding phases are highlighted in light grey. C) Topographic CMC distributions during the gliding phase of the skating cycle.

Stroke-by-stroke approach using wearable inertial sensors for the integrated timing of stroking, breathing and kicking in front-crawl swimming

S. Fantozzi [1], V. Coloretti [1], M.F. Piacentini [2], C. Quagliarotti [2], M. Cortesi [3]
[1]*DEI, University of Bologna, Bologna, Italy,* [2] *Foro Italico, University of Rome Rome, Italy* [3]*QUVI, University of Bologna, Bologna, Italy*

INTRODUCTION

Swimming performance is strictly related to the synergic action among the different body segments. The analysis of a singular body segment does not completely characterize the actions and the movement of the limbs cannot be considered independently [1,2]. Previous studies investigated independently the accuracy of temporal parameters for upper and lower limb actions [3]. To give a complete characterization of the swimmer's action and to understand the coordination between head, upper and lower limbs movement, the combination of these features should be taken into account.
The aim of the present study was to develop and validate an easy-to-use tool for evaluating stroke-by-stroke swimmer's integrated timing of stroking, kicking and breathing.

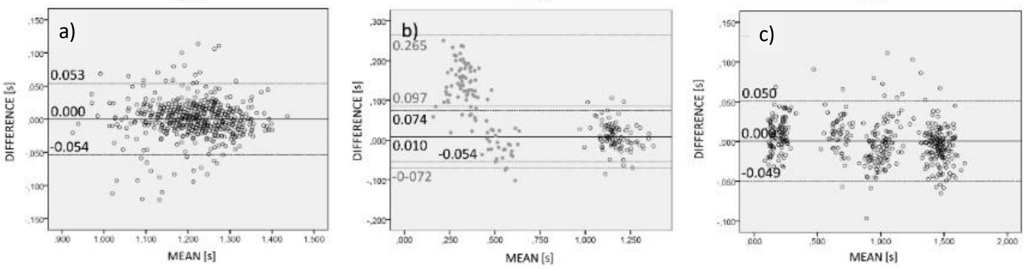
METHODS

Twelve male athletes (age: 19.1 ± 2.3 years; mass: 76.7 ± 3.7 kg; height: 179.0 ± 5.2 cm; level: 686 ± 82.6 FINA points long course, Tier 3 [31]) were acquired during front-crawl swimming at self-selected speed in a 25 m swimming pool (one trial of 100 m). Five tri-axial IMUs (Cometa, Milano, Italy) were calibrated at the beginning of each acquisition session and attached to the head (in the occipital zone between the supreme and superior nuchal lines), forearms (about two centimeters above the styloid), and shanks (about two centimeters above lateral malleolus). The swimming trials were also filmed using a single moving sagittal video camera (Hero7, GoPro, USA, sf = 240 Hz, 1920 × 1080 pixels resolution) for events detection gold standard (TLC). The following parameters, expressed in percentage of the stroke cycle, were estimated: i) the entry of the wrist into the water (WRISTENTRY) estimated from the modulus of the angular jerk measured by the wrist sensor and used for the identification of the stroke cycles; ii) the beat of the lower limb during the downward action (LEGDOWNBEAT) estimated from the zero-crossing of the medio-lateral angular velocity of the IMUs on the ankle was employed; iii) the exit and the entry of the face from/into the water (HEADEXIT and HEADENTRY, respectively) estimated from the maximum/minimum values of the longitudinal angular velocity of the IMUs on the head.

RESULTS

All temporal events showed high agreement with the gold standard confirmed by a root mean squared error less than 0.05 s for absolute temporal parameters and less than 0.7 % for the percentages of the stroke cycle duration, and with correlation coefficients higher than 0.856s.

Figure 1. Bland-Altman plots for WRISTENTRY (open circles), HEADEXIT (grey filled circle), HEADENTRY (open circle) and LEGDOWNBEAT (open circle) compared with TLC.



DISCUSSION

A protocol for integrated analysis of stroking, kicking and breathing using inertial sensors in front-crawl swimming was developed and validated in comparison with the video-analysis technique. All accuracy parameters investigated (RMSE, bias, LoA, and correlation) highlighted high agreement with the gold standard. Furthermore, the protocol proposed is user-friendly and as unobtrusive as possible for the swimmer al-lowing a stroke-by-stroke analysis during training session

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Study of the repeatability of the kinematic parameters related to the Timed Up and Go test

G. Pagano[1], L. Donisi[2], V. Marsico[1], V. Samarelli[1], C. Calabrese[1], I. Scarola[1], M. Cesarelli[2], G. D'Addio[1]

[1]*Clinic al and Scientific Institutes Maugeri SPA SB, Pavia, Italy*

[2]*Dept. of Electric al Engineering and Information Technologies University of Naples "Federico II", Naples, Italy*

INTRODUCTION

Considering the strong diffusion of wearable inertial systems for gait analysis in the clinical setting, aim of the present study is to explore the repeatability of the kinematic parameters related to the Timed Up and Go test in different neuromotor pathologies.

This study is part of the field of pathologies related to gait deficit. The evaluation of the rehabilitation outcome in terms of kinematics is of fundamental importance to evaluate the effect of a physical rehabilitation on the functional recovery of patients. Repeatability represents a valuable study in clinical setting because it can suggest, in this case, which motion parameter can be selected to better characterize a specific pathology.

METHODS

The study population consists of 40 patients with orthopedic and neurological pathologies. Patients were admitted to the Rehabilitation Unit of Maugeri Institute of Care and Scientific Research of Bari (Puglia, Italy). The following seven kinematics were evaluated parameters: 1) Duration of the test (s); 2) Duration of the raised phase (s); 3) Duration of the session (s); 4) Vertical acceleration during the raised phase (m / s2); 5) Vertical acceleration during the sitting phase (m / s2); 6) Average rotation speed during the intermediate rotation phase (degrees / s).7) Average rotation speed during the final rotation phase (degrees / s).

Test-retest repeatability or reliability was assessed through the Intraclass Correlation Coefficient (ICC). The p-value for each ICC (1,1) was reported considering a 95% confidence interval. SPSS software was used to perform statistical analysis.

RESULTS

Study results are reported in the following table. Table reports the descriptive statistics of the two measurements carried out considering the whole study population; the descriptive statistics are reported as mean plus or minus the standard deviation (mean ± sd). Test duration and Vertical acceleration during the raised phase showed a good repeatability; Duration of the raised phase, Duration of the sitting phase, Vertical acceleration during the sitting phase, Mean rotation speed during the intermediate rotation and Mean rotation speed during the intermediate rotation showed a moderate repeatability.

Table 1. Kinematic Parameters.

Kinematic Parameters	Measure 1	Measure 2
Test Duration [s]	0.772	0.001
Duration of the raised phase [s]	0.584	0.019
Duration of the sitting phase [s]	0.555	0.026
Vertical acceleration (raised phase) [m/s2]	0.848	0.000
Vertical acceleration (sitting phase) [m/s2]	0.692	0.005
Mean rotation speed (intermediate rotation phase) [degrees/s]	0.723	0.003
Mean rotation speed (final rotation phase) [degrees/s]	0.551	0.027

DISCUSSION

The results showed that several kinematic parameters related to the TUG test showed a good reliability letting them be proper indexes in identifying the characteristics of the pathologies analyzed.

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Gait analysis in people with COVID-19 history: comparison of motor impairments as a possible consequence of hospitalization in Intensive Care Unit (ICU).

Z. Sawacha[1], M. Romanato[1], A. Mahmoud[2], P. Serafini[3], A. Ruggiero[3], F. Spigarelli[3], G. Squartini[1]
[1]Department of Information Engineering, University of Padova, Padova, Italy, [2]Villa Adria, Santo Stefano, Ancona, Italy, [3]Santo Stefano Rehabilitation Institute, Porto Potenza Picena, Macerata, Italy

INTRODUCTION

SARS-CoV-2 infection (COVID-19) may cause not only respiratory disorders, but also neurological impairment. Neurological manifestations include - but not limited to - peripheral nervous system disorders [1].

METHODS

Three groups were compared: six control subjects, six post COVID-19 subjects who were hospitalized in ICU for more than 35 days and six post COVID-19 subjects who were hospitalized in ICU for less than 35 days. Data were acquired with a 6-cameras motion capture system (100 Hz, Vicon), synchronized with 2 force plates (1000 Hz, AMTI) and an 8-channels sEMG system (1000 Hz, Aurion) that recorded bilaterally the activity of 4 muscles: Tibialis Anterior, Medial Gastrocnemius, Vastus Medialis and Biceps Femoris. Retroreflective markers were placed according to CGM 2.3 marker set [2]. Kinematic and kinetic data were processed using Polygon (v3.5.2, Vicon) and Matlab (v2021a). Sagittal plane kinematics of hip, knee and ankle, pelvic obliquity, intra-extra foot rotation, spatiotemporal parameters, plus hip, knee and ankle power and the ground reaction forces were extracted. The spatiotemporal parameters were statistically analysed by means of Kruskal Wallis test, the kinematics and kinetics data were analyzed through Anova One Way test ($p<0.05$, SPM1D v0.4.6)[3].

RESULTS

Kinematics, kinetics and spatiotemporal parameters revealed statistically significant differences between the three populations. An altered muscle activation timing was also detected.

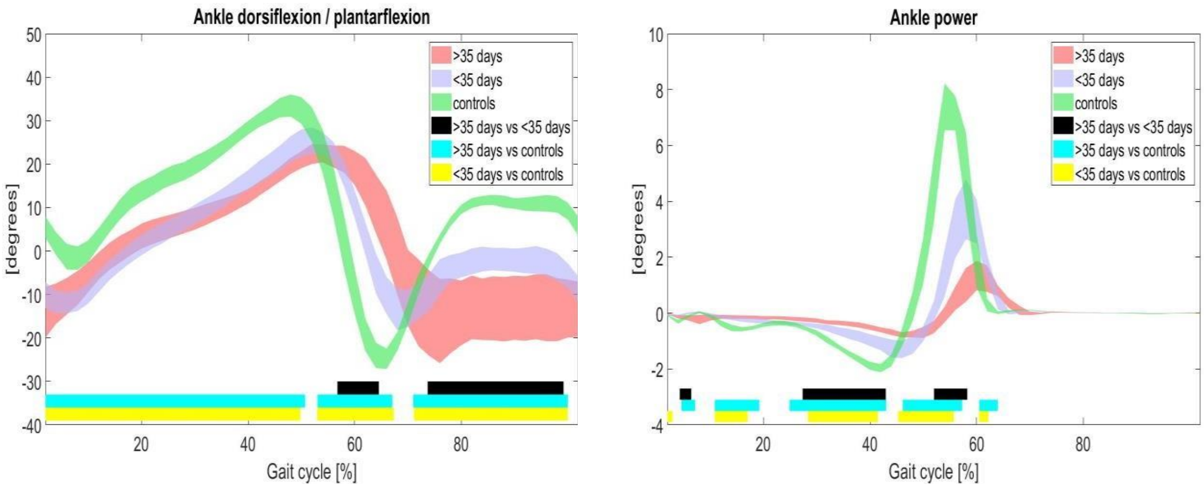

Figure 1. Ankle dorsi/plantarflexion and ankle power median trajectories during walking of the three populations (top) and significant areas indicated by the SnPM{t} statistic (bottom).

DISCUSSION

The current study revealed that severe COVID-19 determines gait impairments.

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Movement analysis and medical imaging integrated tools for 3D project and printing of drop foot orthosis

S. Bisconti[1], G. Tombolini[1], A. Coccia[2,3], G. Pagano[3], M. Cesarelli[2] G. D'Addio[3]
[1] *Tombolini Officine Ortopediche, San Giorgio Jonico, Italy;*
[2] *Department of Information Technologies and Electrical Engineering, University 'Federico II', Naples, Italy;*
[3] *Scientific Clinical Institutes ICS Maugeri SPA SB, Pavia, Italy*

INTRODUCTION

Foot drop can be caused by a variety of diseases and injuries, severely limiting the daily activities of sufferers [1]. In contrast to current practice [2], there is a need to optimise orthotic and daily treatment with Ankle Foot Orthoses (AFO) by integrating the skills and tools of clinicians, technicians and engineers. For the purpose of a fully customised treatment on the patient, the possibility of using CAD design and 3D printing assisted by integrated motion analysis and medical imaging tools is investigated.

METHODS

In this study supported by MISE's APTIS project in Horizon 2020[i], movement analyses were carried out on subjects with foot drop using the stereophotogrammetric system SMART-DX (BTS Bioengineering). A descriptive biomechanical model of the patient's pathological situation was developed and scaled according to the anthropometric measures. An inverse kinematics analysis was performed to reproduce the kinematics of the lower limbs observed during the experimental walking trials, exploiting markers data collected by the motion capture system. Displacement values of the heel during the Toe-Off phase and of the tibia during the Heel-Off phase were specifically inferred in Matlab. Concurrently, the CAD design with the CUBE software took into account multimodal sets of signals and biomedical diagnostic and functional images (i.e. biomedical imaging, stabilometric and dynamic assessment), integrated with the morphological 3D scanning of the patient (Figure 1a). The design of the AFO was iteratively validated through finite element analysis (FEA) using the expected foot displacement determined through the biomechanical analysis (Figure 1b). The AFO and related components were printed using fused deposition modeling (FDM) technology with Delta WASP 4070 and selective laser sintering (SLS) technology with LISA SINTERIT PRO (Figure 1c).

RESULTS

AFOs were successfully printed. Patients show a satisfactory degree of comfort during dynamic use.

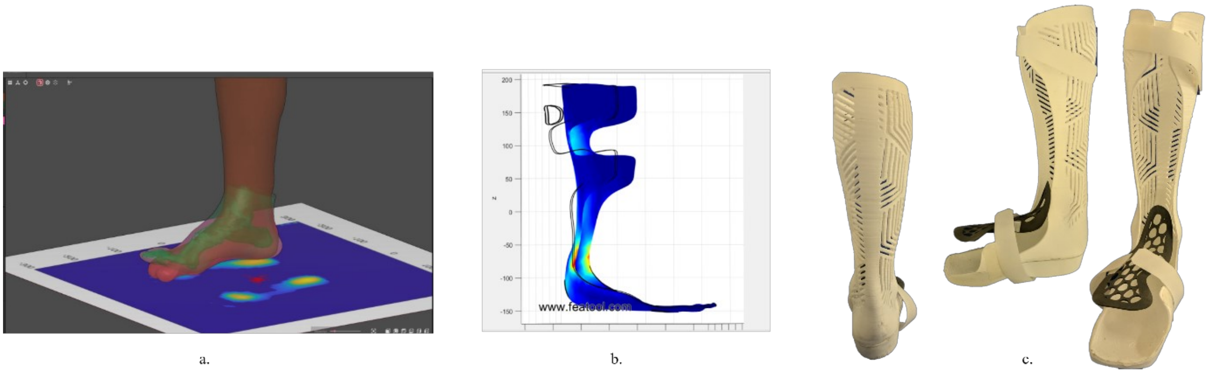

Figure 1 - The process of design and production of customised orthoses: a. CAD design supported by functional and morphological images; b. FEA validation of the orthosis design; c. customised orthosis printed using FDM and SLS technology.

DISCUSSION

Subsequent developments will concern the study of the different performance between commercial and customised orthoses. However, this process may actually represent an improvement over the past, with a view to totally customised treatment on the patient.

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

Evaluation of the rehabilitation outcome in patients with outcomes of orthopedic surgery using inertial technology for gait analysis

G. Pagano[1], D. Leandro[2], E. Losavio[1], A. Loverre[1], L. Dileo[1], V. Proscia[1], G. D'Addio[1]
[1]Clinic al and Scientific Institutes Maugeri SPA SB, Pavia, Italy
[2]Dept. of Electric al Engineering and Information Technolo gies University of Naples "Federico I ", Naples, Italy

INTRODUCTION

The aim of this study is to evaluate the rehabilitation outcome of patients with neuromotor pathologies in terms of space-time parameters using the Stand and Walk test. Gait Analysis has assumed a fundamental role in the process of evaluation, monitoring and clinical-therapeutic decision operating in Rehabilitation Medicine, it is in fact used in several contexts and researches.

METHODS

In the study, the wearable inertial system: Opal by APDM was used. The study has been carried out on a population of 30 patients with knee and hip prosthesis a (71±10 years old of which 70% female), admitted for rehabilitation treatment at Operating Rehabilitation and Functional Recovery Unit of ICS Maugeri Institute of Care and Scientific Research of Bari (Italy). The protocol requires patients to be instructed to remain silent for 30 s e and then ask them to walk at their conforming speed for 7 m, turn 180 ° and return to the starting point. Six parameters have been considered related to APA, gait and turning. Statistical analysis of the results was performed test the Gaussian distribution of all kinematic parameters. Subsequently, differences in the mean values of all kinematics parameters between admission and discharge were studied by appropriate (paired t-test or Wilcoxon paired-pair test of rank) two ANOVA tail test. All statistical tests were performed with a 95% confidence value.

RESULTS

In Table 1 are shown results of ANOVA test between the admission and discharge for each kinematic parameter related to the ISAW test.

Table 1. Duration Phases.

Parameters	Admission	Discharge	Normal Range
APA duration [s]	0.33±0.14	0.46±0.17***	[0.33÷0.55]
First Step Latency [s]	0.71±0.45	0.52±0.37*	[0.21÷0.40]
Stride Velocity [m/s]	0.77±0.17	0.83±0.18*	unreferenced
Stride Length [m]	1.07±0.16	1.13±0.15**	unreferenced
Turning Duration [s]	4.73±1.44	3.89±1.36**	[1.5÷2.2]
Number of Steps [dimensionless]	6.93±1.48	5.93±1.83**	[6]

DISCUSSION

The analysis shows that rehabilitation has a statistically significant impact on the gait of patients suffering from neuromotor diseases. The results show that rehabilitation allows for functional recovery by improving both postural control and gait, bringing a performance closer to normal ranges.

The variation of all the kinematic parameters analyzed towards the normal ranges is certainly correlated to an overall improvement in the movement of patients thanks to the rehabilitation treatment, highlighting the importance of quantitative measures to evaluate the patient's outcome.

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A comparative accuracy study of two markerless methods for estimating the sagittal lower limb joint kinematics with a single RGB-D camera

A. Rago[1], D. Balta[1], U. Della Croce[2], A. Cereatti[1]
[1] *Politecnico di Torino, Torino, Italy.* [2] *University of Sassari, Sassari, Italy.*

INTRODUCTION

Video-based markerless (ML) methods are gaining momentum in clinical gait analysis due to the quality of their output, their affordability and reduced processing time compared to marker-based (MB) methods. The performance of ML methods depends heavily on hardware capabilities. Recently (2020), a new RGB-D camera (Azure Kinect) was released by Microsoft with an integrated built-in software (Body tracking SDK) for joint centre position estimation [1]. This study aims to compare the performance of the above-mentioned SDK to an improved custom version of a ML method (MLM) based on a subject-specific kinematic model [2]. Sagittal lower limb joint angles were validated against a standard MB gait analysis protocol.

METHODS

Five healthy subjects were acquired in a gait analysis laboratory equipped with an RGB-D camera (Azure Kinect, fs = 30 fps) placed laterally to the walkway and a MB system (Vicon Vero, fs = 100 Hz). The latter was used as gold standard. Participants wore ankle socks of different colors and shorts. The acquisitions could not be synchronized due to the mutual interference of the two systems caused by the same working IR wavelength (850 nm) resulting in a visible deterioration of depth images. A static upright posture and 5 gait trials at self-selected speed for both right and left sides were acquired. To assess the performance of the methods, the sagittal lower limb joint kinematics were evaluated and seven gait variables [3] were extracted for each trial: the knee flexion at initial contact (K1), the max flexion at loading response (K2), the max extension in stance phase (K3), the max flexion in swing phase (K5), the ankle max dorsiflexion in stance phase (A3) and swing phase (A5) and the hip max extension in stance phase (H3). Results were compared by calculating the mean differences obtained from the SDK and the MLM with respect to the MB. The reliability was evaluated with the intraclass correlation (ICC).

RESULTS

Table 1. All variables are expressed in degrees except for ICCs.

Variables	*ML mean (SD)*	*SDK mean (SD)*	*GS mean (SD)*	*ML mean difference*	*SDK mean difference*	*ML ICC*	*SDK ICC*
K1	10.0 (5.2)	7.4 (2.5)	6.1 (4.0)	3.8	1.3	0.60	0.52
K2	18.2 (6.0)	13.5 (6.0)	14.2 (4.8)	4.0	-0.8	0.81	0.58
K3	5.7 (5.9)	7.7 (3.0)	6.3 (3.1)	-0.7	1.4	0.31	0.48
K5	64.5 (4.6)	59.7 (4.8)	64.0 (2.6)	0.4	-4.3	0.39	0.19
A3	7.2 (2.6)	46.5 (4.0)	18.4 (3.2)	-11.2	28.1	0.60	0.37
A5	-23.4 (6.9)	25.7 (3.6)	-13.9 (8.5)	-9.5	39.5	0.85	0.36
H3	-12.4 (3.8)	-16.8 (3.1)	-9.1 (4.6)	-3.3	-7.8	0.49	0.80

DISCUSSION

Both the SDK and MLM provided good estimates for knee and hip kinematics while higher differences were found for ankle kinematics, mainly for the SDK in which the foot segment was identified from the lateral malleolus to the toe position. The MLM performance was better at stance and swing phase of knee kinematics, while the SDK performed better during the first 40% of the gait cycle. Regarding hip kinematics, the MLM showed lower mean difference than the SDK during the stance phase. The overall performance of the SDK was affected also by the fact that for two subjects the contralateral limb was identified as the foreground limb. Based on the ICC values, the MLM revealed higher reliability than the SDK except for the hip and knee variables in stance phase. Although the MLM is more time consuming than SDK, its accuracy overcomes the SDK limitations and could be further improved by implementing a 3D model.

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Sessione 4: Movement analysis to support the design and evaluation of orthotic and prosthetic devices

Comparison of spatiotemporal parameters in the gait cycle in children with hemiplegia wearing AFO orthoses

F. Camuncoli [1], L. Piccinini [2], E. Di Stanislao [3], C. Corbetta [2], M. Galli [1]
[1]*Department of Electronics, Information and Bioengineering, Politecnico di Milano, Milan, Italy;*
[2]*Scientific Institute IRCCS Eugenio Medea, Bosisio Parini, Lecco, Italy;* [3]*ITOP SpA Officine Ortopediche, Palestrina, Rome, Italy;*

INTRODUCTION

Cerebral palsy (CP) is a disorder usually caused by brain damage occurring at birth or earlier, up to the age of two years [1,2]. Spastic hemiplegia/hemiparesis is a type of CP that affects only one side of children's body. The types of treatment that can be used depend on the patient's specific symptoms and range from physical and behavioural therapy, pharmacological treatments (with botulinum toxin and baclofen), surgical treatments (with rhizotomy) and the use of mechanical aids.

Conservative treatment on children with CP includes prescribing the use of ankle-foot orthoses (AFOs). In children with hemiplegia, for example, AFOs are prescribed to correct ankle position and affect the pathologic plantarflexion-extension couple of the hyperextended affected knee. Thus, the aim of this study is to compare the spatiotemporal parameters between barefoot walking and with different types of AFOs.

METHODS

Eighteen children were recruited for the Polisocial Award 2019 research project GIFT- enGIneering For sporT for all (age: 8.0±1.5 years, height: 1.29±0.07 m, mass: 27.3±5.4 kg (mean±SD)). They were provided with a custom-designed AFO designed by ITOP Officine Ortopediche SpA. The parents or guarantors signed informed consent and the study was approved by the ethics committee of the IRCCS Eugenio Medea – Associazione La Nostra Famiglia where the gait analysis were performed. 22 reflective markers were applied following the Davis protocol. Children were asked to walk at self-selected pace along the walkway in order to obtain at least 5 trials per condition: (i) barefoot, (ii) with commonly used AFO, (ii) with new orthosis at t0 (the day of delivery of the brace) and (iv) with new orthosis at t1 (after about 30 days of conditioning). Kinematics was acquired by means of an optoelectronic system consisting of 8 cameras (Smart DX 700, BTS Bioengineering, Milano, Italy). The spatiotemporal parameters taken into consideration (velocity, cadence, step width, stride length, step length, stance and swing phase, double support, single support) were calculated using a protocol in SMART Analyzer (BTS Bioengineering, Milano, Italy). Three valid trials were selected for each patient, one full gait cycle (HS-HS) was segmented for each trial for both the affected and the less affected side. Then, the parameters were averaged for each condition (Figure 1).

To compare between the four conditions, after the data normality check, a two-way ANOVA repeated measures and a one-way ANOVA repeated measure ($\alpha = 0.05$) were performed followed by post hoc tests with Bonferroni correction (ANOVA2rm on stride and step length, stance and swing phase, double and single support, ANOVA1rm on speed cadence and step width).

RESULTS

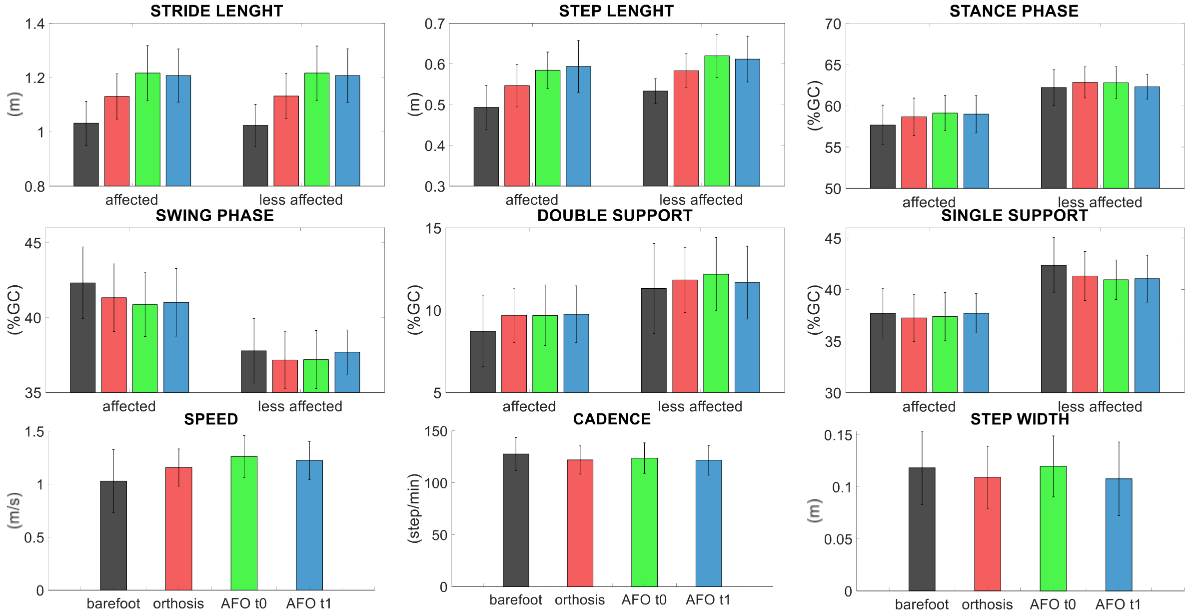

Figure 1. spatio-temporal parameters plot Mean and SD are represented.

DISCUSSION

With respect to the barefoot condition, wearing an AFOs (orthosis, AFO T0 and AFO T1) resulted in an increase in speed, a reduction in cadence, while stride width remained almost unchanged [3]. An asymmetry can be also observed between the affected and the less affected limb in relation to the temporal parameters (stance, swing, single and double support) that is not compensated even with the presence of the new device.

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Effects of instrumental therapy compared to convection therapy in subjects undergoing knee replacement

S. Carozzo[1], F. Coschignano[1], R. Battaglia[1], A. Giungato[1], F. Grillo[1], L. Pignolo[1], M. Raso[1], A Demeco[1]

[1] *S. Anna Institute, Crotone, Italy*

INTRODUCTION

Total knee replacement (TKR) surgery is frequently done and highly successfully. It relieves pain and improves knee function in people with advanced arthritis of the joint [1]. Rehabilitation shows a key role in improving functional outcomes and quality of life in patients with TKR. Visual feedback showed interesting results in increasing motor control in post-operative patients [2]. The study aims to evaluate the effectiveness of the use of motor rehabilitation tools in orthopedic patients, in particular on subjects undergoing intensive rehabilitation after knee replacement.

METHODS

A clinical randomized controlled study including patients undergoing intensive rehabilitation after TKR and randomly divided in 2 groups (1:1), Group A, introducing visual feedback utilizing Walker View 3.0 SCX and ProKin 252 (Bergamo, Italy) and Group B, conventional rehabilitation treatment. At the beginning of treatment (T0) and at the end of treatment (T1), the subjects underwent physiatric examination, clinical scales (VAS, Barthel Index) and gait analysis (BTS Bioengineering, Garbagnate Milanese MI).

RESULTS

We included 60 subjects mean age 70 ± 5, post-operation therapy period (37 ± 7 days). As shown in Table 1, both groups improved in the functional outcomes analyzed from T0 to T1. However, at T1 we registered a statistical difference in gait analysis between Group A and Group B. In particular, Support Phase (61.06 ± 2.32, 63.18 ± 4.06, *p-value* < 0,05) Index Symmetry (87.88 ± 6.72, 83.78 ± 3.67, *p-value* < 0,05) Obliquity (73.02 ± 12.42, 59.84 ± 12.04, *p-value* < 0,01) Rotation (83.77 ± 15.30, - 76.23 ± 2.71, *p-value* < 0,05) have a higher value in VFT group.

Table 1. Mean ± SD. * statistical significance (p<0.05).

	Group A			Group B			Group A vs Group B
	T0	T1		T0	T1		T1
			p			*p*	*p*
Barthel Index	46.75 ± 17.49	95.50 ± 6.69	< 0,001*	47.25 ± 6.78	95.35 ± 3.87	< 0,001*	0.926
VAS	63.50 ± 19.81	16.50 ± 10.40	< 0,001*	62.5 ± 12.08	16.5 ± 5.87	< 0,001*	1,000
Cadence	66.18 ± 9.71	83.85 ± 5.80	< 0,001*	64.78 ± 16.27	82.52 ± 5.78	< 0,001*	0.477
Velocity	0.58 ± 0.12	0.80 ± 0.71	< 0,001*	0.55 ± 0.18	0.75 ± 0.11	< 0,001*	0.033
Cycle Duration	2.11 ± 0.42	1.50 ± 0.16	< 0,001*	2.26 ± 0.45	1.64 ± 0.28	< 0,001*	0.100
Cycle Length	1.23 ± 0.15	1.04 ± 0.11	< 0,001*	1.21 ± 0.12	1.05 ± 0.99	< 0,001*	0.060
Support Phase	74.71 ± 3.12	61.06 ± 2.32	< 0,001*	70.55 ± 4.71	63.18 ± 4.06	< 0,001*	< 0,05*
Index Symmetry	70.03 ± 11.18	87.88 ± 6.72	< 0,001*	73.99 ± 4.07	83.78 ± 3.67	< 0,001*	< 0,05*
Propulsion	3.36 ± 0.73	5.24 ± 1.25	< 0,001*	3.71 ± 0.97	5.06 ± 1.11	< 0,001*	0.633
Tilt	71.92 ± 8.57	90.8 ± 4.54	< 0,001*	74.52 ± 9.29	88.14 ± 9.30	< 0,001*	0.258
Obliquity	43.14 ± 9.91	73.02 ± 12.42	< 0,001*	43.63 ± 4.79	59.84 ± 12.04	< 0,001*	< 0,01*
Rotation	61.52 ± 20.72	83.77 ± 15.30	< 0,001*	63.80 ± 4.95	76.23 ± 2.71	< 0,001*	< 0,05*

DISCUSSION

The results of this study suggest that the conjunction of conventional therapy and VFT could improve gait outcomes of patients with TKN, sensitizing the motor control strategy, through the self-correction of the gait and posture deficits. VFT should be considered in the rehabilitation protocol of patients with TKR to improve knee function to potentially reduce the risk of fall.

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Effects of a robotic end-effector device on muscle patterns while walking under different levels of assistance

A. Bellitto[1,2], L. Roascio[1,2], T. Rossi[1,2], G. Marchesi[1,2], C. Pierella[1,2], A. Massone[2], M. Casadio[1,2]
[1]DIBRIS, University of Genova, GE, Italy; [2]SCIL, Spinal Cord Unit, Santa Corona Hospital, ASL2, SV, Italy

INTRODUCTION

End-effector robots for gait rehabilitation allow an intensive, controlled and repetitive training of the lower limbs. These devices assist the gait cycle by providing body weight support while applying mechanical forces directly to the user's feet. Several studies have shown how end-effector robots can improve gait kinematics, however little research has been conducted to investigate how the device might affect the gait muscle activation patterns of the user. Our aim was to investigate: (i) if the device induces different muscle patterns than those adopted during overground walking and (ii) whether and how different levels of assistance influence muscle patterns while walking with the device.

METHODS

16 healthy volunteers walked 100 steps overground and with the support of an end-effector robotic device (GEO-system). In the latter case, participants were asked to walk while the device provided maximum, adaptive, and no bilateral assistance. During walking we recorded, using an electromyographic system (EMG), the activity of 8 muscles from each leg: tibialis anterior (TA), gastrocnemius medialis (GM), soleus (SOL), rectus femoris (RF), vastus medialis (VM), semitendinosus (ST), biceps femoris (BF), gluteus medius (GLM). At the same time, 2 Inertial Measurement Units (IMUs) were used to measure the angular velocity and angles of both feet. The gait cycle events were detected using the IMUs data and were used to segment the EMG signals. The latter were used to extract, with a non-negative matrix factorization algorithm [1], the muscle synergies - weights coefficients and activation profiles - of each walking condition. The same paradigm was also adopted to investigate the changes in muscle strategies during the ascent - descent of stairs. In the following, we will only describe and discuss the results of the overground walking task.

RESULTS

Differences in the muscle activation patterns were observed between overground and end-effector assisted walking. When walking with the device, regardless of the assistance provided, the activity of the distal muscles (TA, SOL, GM) decreased, as well as the activity of most of the proximal muscles (GLM, ST, BF). No relevant differences were observed in muscle activations of the knee extensors (RF, VM), while changes in timing were observed in the muscle activations of the TAs, STs and BFs. In the end-effector assisted walking, the TAs were active only in the swing phase of the gait cycle, while the STs and BFs were active only in the stance phase of the gait cycle. Moreover, no differences in the muscle activation timings were observed when walking with the device in all assistive modalities. The only changes induced by the type of assistance were at the level of the STs and TAs. The activity of both muscles in the no assistance condition was higher than the maximum and adaptive assistance conditions. The 4 muscle synergies extracted for each walking condition confirmed these observations. In synergy 1, which is mainly described by ST, BF and TA, all the end-effector walking conditions appear to have a lower contribution of the ST and TA. In synergy 2 and 3, described respectively by the TA and the GLM, the weights during end-effector assisted walking are the same as those of the overground walking. In synergy 4, which is mainly described by the SOL and GM, the weights of both muscles in the end-effector walking conditions display a smaller contribution than in the overground walking condition. As expected, the activation profile of the muscle synergies in the end-effector and overground walking conditions appear to have different activations timings (see Table 1).

Table 1. Intervals in which the activation profile has the highest activity expressed as a % of the gait cycle

	Synergy 1	Synergy 2	Synergy 3	Synergy 4
Overground	0-20%, 50-100%	0-20%, 40-100%	0-40%, 50-100%	0-60%
End-effector	0-20%, 40-60%, 80-100%	40-100%	0-60%, 80-100%	0-60%

DISCUSSION

The differences observed in the muscle patterns between end-effector assisted walking and overground walking appeared more influenced by the mechanical structure of the device than by the assistance provided. Specifically, the mechanical constrains due to anchoring the feet of the user to the platforms of the device and to the absence of a forward progression in space while walking may be the reasons behind the muscle patterns differences.

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Gait analysis driven design and 3D printing of plantar foot orthosis

A. Guiotto[1], D. Santini[1,2], E. Bertoncello[2], Z. Sawacha[1,3]
[1] *BiomovLab, Dept. of Information Engineering, University of Padua, Padova, Italy,* [2] *Orthomedica S.r.l., Padova, Italy,* [3] *Dept. of Medicine, University of Padua, Padova, Italy*

INTRODUCTION

Customized insoles are generally prescribed to treat or prevent gait modifications and biomechanical changes related to foot deformities that can cause abnormal foot load. These orthoses have the aim of reducing excessive plantar pressures or providing stability or increasing contact area and comfort [1]. Digital scanning, computer-assisted surface modeling techniques, and additive manufacturing are the latest developments in orthotic production. These technologies enable traditional manufacturing processes and designs to be digitalized with control and precision [2]. However, these methods have some limitations: they are still based on the experience of orthopedic technicians [3], only static or bare foot pressure is obtained, unloaded foot shapes are created or inappropriate materials are used for CAD-CAM processing. To overcome these limits, the goal of this study was to develop a method for producing 3D-printed orthoses from plantar pressure data collected through sensorized insoles during walking.

METHODS

A patient with a flat foot was asked to walk barefoot on a treadmill (2 km/h) and then with his shoes on the floor (at self-selected speed), at the orthopedic manufacturer's site during the regular assessment for the production of plantar insoles. Plantar pressure data were acquired both by the instrumented treadmill (I-Runner, Impronta Medica) and by plantar pressure insoles into the shoes (PedarX, Novel gmbh). Afterwards, two different workflows were used to design and produce orthopedic insoles:

(1) manufacturer routine methods have been applied, which involves collecting footprints on the instrument treadmill, processing the plantar pressure map through the software Freestep and Easycad Insole (Sensor Medica), producing the insole with the CAD-CAM milling technique;
(2) new method involves the use of PedarX data, processed through self-developed codes, and a stl surface generation based on these plantar pressure data. This stl was further processed through the free 3D modeling software Blender and EasyCAD, then the insole was printed with a 3D printer (Bioflex material, straight filling, 90% infill).

RESULTS

In Figure 1 is represented the pipeline of the new method (2).

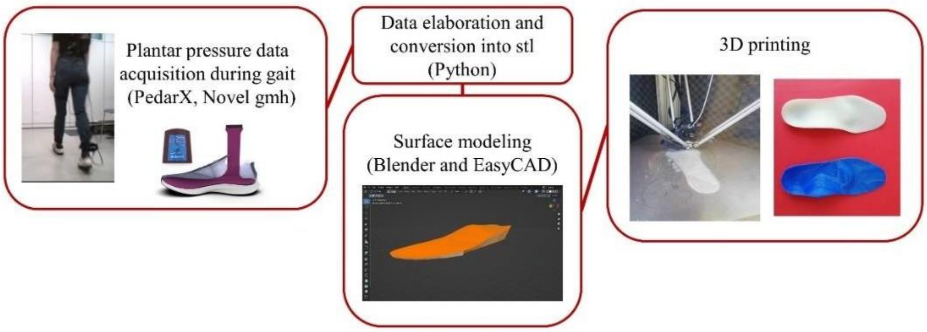

Figure 1. Pipeline of the procedure.

DISCUSSION

The final result was promising. Since there are no manual interventions by technicians capable of injecting subjectivity into the final product, it ensures that it can be easily reproduced and is consistent with the previously created 3D model.

In addition, the possibility of generating the plantar orthosis model from plantar pressure insoles, enables the necessary data to be obtained under free conditions, taking into account the relationship between the foot and the shoe, without the constraints of an instrumented treadmill. As development progresses, comparisons between the two methods of producing insoles will be made, and new filling materials and different filling percentages will be studied to optimize 3D printing.

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The effect of a passive exoskeleton on trunk co-activation during liftings at different risk levels

G.Chini[1], T. Varrecchia[1], A. Silvetti[1], A. Tatarelli[1,2], L. Fiori[1,2], F. Draicchio[1], M. Serrao[2], B. Montante[3], R. Ciancia[3], M. Michieli[3], M. Rupolo[3], A. Ranavolo[1]

[1] *INAIL, Monte Porzio Catone, Rome, Italy,* [2] *Sapienza University of Rome, Rome, Italy,* [3] *Aviano Oncology Reference Center (CRO), IRCCS, Pordenone, Italy*

INTRODUCTION

The new Industry 4.0 scenarios offer opportunity for both the prevention of biomechanical overload risks and the implementation of extra return-to-work initiatives for people with disabilities. Wearable assistive devices (e.g., an industrial exoskeleton) can help to lower the risk of acquiring work-related musculoskeletal diseases (WMSDs) caused by manual material handling (MMH) tasks, among other things [1]. The most prevalent and expensive musculoskeletal diseases are WLBDs, which are primarily caused by manual lifting jobs [1]. This study aims to investigate the influence of TRUExo, a passive exoskeleton for the trunk composed of a textile and a mechanical component for energy restitution, on trunk coactivation in lifting activities at various risk levels (more details cannot currently be described because the device is under patent).

METHODS

Twelve healthy volunteers (age: 36.33±7.66 years; BMI: 22.34±2.21 kg/m2; 6 females and 6 males) completed the lifting tasks designed using the revised NIOSH lifting equation, [2], at progressively increasing lifting indexes (from 1 to 3). The tasks were performed with and without the TRUExo exoskeleton, and the activity of the erector spinae longissimus (RESL) and rectus abdominis superior (RAS) was recorded bilaterally using a 16-channel Wi-Fi transmission surface electromyograph (Mini Wave Infinity, Cometa, Milan, Italy) system at a sampling rate of 2000 Hz. Before beginning the lifting tasks, participants completed three repetitions of a specific exercise to record the isometric maximal voluntary contractions (iMVCs) for the muscles under investigation. Then, after sEMG processing and normalization respect to iMVC values, we computed the time-varying multi-muscle co-activation function (TMCf), [3].

RESULTS

Our findings reveal that the mean TMCf of all patients is lower with the passive exoskeleton than without it at each LI. The mean of the TMCf reduces significantly with LI when wearing the exoskeleton, according to two-way repeated-measures ANOVA and post-hoc analysis (Fig. 1 B).

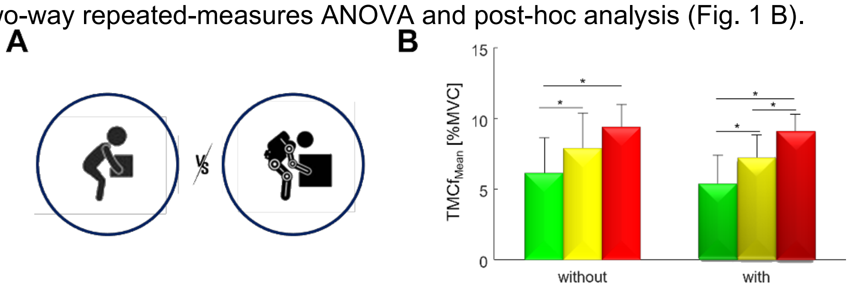

Figure 1. Panel A shows the experimental setup, with two icons representing the two conditions we compared (wearing and not wearing an exoskeleton). Panel B illustrates the mean (bar height) and standard deviation (error bar length) of the TMCf mean at three risk levels (LI=1 green, LI=2 yellow, and LI=3 red) without and with the exoskeleton.

DISCUSSION

The results reveal that the TMCf increases in relation to the risk levels both with and without the exoskeleton, but the TMCf is lower at each LI when the subject wears the exoskeleton (Figure 1, B). These findings could lend credence to the notion that a passive exoskeleton worn during a working activity could alleviate biomechanical load and, as a result, lower the likelihood of WMSD occurrence. Furthermore, our findings highlight the TMCf's sensitivity to differentiate different risk levels even when wearing an exoskeleton, implying that it might be used as an operational tool to assess biomechanical risk in situations where traditional approaches (e.g., NIOSH's method) cannot be used.

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Sessione 5: Wearable systems in movement analysis, home monitoring and actigraphy

Inertial measurement units-based assessment of gait to identify depression

G. Fransvea[1,2], E. Vendrame[1], E. Patron[3], F.Mura[3], C. Cipriani[1], C. Gentili[3], A. Mannini[2]
[1]*The BioRobotics Inst., Scuola Sant'Anna, Pi, Italy;* [2]*IRCCS Fond. Don Carlo Gnocchi, Firenze, Italy;* [3]*Dept. General Psycology, Univ. Padua, Italy*

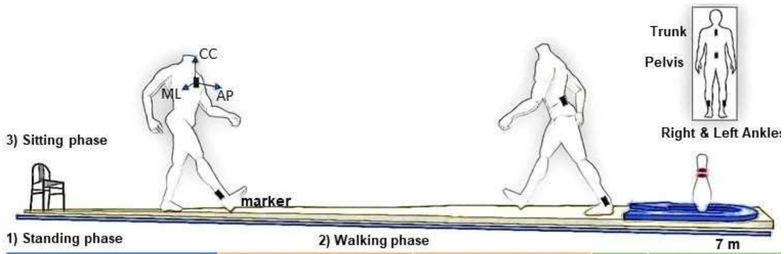
INTRODUCTION

Major Depressive Disorder (MDD) causes a variety of emotional and physical issues leading to severe clinical implications [1]. In MDD patients, a strong association between psychomotor deterioration and gait components has been found [2]. Instrumental gait analysis holds a crucial role in precision evaluation of movement in MDD [3]. Targeting a solution for an ecological assessment of movement, Inertial Measurement Units (IMUs) signals were recorded during a Timed Up and Go (TUG) test to investigate temporal and spatial parameters in both MDD patients and age matched controls.

METHODS

48 participants, (28 Controls, C and 14 Depressed, D), were enrolled into the study after signing a written consent. Four IMUs (Shimmer Sensing), placed at both ankles, at the trunk and at the pelvis, were adopted with a sampling frequency of 250Hz while subjects performed 3 trials of a 7m-TUG test. After filtering (4Hz low pass filter) and segmenting IMU raw data in the 3 main TUG test phases (standing, walking and sitting), gait events (Toe Off, Heel Strike and Mid Swing) were detected from signal coming from ankle-worn IMUs to drive gait spatio-temporal parameters estimation (Fig.1).

In addition, using pelvis and trunk sensors, acceleration ranges and the gyroscope complexity index (CI) [4] were calculated along the 3 directions (antero-posterior AP, cranio-caudal CC and medio-lateral ML). The median among the 3 trials was retained to evaluate the correlation between instrumental parameters and the presence (via a logistic regression adjusted for age and sex). Significance threshold was set at p-value=0.05.



Walking Variable	Control (N=28) Median and IQR	Depressed (N=14) Median and IQR	Sign.	Nagelkerke's R^2
Walking time, [s]	12.31 [3.50]	12.80 [3.10]	.210	.095
Walking speed [m/s]	0.50 [0.11]	0.53 [0.10]	.565	.055
Cadence, [N.strides/minute]	71.17 [13.03]	68.59 [9.48]	.966	.045
T stance [s]	0.67 [0.10]	0.65 [0.13]	.962	.045
T swing [s]	0.47 [0.051]	0.46 [0.13]	.398	.068
Pelvis Acc Range ML, [m/s²]	6.22 [1.85]	7.75 [2.42]	.014*	.274
Pelvis Acc Range AP, [m/s²]	6.56 [2.08]	7.50 [1.76]	.508	.059
Pelvis Acc Range CC, [m/s²]	7.53 [2.12]	7.46 [2.28]	.729	.049
Trunk Acc Range ML, [m/s²]	5.84 [2.28]	7.31 [3.37]	.253	.091
Trunk Acc Range AP, [m/s²]	7.43 [2.15]	7.74 [2.46]	.165	.174
Trunk Acc Range CC, [m/s²]	8.00 [2.81]	8.54 [1.75]	.480	.128
CI - Trunk Gyro AP	3.27 [0.81]	3.69 [0.77]	.024*	.228
CI - Trunk Gyro ML	3.11 [0.73]	3.01 [1.62]	.631	.052
CI - Trunk Gyro CC	1.54 [0.52]	1.68 [1.05]	.199	.099
CI - Pelvis Gyro AP	3.22 [0.61]	3.37 [0.76]	.554	.056
CI - Pelvis Gyro ML	3.08 [0.67]	3.03 [1.30]	.256	.086
CI - Pelvis Gyro CC	1.65 [0.68]	2.00 [1.07]	.070	.177

Figure 1. TUG test and its segmented phases are shown. The black rectangles represent the markers and their positions. Descriptive and inferential statistics are reported in the table below

RESULTS & DISCUSSION

The C group included 8 males and 20 females (median age 23 years [IQR=3]) and the D group included 2 males and 12 females (median age 22 years [IQR=5]). Only ML acceleration range for pelvis and AP gyroscope CI for trunk were significantly associated to depression. The identification of depression markers from wearable sensors could enable the long-term objective of depression mass screening using portable devices (Fig.1). Among the tested parameters, a larger pelvis ML acceleration range was found in patients, coherently with previous literature findings [1]. As Adolph et al. [5] noticed such higher oscillation can be associated to the request of walking on a pre-defined path, imposing an external constraint on the walk, thus making this parameter an object for further investigations in ecological setting. Differently from previous studies analyzing longer walking bouts [6], we were unable to identify a significant reduction of walking speed in the D group. Up to our knowledge, no study compared CI between healthy individuals and depressed patients, preventing the comparison of our results to literature findings. Nevertheless, the AP gyroscope CI, that contains meaningful information on the posture stability, is proved to be a predictor of the MDD. Overall, such parameters may be used in a Machine Learning model embedded in portable devices to predict the occurrence of MDD.

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Performance of a multi-sensor wearable system for validating gait assessment: preliminary results on patients and healthy controls

F. Salis[1,2], T. Bonci[3], S. Bertuletti[1,2], M. Caruso[2,4], K. Scott[3], E. Buckley[3], L. Alcock[5], S. Del Din[5], L. Rochester[5], E. Gazit[6], J. M. Hausdorff[6], C. Hansen[7], W. Maetzler[7], L. Schwickert[8], C. Becker[8], C. Mazzà[3], A. Cereatti[2,4], on behalf of the Mobilise-D consortium.

[1] *University of Sassari, Sassari, Italy,* [2] *IuC BoHNes, Sassari, Italy,* [3] *University of Sheffield, Sheffield, UK,* [4] *Polytechnic University of Turin, Turin, Italy,* [5] *Newcastle University, Newcastle, UK,* [6] *Tel Aviv Sourasky Medical Centre, Tel Aviv, Israel,* [7] *University Hospital Schleswig-Holstein, Kiel, Germany,* [8] *Robert-Bosch-Hospital, Stuttgart, Germany*

INTRODUCTION

Real-world (RW) gait analysis is becoming increasingly important since in these conditions an individual's mobility performance can be measured, in addition to what happens in a standardised lab environment, where mobility capacity is assessed. This is even more relevant in the presence of a motor disability, when continuous daily-life monitoring can unveil limitations in movement, better stratify disease progression and the efficacy of medical treatments [1]. Wearable inertial measurement units (IMUs) represent the most valid solution to tackle this challenge, but their validation requires RW gait data from a reliable Gold Standard (GS). This study evaluates the performance of a wearable multi-sensor system (INDIP) which was specifically conceived to be used as a RW GS [2]. In particular, the INDIP performance in estimating digital mobility outcomes (DMOs) was assessed against a stereophotogrammetric (SP) system, on healthy older adults and patients from five different cohorts, following a purposely designed experimental protocol [3].

METHODS

The INDIP system includes three IMUs (sampling frequency (fs) =100 Hz) positioned on lower back and feet, two pressure insoles (16 sensing elements, fs=100 Hz) and two time-of-flight distance sensors (fs=50 Hz, range=0.2m) [2]. Experiments were carried out on 107 participants from six different cohorts (Healthy Adults (HA), Parkinson's Disease (PD), Multiple Sclerosis (MS), Chronic Obstructive Pulmonary Disease (COPD), Congestive Heart Failure (CHF), Proximal Femoral Fracture (PFF)) while performing a complex eleven-task protocol [3]. Walking bouts (WBs) were obtained from the INDIP data, according to the flowchart described in [2]. Then, for each WB, relevant DMOs were computed. Accuracy of the estimated DMOs was evaluated at cohort level in terms of median relative error (%). For sake of brevity, here we only report walking speed results.

Table 1. Results for walking speed. STD: Standard Deviation

			Walking Speed		
Cohort	Participants number	WBs number	Mean ± STD (INDIP)	Mean ± STD (SP)	Median Relative Error (%)
HA	20	237	0.85 ± 0.30 m/s	0.85 ± 0.30 m/s	2.28 %
PD	20	241	0.74 ± 0.30 m/s	0.72 ± 0.30 m/s	2.42 %
MS	19	238	0.79 ± 0.30 m/s	0.79 ± 0.30 m/s	2.55 %
COPD	17	220	0.81 ± 0.30 m/s	0.81 ± 0.31 m/s	2.02 %
CHF	10	105	0.85 ± 0.33 m/s	0.80 ± 0.29 m/s	2.58 %
PFF	17	193	0.64 ± 0.33 m/s	0.64 ± 0.32 m/s	2.32 %

RESULTS

A total of 103 subjects were considered for the analysis (1234 WBs in total). Results at cohort level for WB walking speed are presented in Table 1. Median relative errors ranged from 2.02% to 2.58%.

DISCUSSION

Results reported for the WB walking speed showed very low median relative errors across all cohorts. For each cohort, the distributions of values from the INDIP and SP were very similar as shown by the means and standard deviations in Table 1. Such low differences are excellent, especially when considering the complexity of the tasks included in the experimental protocol. In conclusion, the INDIP system is an accurate reference system for RW gait analysis.

ACKNOWLEDGMENTS

This study was supported by Mobilise-D project (EU H2020, EFPIA, and IMI 2 Joint Undertaking; Grant no. 820820).

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Technology-based assessment of Short Physical Performance Battery in elderly population.

M. Musci [1], S. Aresta [1], R. Sardone [1], I. Bortone [1]
[1] *I.R.C.C.S. "Saverio de Bellis", Castellana Grotte, Italia*

INTRODUCTION

The Short Physical Performance Battery (SPPB) is an objective evaluation of the lower extremity strength [1]. It has been proposed as a reliable method to assess the physical performance of elderly people (65+) through three simple tasks of daily life (gait, standing, chair stand) [2]. In clinical research, the SPPB is administered by research staff who are experienced in the standardized protocol of the examination, with each component measured manually by a stopwatch [3, 4]. Therefore, these investigations may be subject to possible interrater and intrarater variabilities [5]. This work aims to validate an automatic method for the objective assessment of SPPB through the combination of wearable inertial and sEMG sensors.

METHODS

The present study included a sub-cohort of Salus in the Apulia Study of 137 old subjects, recruited consecutively from 2019 on a recall-based from an ongoing population-based prospective cohort comprising 2472 individuals aged 65+ and residents in Castellana Grotte, Puglia (Italy). Eligible participants were equipped with an inertial sensor (positioned around the subjets' waist, BTS G-SENSOR2, BTS SpA) and four surface electromyographic probes (BTS FREEEMG, BTS SpA) on Tibialis Anterior (TA) and Gastrocnemius Medialis (GAM) of both legs. The medical doctor instructed subjects to perform three different tasks: balance (stance phase, semi-tandem phase, and tandem phase), five repetition STS and 4-m walk. A stopwatch was used to measure the time required by the subject to complete each task and then assign the SPPB score according to the specific range (SPPB). Kinematics and EMG data of subjects were collected via BTS EMGAnalyzer and exported in MATLAB R2020a to calculate the technology-based SPPB (tSPPB). Descriptive statistics were used to describe the demographic characteristics and outcomes of the sample. The Spearman correlations were used to explore the relationship between the SPPB and tSPPB total score and the three-component scores. We compared the internal consistency of the SPPB and tSPPB using Cronbach's alpha.

RESULTS

Ninety-seven subjects (mean age [±SD] = 75.1 ± 5.53, female = 50.5%) were finally included in the analysis. The total SPPB (9.49 ± 2.55) and tSPPB (8.88 ± 2.51) scores were significantly different, yet highly correlated ($r = 0.87$, $p < 0.01$). The alpha coefficient for the SPPB score was high (0.93, 95% CI: 0.90 - 0.96), suggesting that the two methods have relatively high internal consistency.

DISCUSSION

Technology-based assessment of SPPB represents a step forward in adapting the administration of objective measures of physical function to significantly expand the reach of research and clinical practice to assess populations at risk of functional decline.

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Gait smoothness using wearable sensors in patients with neurological disorders: a comparison of different metrics

R. Montemurro [1], E. Bergamini [2,3], A. Orejel-Bustos [2,3], V. Belluscio [2,3], M. Tramontano [2,3], G. Vannozzi [2,3]

[1] Roma Tre University, Rome, Italy, [2] University of Rome "Foro Italico", Rome, Italy, [3] IRCCS Santa Lucia Foundation, Rome, Italy

INTRODUCTION

Smoothness (i.e. non-intermittency) of movement [1] is a clinically relevant parameter, proven to decrease in neurological populations, like Multiple Sclerosis (MS) or Traumatic Brain Injury (TBI). Many metrics have been proposed to quantify smoothness, differing in the considered data source and mathematical approach, and mainly focused on upper limbs movements [2]. Although locomotion is a major component of daily physical activities and a key to functional independence, it is unclear whether and how these metrics can be applied to locomotion [3]. In addition, inertial measurement units (IMUs) are increasingly used to estimate gait smoothness [1,4], however no consensus exists about which IMU signal and metrics should be considered. The aim of this study is to compare two metrics commonly used to quantify movement smoothness, considering as data source both acceleration and angular velocity signals measured during locomotion in MS and TBI populations as well as in healthy subjects.

METHODS

Thirty-three patients suffering from MS (24 F; 49.8±9.3 y; EDSS 4.0±1.6), 30 patients suffering from TBI (11 F; 35.8±12.8 y; DGI 17.3±4.7), and 43 healthy adults (HC) (12 F; 33.0±10.8 y) were enrolled in this study (CE/PROG.700). Three IMUs (APDM Opal, 128 Hz) were located on the lower trunk and on both legs. Participants performed a 10 m walk Test (10mWT) for three times. Stride segmentation was performed using leg-mounted IMUs, and two smoothness parameters were calculated for each stride and each direction (antero-posterior AP, medio-lateral ML, cranio-caudal CC) using trunk linear accelerations (*a*) and angular velocities (*w*) as source data: the Spectral Arc Length (SPARC) and the log dimensionless jerk (LDLJ) [1]. Median and inter quartile range (IQR) were calculated over all strides for each participant and the IQR/median was obtained for each metrics. To test the effect of the considered populations (MS, TBI, HC) and of the considered metrics (SPARC*a*, SPACR*w*, LDLJ*a*, LDLJ*w*) on the results, a mixed model ANOVA was run after verifying for normal data distribution. *Post-hoc* analysis was also performed using Bonferroni-Holmes correction for multiple comparisons.

RESULTS

Both population and metrics significantly influenced the smoothness values ($p<0.001$), with a significant interaction between these two factors ($p<0.01$). The IQR/median ratio was significantly smaller for LDLJ with respect to SPARC for both acceleration and angular velocity signals ($p<0.001$) (Figure 1).

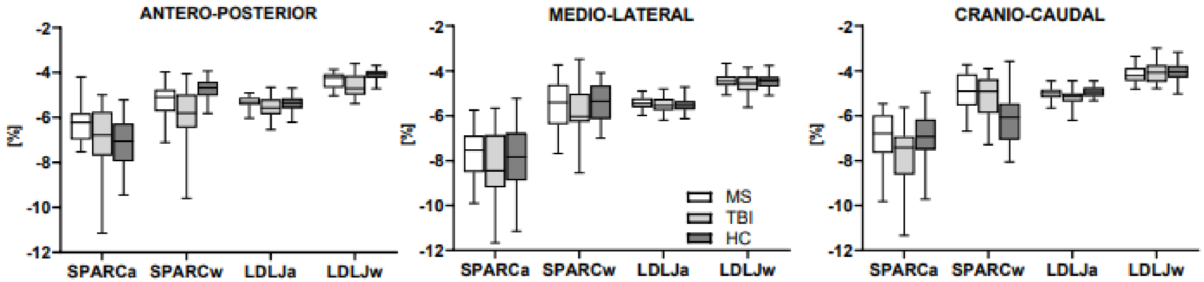

Figure 1. Boxplots of SPARC and LDLJ smoothness metrics for MS, TBI, and HC.

DISCUSSION

The considered metrics and data source influence the final gait smoothness outcome and, thus, its clinical interpretation. LDLJ is characterized by a significant smaller variability with respect to SPARC and can discriminate not only between HC and the two neurological populations, but also between MS and TBI. Both LDLJ*a* and LDLJ*w* are good candidate for quantifying smoothness during locomotion.

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A biomechanical approach to study lunge in fence athletes

S. Aresta[1], I. Bortone[1], F. Bottiglione[2]
[1] Data Sciences and Innovation, N.I of Gastroenterology "S. de Bellis", Castellana Grotte, Bari, Italy
[2] Department of Mechanical Mathematics and Management (DMMM), Polytechnic of Bari, Bari, Italy

INTRODUCTION

Fencing requires neuromuscular coordination, strength, and power, and it has a high impact on the musculoskeletal system [1—5]. The lunge is the most important strike action. It is produced with explosive power and surprises the opponent to score points. The lunge starts from the armed arm, which must be moved as quickly as possible toward the opponent, combined with lower body movements to provide a boosting action [4]. The present study aims at assessing kinematics and electromyographic differences between tasks and categories.

METHODS

The participants were 28 male and female, élite and recreational fencers, practicing foil and épée. The age ranged from 8 to 35 years old. Anthropometric and biographical information were taken. Kinematics data were acquired using a wearable inertial system BTS G-SENSOR2, positioned on the L5 vertebra. Four wearable EMG probes BTS FREEEMG 1000 were used to detect EMG signal of Deltoideus Anterior (DLTA) and Rectus femoris (RF) both on the armed side; Erector Longissimus muscle (LONG) and Gastrocnemius medialis (GAM), on the opposite one. These devices were synchronized by the acquisition software BTS EMG-Analyzer. Muscles' MVC and two trials of lunge (AF), step forward lunge (AA) and step backward lunge (DA) were taken. Data were processed with MATLAB and Tracker. V\Wilcoxon's effect size for continuous variables and prevalence differences for categorical ones.

RESULTS

Age and anthropometric measures were statistically different between the two categories ($P < 0.05$). No statistically significant differences are observed between the sexes, excluding thigh circumference ($P < 0.05$). The normalized distances and x-axis ROM between tasks and the y-axis ROM in the second trial (AA), the mean normalized muscle activation of DLTA, RF, and GAM between categories were statistically different ($P <0.05$). No significant statistical differences in muscle activation patterns were observed between different categories. Each correlation coefficient was interpreted based on a previously described classification using similar variables: 0-0.4 (weak), 0.4-0.7 (moderate), and 0.7-1.0 (strong). Table 1 summarizes the results observed from the correlation, the direction of the arrow stands for the direction of correlation (positive or negative), while the number of arrows is the intensity of correlation (weak, moderate, or strong). It is important to emphasize the negative correlation between lunge time and activation intensity of the LONG muscle, as well as the positive correlation between lunge distance and activation intensity of the GAM muscle.

	Distance	DLTA	RF	LONG	GAM
Age	↑↑		↑↑		
On guarde height	↑↑↑		↑↑		↑↑
Leg Length	↑↑		↑		↑↑
Front Thigh Circumference		↑			
Armed Arm Circumference					
Weapon Length	↑↑	↑↑			
Time				↓	
Distance					↑↑

DISCUSSION

Differences have been observed in some kinematic and electromyographic parameters among categories and tasks. No substantial difference in muscle patterns is observed between different categories. Furthermore, correlations have emerged between muscular activity and spatiotemporal variables of movement: a greater rapidity of movement is associated with greater activity of the LONG, because it is balance responsible. A longer lunge distance is related to a greater activity of the GAM (boosting muscle).

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Estimation of running biomechanical parameters using magneto-inertial sensors: a preliminary investigation

R. Rossanigo [1], S. Bertuletti [1], V. Camomilla [2], A. Orejel Bustos [2], C. Agresta [3], J. Zendler [4], M. Risatti [5], A. Sanfelici [5], A. Cereatti [6]

[1] University of Sassari, Sassari, Italy, [2] University of Rome 'Foro Italico', Rome, Italy, [3] University of Washington, Seattle, Washington, [4] Rimkus Consulting Group, Houston, Texas, [5] Diadora S.p.A., Treviso, Italy, [6] Politecnico di Torino, Turin, Italy

INTRODUCTION

Many runners perform training sessions outdoors and on varying surfaces (e.g., track, paved path, trail). Training surface has been shown to influence running spatiotemporal measures and stiffness [1]. However, applied research in understanding training surface influence has been limited by lack of robust methodology to capture biomechanics in-the-field. The increasing availability of wearable magneto-inertial sensors (MIMUs) is now making it possible to perform in-field assessment of running biomechanics [2]. Validation of new inertial-based methods is vital to widespread field use. In this study, we compared inertial-based methods for running biomechanical analysis and against gold-standard stereo-photogrammetric system (SP).

METHODS

Ten recreational male runners (age: 32.3 ± 10.0 years) were enrolled and asked to run on a treadmill at 14 km/hr for 8 trials lasting 6 minutes. We simulated changes in surface in a controlled lab setting by using 8 different footwear conditions. Participants were instrumented with MIMUs (mod: Opal v2, APDM, Portland, USA; fs=200 sample/s) attached on the pelvis (L5) and the instep of both feet, and retroreflective markers on heels, toes, and each MIMU (recorded with a 9-camera Vero system, Vicon, Oxford, UK; fs=200 sample/s).

The estimated relevant biomechanical parameters included: stride/stance/swing duration, stride rate, vertical oscillations of the center of mass (CoM), and vertical/leg stiffness. Gait events (initial and final contacts) were estimated using a modified version of the MIMU-based method proposed by Benson et al. [2]. CoM vertical displacement was estimated as the vertical component of the L5 MIMU trajectory. Vertical and leg stiffness were computed starting from CoM displacement, stance interval, and swing interval [3]. For each participant and trial condition, errors with respect to SP were computed (80 values for each parameter) and root mean squared errors (RMSE) across participants and conditions were then calculated. In addition, a Bland-Altman analysis was used to quantify the agreement between MIMU and SP outcomes in terms of 50% limits of agreement interval (LoAI).

RESULTS

Differences between MIMU-based and SP-based parameters over all the runners are reported in Table 1.

Table 1. Descriptive statistics of MIMU-based running parameters and of their differences with respect to SP.

	Stance duration (ms)	Swing duration (ms)	Stride duration (ms)	Stride rate (strides/ min)	CoM vertical displacement (mm)	Vertical Stiffness (kN/m)	Leg Stiffness (kN/m)
Mean±SD	240±12	448±26	689±28	86.6±3.3	47±6	66.17±6.76	16.02±2.04
RMSE	22	22	1	0.7	1	6.52	4.77
50% LoAI	18	17	1	0.8	2	6.63	4.12

DISCUSSION

Results showed high accuracy especially in the estimation of stride duration, stride rate and CoM vertical displacement. The level of uncertainty associated to each biomechanical variable, as provided by the LoAIs, can be used to detect differences in surface conditions (footwear conditions). Future analysis and development of field methods will investigate the influence of unconstrained movements (outdoor, no treadmill) in addition to varying surface conditions and the influence of running speed on inertial-based method accuracy.

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Motor-cognitive interference in balance and gait tasks of increasing complexity: a fNIRS and IMUs study

V. Belluscio[1,2], G. Cartocci[3], T. Terbojevich[3], P. Di Feo[1], M. Ferrari[4], V. Quaresima[4], F. Babiloni[3], G. Vannozzi[1,2]

[1]Università degli Studi di Roma "Foro Italico", Roma, Italy; [2]Fondazione Santa Lucia, Roma, Italy; [3]Università degli Studi di Roma "La Sapienza", Roma, Italy; [4]Università degli Studi dell'Aquila, L'Acquila, Italy

INTRODUCTION

Moving in real environments requires to consider not only ecological motor tasks (e.g., curvilinear walking), but also the cognitive load associated with the motor performance [1, 2]. Wearable technology provides non-invasive monitoring solutions for both aspects, through inertial sensors and functional Near-Infrared Spectroscopy (fNIRS) technique. Specifically, fNIRS assesses cortical activity through the hemodynamic response of the brain [3] and can be performed while the participant freely moves in the environment [3, 4]. In this context, the prefrontal cortex (PFC) is of particular interest: it regulates executive functions and has the potential to reveal crucial information related to cognitive processes and dynamic gait indices [1, 3-4]. While it is well known that different motor tasks are characterized by different PFC activations, it is not clearly understood how PFC activation changes with increased complexity of balance locomotion tasks yet. Therefore, the study aims at filling this gap investigating motor-cognitive interference in balance and gait tasks of increasing difficulty.

METHODS

Twenty healthy young adults (11 females, 24.4±2.7 years) randomly performed four different motor tasks of 60s each related to dynamic (linear walking, LW, and tandem walking, TW) and static (doubleleg stance, DLS, and single-leg stance, SLS) balance while wearing: i) a fNIRS brain cap (Brite 24, Artinis, The Netherlands) to measure the PFC changes in oxygenated hemoglobin (ΔO2Hb), and ii) 4 synchronized measurement units (IMUs, Opal, APDM, USA) at sternum, pelvis and both lateral malleoli to quantify gait and balance motor patterns. Repeated measures ANOVA (ΔO2Hb) and t-tests (IMUs) were computed to investigate differences among tasks.

RESULTS

fNIRS (top panel) and IMUs (bottom panels) results are displayed in Figure 1.

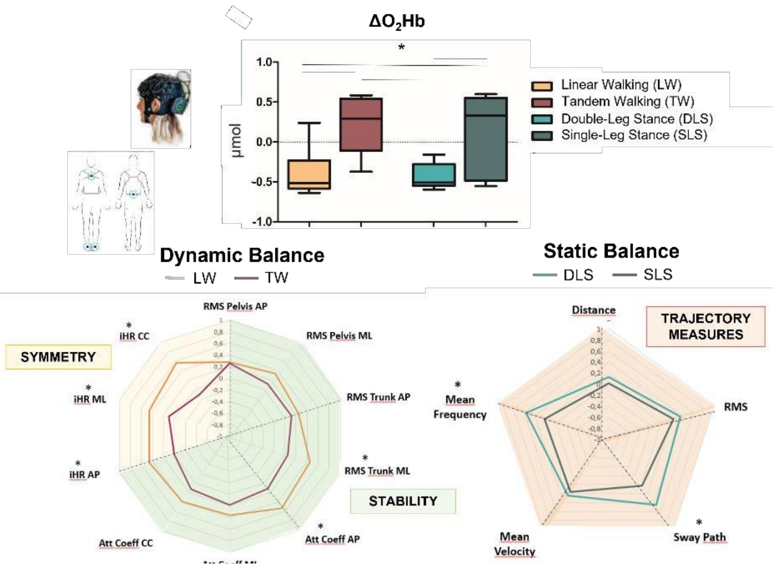

Figure 1. * indicates statistically significant differences (for ΔO2Hb after Holm-Bonferroni correction for multiple comparisons). Radar charts: larger values indicate better performance (parameters were inverted when needed).

DISCUSSION

As expected, more challenging motor tasks (TW and SLS) require greater PFC activation, suggesting the use of additional attentional resources during tasks of increased difficulty. In addition, motor performance suffers of tasks complexity, as clearly emerge from dynamic gait indices and postural parameters. This study lays foundation for better understanding the motor-cognitive interference in ecological gait and balance tasks.

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IMU-based assessment of motor control in a population of young subjects with idiopathic scoliosis: preliminary results from the motor-child study

GM Farella[1], F Vanzini[1], R. Tedeschi[1], MG Benedetti[1], MC Bisi[2], R Stagni[2]
[1]Physical Medicine and Rehabilitation Unit, IRCCS-Istituto Ortopedico Rizzoli, Bologna, Italy
[2]Department of Electric, Electronic and Information Engineering "Guglielmo Marconi" – DEI, University of Bologna, Italy

INTRODUCTION

Motor development is an adaptive process occurring within a self-organizing system and influenced by several factors. While evidence exists for motor control in severe pathologies (cerebral palsy), minor musculoskeletal conditions, such as scoliosis, have never been explored. Clinical-functional tests used for the analysis of motor control (Movement ABC-2 or TGMD-2) are time-consuming, hindering their applicability to large populations. In recent years wearable Inertial Measurement Units (IMUs) were introduced for low-cost ambulatory quantitative assessment allowing the estimation of temporal gait parameters [1] and of dynamics of motor control through nonlinear metrics [2-4]. The aim of this work was to assess motor control alterations in children affected by idiopathic scoliosis using clinical-functional tests and IMU-based metrics related to motor control.

METHODS

34 children aged between 6 and 16 years with scoliosis (ATR ≥ 5 ° or Cobb ≥ 10°) were included. They underwent MovementABC-2 for clinical assessment of motor competence. Three tri-axial IMUs (MetamotionR, mbient-Lab, USA) were attached on the lower back and on the shanks [5] of each child. 3D acceleration and angular velocity data were recorded at 200Hz while the participants walked at self-selected speed back and forth, two times in normal (NW) and once in tandem walking (TW) along a 15m path.

Stride (StrideT, seconds), stance (StanceT, % of StrideT), and double support time (DS, % of StrideT) were calculated from foot contact events. Temporal parameter variability was calculated as standard deviation. MSE (τ from 1 to 6), related to complexity and automaticity, and RQA, related to pattern regularity, were calculated on trunk acceleration data along the 3 directions. Data were compared to those of matched healthy peers.

RESULTS

Movement ABC-2 test: 12 patients received scores above the 50th percentile (35.3%) and 22 below (64.7%). No significant correlation was observed with the degree of scoliosis (Cobb angle) or the degrees of torsion (ATR).

Temporal parameters: subjects resulted slower during NW (longer StrideT), with larger dispersion of StanceT and DS than healthy peers. During TW, subjects above 12 years of age resulted slower, with longer StanceT and longer DS for increasing age as compared to their healthy peers.

Non-linear metrics: subjects showed larger MSE during NW for lower values of τ (1 to 3) in the ML and V direction and reduced RQA in AP direction for increasing age as compared to healthy peers; during TW, reduced MSE for lower values of τ (1 to 3) in the V and AP direction and increased RQA in AP direction.

DISCUSSION

Children affected by idiopathic scoliosis showed alterations of motor control. In particular, temporal parameters highlighted a slower and less stable gait, more evident for increasing age as related to TW. Lower stability is also related to a less mature motor control with a delay in the development of the automaticity characterizing healthy peers, and a reduced development of the motor complexity required for more demanding locomotor tasks.

These preliminary data suggest that idiopathic scoliosis affects motor control in the developing population. IMU-derived metrics demonstrated their effectiveness in complementing clinical assessment.

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Sessione 6: Movement analysis to support the clinical decision and outcome assessment

Gait deviation index to quantify the effect of functional surgery on walking kinematics in stroke patients

G. Basini [1], I. Campanini [2], P. Zerbinati [1], M. Galletti [1], C. Rambelli [1,3], F. Mascioli [1], P. Prati [1], B. Damiano [2], S. Scaltriti [2], A. Merlo [1,2], D. Mazzoli [1]

[1] Gait&Motion Analysis Laboratory, Sol et Salus Hospital, Torre Pedrera Rimini (RN), Italy; [2] LAM-Motion Analysis Laboratory, Neuromotor and Rehabilitation Department, Azienda USL-IRCCS di Reggio Emilia, Correggio (RE), Italy; [3] Department of Neuroscience, Section of Rehabilitation, University of Padova, Italy

INTRODUCTION

The Gait Deviation Index (GDI) summarizes on a 0-100 basis the distance of a patient's kinematic from the normal reference pattern [1]. It has been developed and used to assess the effect of functional surgery (FS) supported by gait analysis (GA) in large cohorts of children with cerebral palsy [2]. The use of GDI and the computation of effect sizes are suggested to allow for the conduction of systematic reviews on the impact of GA on treatment outcomes [3]. Despite of the increasing use of FS in adults with acquired joint deformities consequent to a stroke, there are no studies in literature using the GDI to investigate the effects FS on walking kinematics in these patients.

METHODS

The databases of two laboratories were retrospectively analyzed to extract data from patients with the following inclusion criteria: hemiparesis consequent to ischemic or hemorrhagic stroke, referral to the laboratories for clinical and instrumental assessment – gait analysis (GA) with EMG – preliminary to FS, lower limb FS performed by the same surgeon (author PZ), available GA data before and three months after FS, available informed consent. Gait kinematics was acquired using a commercial system (BTS Smart DX, BTS Bioengineering) and the so-called Conventional Protocol. GDI was computed by the GA system as in [1]. GDI values of the affected side were compared before and three months after surgery using the paired t-test. The Cohen's d (effect size) with its 95% confidence interval was computed.

RESULTS

Preliminary results are presented, related to a two-year period. Twenty-nine patients met the inclusion criteria. Of these, 8 needed an orthosis to walk and had a presurgical EMG assessment only. The remaining 21 patients, 56.4(10.3) years, 6/15 M/F, 19/2 L/R affected side, were included in the study. Preoperative walking speed was 0.30(0.18) m/s. Median FAC was 4 (range 2-7), WHS was 4 (2-6), and RMI was 11 (5-14). Three to eight gait trials per session were used for GDI computation. At the three-months mark, GDI significantly increased from 72(11) to 75(11) (p=0.004), with a moderate effect size of 0.71 (95%IC 0.22–1.12). The relationship between pre- and post-operative values is presented in Figure 1. A subgroup of subjects had an increase in GDI, irrespective of their initial condition, a subgroup of patients had no variations in GDI while a few patients had a worsening in GDI.

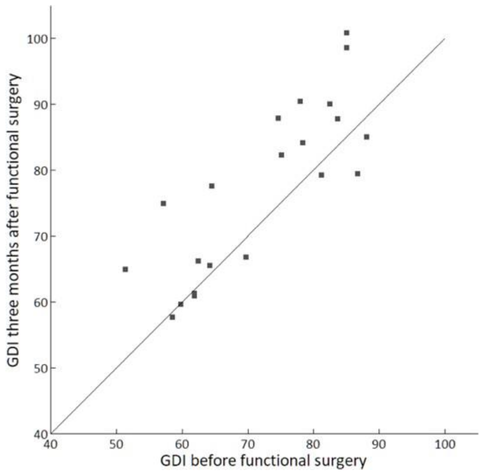

Figure 1. GDI before/after FS

DISCUSSION

For the first time in literature, we used the GDI to investigate the effect of FS on gait kinematics in adults with stroke. Our results confirm, on average, the efficacy of FS in improving walking ability. GDI allowed easily merging data from different laboratories. It could be used to identify clusters of improved/not improved patients to further investigate their characteristics. In clinical trials, GDI could be used to compare the efficacy of different of different treatments, e.g. FS v. focal inhibition or of different surgical approaches, e.g. with and without preoperative GA, as in [4]. Positive results would promote the use of GA in the assessment of stroke patients and support its reimbursement by both national health systems and private insurances.

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Just a matter of indexes: symmetry in walking

E. Bergamini [1], A. Cereatti [2], G. Pavei [3]
[1] University of Rome "Foro Italico", Rome, Italy, [2] Turin Polytechnic University, Turin, Italy, [3] University of Milan, Milan, Italy

INTRODUCTION

Gait symmetry is related to differences between the left and right side of the body and provides information about functional limitation due to pathology/injury [1]. Many metrics exist to quantify gait symmetry, differing for the considered data source and mathematical approach [1]. Although the body center of mass (BCoM) is the point that globally represents an individual's movement, very few studies have focused on the quantification of gait symmetry from its trajectory (Simmetry Index, SI) [2]. Conversely, the use of the Harmonic Ratio and of its improved version (iHR) has gained great popularity in recent years [3], being extracted from trunk 3D accelerations easily measured by wearable inertial devices. The relationship between the SI and iHR, however, has not been quantified yet. The aim of this study is thus to investigate this relationship in healthy adults during walking at different speeds.

METHODS

Five healthy adults (2 women, 1.69±0.08 m, 29.8±2.8 y) participates to this study (CAR 101/2021). They walked for 60 s on a treadmill at six different speeds (from 0.55 to 1.95 m/s with step of 0.28 m/s). The trajectories of 18 markers located on the main joint centers [4] were collected by an optoelectronic system (Vicon, 200 Hz). Simultaneously, lower trunk 3D linear accelerations were measured by an inertial sensor (APDM Opal, 200 Hz). The 3D trajectory of the BCoM was estimated from marker trajectories as the weighted mean of an 11-segment model [4]. Gait symmetry was then quantified for each stride and each direction (antero-posterior AP, medio-lateral ML, cranio-caudal CC) using two indices: the Symmetry Index (SI) from the BCoM trajectory [2] and the iHR from the trunk accelerations [3]. Both iHR and SI are based on the harmonic content of the relevant signal and range from 100% (perfect symmetry) to 0% (total asymmetry). To assess the effect of walking speed on SI and iHR values, a two-way repeated measure ANOVA was performed after verifying for normal data distribution.

RESULTS

A total number of 1572 strides were analyzed, with a minimum of 288 strides for each participant. SI and iHR significantly differed in all three directions for each velocity ($p<0.01$), except at 1.39, 1.67 and 1.95 m/s in the ML direction (Fig. 1). When considering the effect of gait speed on symmetry values, the latter significantly changed only for the AP and CC components ($p<0.0001$) (Fig. 1).

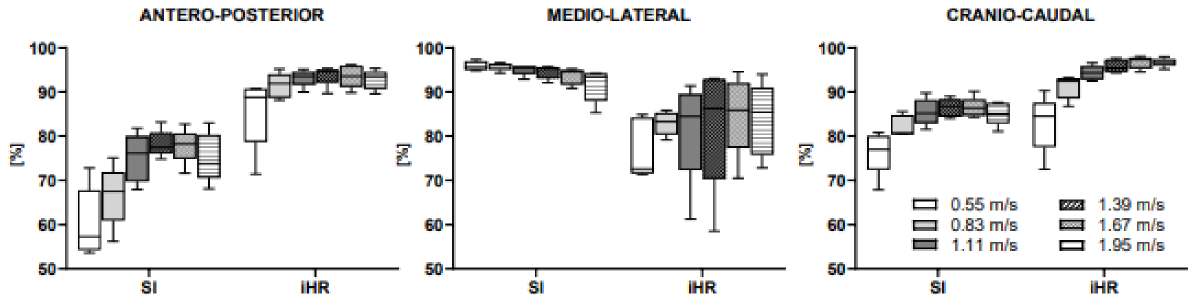

Figure 1. SI and iHR values.

DISCUSSION

SI and iHR may provide substantial different information about the level of gait symmetry, with iHR characterized by greater values in AP and CC directions and smaller values in ML direction. Interestingly, gait symmetry increases with speed, at least up to 1.67 m/s, in AP and CC directions. This is not the case for the ML component: whereas SI slightly decreases with speed ($p<0.05$), the high variability of iHR, already discussed in the literature [4], does not allow to identify any clear trend. It is suggested to carefully describe the methodology used to assess gait symmetry, as the type of data and the method used may strongly influence the final outcome and, thus, its clinical interpretation.

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Electromyographic evaluation of the clinical and biomechanical effects of yoga on the flexion-relaxation phenomenon: a Prophet approach

N. Marotta[1], A. de Sire[1], A. Ammendolia[1]

[1] *Department of Medical and Surgical Sciences, University of Catanzaro "Magna Graecia", Catanzaro, Italy*

INTRODUCTION

Myoelectric silencing of the spinal erector muscles in the trunk flexion posture is indicative of greater spine sharing loads. The evaluation of the flexion relaxation phenomenon is a valid clinical tool able to contribute to the low back pain management [1]. In the broad scenario of low back pain therapy, there is increasing interest in non-traditional interventions such as Yoga, although the scientific evidence does not always analyze the biomechanical significance [2]. Therefore, the aim of this observational study was to evaluate the clinical and biomechanical effects of Yoga on the flexion-relaxation phenomenon of the lumbar erector muscles, through surface electromyography (sEMG) combined with an inertial sensor.

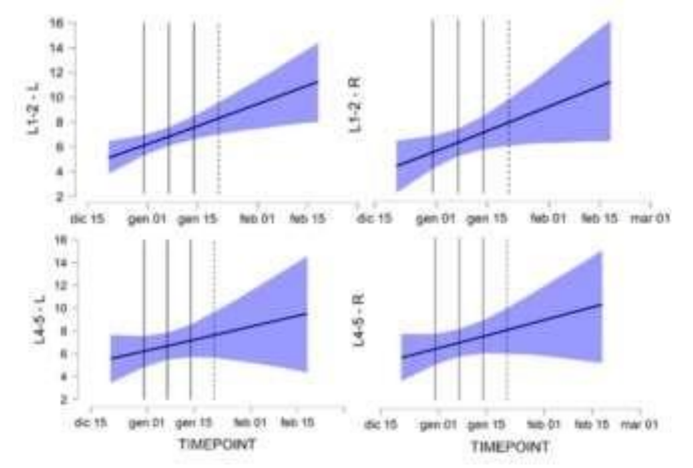
METHODS

Healthy young adults (ages 18 to 40) were selected as participants without chronic nonspecific low back pain for at least three months. The intervention consisted of a Yoga program lasting one hour specific for the lumbar spine Asana, for 4 sessions (2 times/week for 2 weeks), the first in presence and the other three in tele-approach. At the end of each session an evaluation was carried out, thus setting the T0 as the baseline, until the end of the fourth session as T4. The trunk flexion-relaxation phenomenon was performed by asking the participant to slowly flex the trunk forward to full flexion, pausing for 3 seconds and then returning to the standing starting position. The sEMG signal coupled to an inertial sensor was collected to quantify the flexion-relaxation ratio (FRR). Then, using a Prophet model, which allows time series prediction, we have traced the forecast of the FRR trend of the erector spinal muscles of the lumbar spine (Fig.1).

RESULTS

We included 13 healthy women (mean age: 28±8 years; BMI 20.0±0.9 kg/m2). No significant asymmetries were evaluated and Friedman's test reported slight significant differences (left L1-L2 p= .039, right p=0.041; left L4-L5 p=0.045, right p=0.040). Therefore, we performed a Prophet evaluation to analyze FRR trends, finding a growth rate of 0.45±0.3 for left L1-L2, 0.38±0.4 on the right, 0.25±0.4 for L4-L5 on the left and 0.25±0.3 on the right. With an Rhat≤1.01, excluding possible convergence problems. At one month from the end of the intervention, all lower confidence intervals curve remained above the thresholds of the baseline assessments.

Figure 1. FFR Forecast Plots. The prophet model predicts future values starting from the dotted line (T4), with a hypothetical curve and confidence intervals



DISCUSSION

This study aimed to evaluate the role of Yoga in the prevention of lumbar spine disorders through the kinematic and electromyographic evaluation of the flexion-relaxation phenomenon. Processing the results using a Prophet approach predicts a positive influence even after the end of the Yoga sessions. Surface electromyography coupled to an inertial sensor provides reliable assessments of the lumbar spine, a prediction model can guarantee evidence on the positive introduction of Yoga asanas in the clinical management of any development of low back pain. In light of these results, future prospective studies might focus on the effects of yoga in clinical and biomechanical terms on patients with chronic nonspecific low back pain.

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EMG-based co-contraction indexes for the assessment of motor impairments in persons post-stroke

V. Bandini[1], I. Carpinella[1], A. Marzegan[1], J. Jonsdottir[1], C.A. Frigo[2], M. Ferrarin[1], T. Lencioni[1].
[1] *IRCCS Fondazione Don Carlo Gnocchi, Milan, Italy,* [2] *Politecnico di Milano, Milan, Italy.*

INTRODUCTION

Neuromuscular coordination can be described by activations of agonist–antagonist (AA) muscle pairs and plays an important role in the performing of daily activities. It is an important mechanism used by the central nervous system to regulate joint stability and provide movement accuracy [1]. As a result of a stroke there is an alteration in these coordination patterns that results in motor deficits of the arm function [2]. In fact, persons post-stroke have an exaggerated AA muscle co-contraction [2] associated to a higher joint stiffness [1]. The amount of co-contraction can be quantified through the use of EMG-based co-contraction indexes (CCIs) [1,2]. Therefore, the purpose of the study was to evaluate whether such EMG-based CCIs are able to assess impairment in the motor control of the upper limb in persons post-stroke.

METHODS

Thirty-five persons post-stroke, in chronic or sub-acute stages, were recruited in this study. Both paretic and non-paretic arms were evaluated during the execution of functional tasks related to activities of daily living (i.e., reaching, object placing and forearm pronation). The upper limb kinematics and EMG data of three AA muscle pairs (anterior/posterior deltoids, triceps/biceps and pronator/supinator) were recorded through a movement analysis system. Ten healthy subjects (HS) provided the normative data. The Rudolph's CCI [1] was computed as proposed by Don (range 0-100%, higher values indicate a greater AA muscle co-contraction) [3]. All participants post-stroke were clinically assessed through the Fugl-Meyer Motor Assessment of Upper Extremity (FM-UE).
The differences of Rudolph's CCI between HS and subjects post-stroke, considering both the more affected (MA) and the less affected (LA) arm, were tested by ANOVA. Bonferroni post-hoc analysis was also used to establish if there were statistically significant differences among the three groups.

RESULTS

A deviation from normative data for the MA CCIs was found in almost all functional tasks and antagonist muscle pairs. The LA CCIs also showed a significant deviation from HS. Such pattern is reported in Figure 1 for Rudolph's CCI during the forearm pronation task.

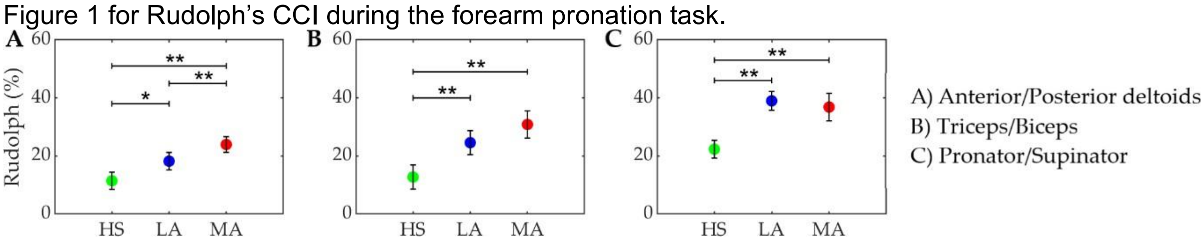

Figure 1. Rudolph's CCI of healthy subjects (HS, green circles) and of persons post-stroke (less-affected arm LA, blue circles and more affected arm MA arm, red circles) during the performance of the forearm pronation task. Circles and whiskers represent, respectively, mean and the 95% confidence interval of the Rudolph's CCI. $^{**}P<0.05$. $^{*}0.05 \leq P \leq 0.10$.

DISCUSSION

Higher values of the EMG-based CCI were found both in LA and MA arms in persons post-stroke, indicating alterations in the neuromotor coordination for both sides. The altered AA muscle activation of the LA arm (non-paretic, ipsilateral to the brain lesion) in persons post-stroke, despite its kinematics not being compromised, could be a consequence of the over-use of the non-paretic limb in performing functional tasks. Therefore, also the non-paretic upper limb may benefit from rehabilitation, as recently suggested [4]. Our results show that EMG-based CCI is a quantitative and objective measure able to detect motor control impairment, not detectable by clinical scales.

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Differentiating idiopathic Parkinson's disease from vascular parkinsonism and essential tremor plus with spatiotemporal variables of gait

I. Arcolin[1], M. Giardini[1], A. Solop[2], S. Guglielmetti[1], S. Corna[1], M. Godi[1]
[1] Department of Physical Medicine and Rehabilitation, Istituti Clinici Scientifici Maugeri Spa SB, IRCCS, Veruno (NO), Italy, [2] Nuclear Medicine Unit, Istituti Clinici Scientifici Maugeri Spa SB, IRCCS, Veruno (NO), Italy

INTRODUCTION

Diagnostic accuracy to differentiate Parkinson's Disease (PD) from other neurological disorders by movement disorder specialists is >85% for longer duration (>5years) and medication-responsive people with PD [1]. However, this accuracy remains suboptimal (<55%) in the early stages of disease, i.e. when symptoms may be very subtle [1]. Therefore, it's of paramount importance to identify diagnostic markers which could help in timely and accurate diagnosis and in clinical management [2]. Gait may be a potential marker since its impairments appear in the very early disease, may precede the onset of overt motor signs and evolve more rapidly than other motor features [2,3]. The purpose of this work is to assess whether gait variables, known to correctly classify PD from healthy subjects [4], are capable to differentiate PD from other Parkinsonism in subjects with an onset of symptoms from less than 3 years.

METHODS

17 drug-naïve individuals with PD (mean age 70.0±7.4 yrs), 9 with vascular parkinsonism (VP, mean age 76.6±5.5 yrs) and 9 with essential tremor plus (ET, mean age 65.9±8.1 yrs) were enrolled. Eight spatiotemporal variables of gait [4] were acquired using a GAITRite® electronic walkway under comfortable walking. To assess the diagnostic performance of each variable in discriminating PD from VP and ET, the area under the receiver operating characteristic curve (AUC) and its 95% Confidence Interval (95% CI) were assessed.

RESULTS

Participants with PD were not different from VP and ET regarding sex (p=0.86 and p=0.13, respectively) and age (0.07 and 0.06, respectively). Of the gait variables considered, gait speed, step time and step time asymmetry showed a moderate ability in differentiating PD from the other movement disorders (Table 1). In addition, double support time and swing time CV were able to differentiate individuals with PD from those with ET. The gait model, obtained combining the 8 gait variables, showed the highest ability in discriminating PD from VP (AUC=0.90) and ET (AUC=0.86), with a diagnostic accuracy of 88.5% and 80.8%, respectively.

Table 1. Ability of the eight gait variables and of the model in discriminating PD from vascular and ET.

	PD vs vascular		**PD vs ET**	
	AUC	**95% CI**	**AUC**	**95% CI**
Gait speed (cm/s)	0.73	0.51-0.95	0.76	0.67-0.95
Step time (s)	0.74	0.55-0.93	0.71	0.50-0.92
Double support time (s)	0.69	0.47-0.91	0.76	0.54-0.97
Step length CV (%)	0.61	0.36-0.87	0.69	0.46-0.92
Swing time CV (%)	0.56	0.28-0.85	0.76	0.53-0.98
Step velocity CV (%)	0.63	0.34-0.92	0.56	0.32-0.80
Step time asymmetry (%)	0.85	0.70-1.0	0.81	0.64-0.98
Swing time asymmetry (%)	0.65	0.44-0.87	0.66	0.44-0.88
MODEL	0.90	0.78-1.00	0.86	0.71-1.00

DISCUSSION

This study found that spatiotemporal gait variables, assessed with a sensorized mat, can be used to differentiate PD from VAS and ET. In particular, the model of gait obtained combining several variables had a good diagnostic accuracy in the first ages of disease. This provides a foundation for future research to investigate the use of gait assessment as a clinical tool to aid diagnostic accuracy of PD subtypes, allowing the correct treatment and care to be applied [5].

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Freely available dataset of long-lasting surface electromyographic signals during walking

F. Di Nardo[1], C. Morbidoni[2], S. Fioretti[1]
[1] *Department of Information Engineering, Università Politecnica delle Marche, Ancona, Italy*
[2] *Department of Management and Business Administration, University of Chieti-Pescara, Pescara, Italy*

INTRODUCTION

It is acknowledged that surface electromyography (sEMG) signals vary from subject to subject and even within the same person [1]. In this scenario, it is important to analyze the natural variability associated with muscle activity during free walking to improve the interpretation of sEMG signals in both physiological and pathological conditions. Although few strides might be enough in some applications, the analysis of a larger number of gait cycles is highly recommended to analyze the variability of muscle recruitment during walking. However, free databases including long-lasting sEMG signals during walking are very uncommon to find. To fill this gap, the present study aims to introduce a database composed of long-lasting (around 5 minutes) surface EMG signals recorded from 2011 and 2018 during ground walking of 31 young able-bodied subjects. Synchronized basographic and electrogoniometric data are provided to allow users to achieve a spatial/temporal characterization of the sEMG signals.

METHODS

Basographic, electrogoniometric, and sEMG signals were acquired in a population of 31 young able-bodied subjects at Movement Analysis Lab, Università Politecnica delle Marche, Ancona, Italy. Inclusion criteria: 20 years < age < 30 years; 18.5 Kg/m^2 < body mass index, BMI < 25 Kg/m^2. Subjects with pathological condition, joint pain, or undergone orthopedic surgery were excluded. All signals were recorded with a sampling rate of 2 kHz and a resolution of 12 bit by the multichannel recording system Step32, Medical Technology, Italy. Probes were applied over gastrocnemius lateralis (GL), tibialis anterior (TA), rectus femoris (RF), vastus lateralis (VL), and hamstrings (Ham) in both legs. Subjects have been asked to walk barefoot on level ground for around 5 min at their natural speed and pace, following an eight-shaped path which includes rectilinear segments and curves, including reversing, acceleration, and deceleration.

RESULTS

The data base is composed of a total of 310 sEMG signals of average duration = 258 ± 53 s. Associated basographic and electrogoniometric data are provided. An example of a portion of basographic, electrogoniometric, and sEMG signals in a single stride is depicted in the following Fig. 1. Data are reported in function of gait cycle percentage.

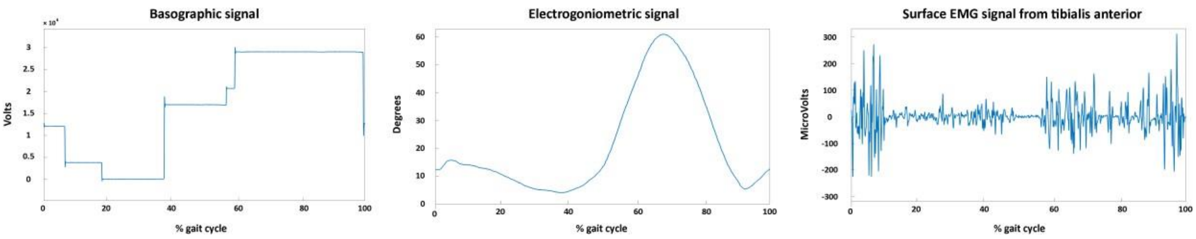

Figure 1. Example of raw signals included in the database. For clarity, a single stride is reported.

DISCUSSION

The considerable length of the signals makes this dataset very suitable for those studies where the numerosity of the data is essential, such as machine/deep learning approaches, studies for analyzing and quantifying the variability of muscle recruitment during physiological walking, creation of reference dataset in the characterization of pathological condition, and the validation of novel sEMG-based algorithms. This dataset is freely available, consulting the public repository of medical research data PhysioNet [2,3].

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Evaluation of balance and gait in stroke patients: correlation between stabilometric indices and gait analysis parameters

C.Iacovelli[1,2], L. Castelli[2,3], S. Giovannini[4,5], G. Salvatori[4], R. Bernabei[2,4], P. Caliandro[6]

[1] *UOC Riabilitazione e Medicina Fisica, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy*

[2] *Department of Aging, Neurological, Orthopaedic and Head-Neck Sciences, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy*

[3] *UOC Neuroriabilitazione ad Alta Intensità, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy*

[4] *Department of Geriatrics and Orthopaedics, Università Cattolica del Sacro Cuore, Rome, Italy*

[5] *UOS Riabilitazione Post-Acuzie, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy*

[6] *Unità Operativa Neurologia, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy*

INTRODUCTION

Stroke is the leading cause of disability worldwide, with a significant individual, family and economic impact. Restoring balance and a more fluid, safe and correct gait is a prerequisite for the patient to recover autonomy in activities of daily life. Furthermore, a consequence of impaired gait recovery in stroke patients is the high risk of falls, which worsens their quality of life [1]. Since many falls are predictable, early identification of the risk of falls is crucial for developing tailored interventions to prevent such falls. Recently, an instrumental fall risk assessment index was developed using the Hunova® robotic platform (Silver Index - Movendo Technology, srl, Genoa, IT) with the aim of giving an early indication of this risk using numerical data of both static and dynamic balance [2]. In order to combine an instrumental assessment of balance and walking with a clinical evaluation, the aim of this study is to evaluate the correlation between the Silver Index and gait analysis parameters in order to be able to propose more personalized rehabilitation training.

METHODS

We enrolled 12 stroke patients, aged between 70 and 95 years. The risk of falls evaluation was performed by Hunova® robotic platform computing the Silver Index. The gait was analyzed by an optoelectronic system with 8 infrared cameras (SMART-DX500 – BTS Bioengineering, Milan, IT). We used the Davis protocol that includes 22 markers. For each patient we calculated the mean values as well as the coefficient of variation (CV) and the multiple correlation coefficient (CMC) of spatio-temporal parameters and joint kinematic parameters. We assessed CV and CMC to quantify variability of the discrete and continuous variables, respectively [3]. We used Spearman test to calculate the correlation between the Silver Index and the gait analysis parameters.

RESULTS

The correlation analysis shows a statistically significant correlation between the Silver Index and the stance phase of the unaffected side (%) ($p=0.036$, $\rho=0.700$) and between the Silver Index and the swing phase of the unaffected side (%) ($p=0.036$, $\rho=-0.700$). Furthermore, the Silver Index correlates with the variability of step width ($p=0.007$, $\rho=-0.816$).

DISCUSSION

These preliminary results show that the risk of falling is higher in patients who have a longer stance phase of the unaffected limb and a shorter duration of the swing phase always of the unaffected limb. Furthermore, our results show that patients who fall more have less variability in step width. This could be an indication that these patients are unable to make the continuous adjustments that occur physiologically during gait and thus fail to produce dynamic adaptation during walking.

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Face mobility evaluation in Spinal Muscular Atrophy

E.Pegolo[1],E.Carraro[2],F.Cibin[3],F.Spolaor[1],F.Salmin[2],M.C.Frisoni[2],S.Becchiati[2],V.A.Sanson[2,4],Z.Sawacha[1,5]

[1] Department of Information Engineering, University of Padova, Padua, Italy [2] The Nemo Center in Milan, Neurorehabilitation Unit [3] BBSoF S.r.l., Padova, Italy [4] University of Milan, Milan, Italy [5] Department of Medicine, University of Padova, Padua, Italy

INTRODUCTION

Spinal Muscular Atrophy (SMA) is a neurodegenerative disorder that affects motor neurons causing symptoms that often include progressive muscle atrophy, weakness and paralysis in the trunk and limbs as well as muscles involved in facial, jaw, and respiratory tasks [1]. While impairments in upper and lower limbs have been widely investigated, details about muscular function are still lacking. The aim of this work was to investigate face mobility in SMA. Firstly, we apply a face tracking algorithm to quantify face mobility in different tasks and then we evaluate Maximum Voluntary Contraction (MVC) by means of surface electromyography (EMG); results were compared with a cohort of healthy subjects.

METHODS

20 adults (age: 32.3±13.17) and 11 kids (age<15 years, age: 8.73±3.32) affected by SMA and 10 healthy controls (HC) both adults (age: 27.10±5.65) and children (age: 10.50±3.24) were evaluated. Frontal face videos were recorded while subjects were comfortably seated. They were instructed to perform the following tasks: (1)frowning, (2)eye closure without exertion, (3)eye closure with exertion, (4)tight-lipped smile, (5)smile, (6)kiss, (7)cheeks inflation. A neutral face expression was acquired as reference. Face mobility index (FMI [2]) was computed and compared across tasks and different cohorts of subjects through Wilkoxon signed rank test ($p<0.05$). Furthermore, EMG signals during three MVCs of three facial muscles (frontalis, masseter, and mentalis muscles) were acquired on a subset of the whole cohort of SMA subjects. Only EMG signals of adult HC were acquired for comparison. Root mean square (RMS) value was calculated on the contractions and the maximum value was considered for comparison.

RESULTS

Results are reported in Figure 1.

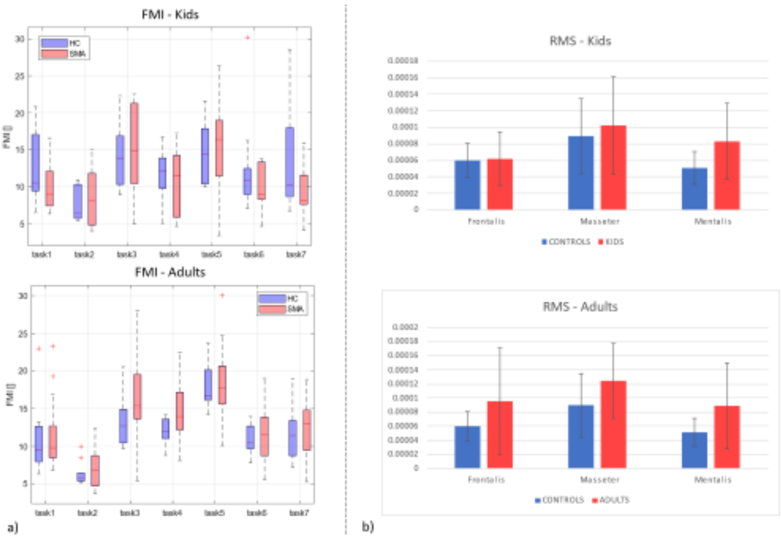

Figure1. Results of the FMI (a) and the RMS computed on the EMG collected during the MVC (b).

DISCUSSION

Both EMG and FMI results highlighted similar outcomes: in the same tasks where, SMA subjects recorded higher RMS than HC, they also displayed greater values of FMI in almost all the tasks. This could indicate the need to recruit larger number of muscle units than HC to perform similar tasks. Further analysis are needed to confirm this hypothesis.

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Sessione 7: Machine learning for motion analysis

A deep learning model to discern indoor from outdoor environments based on data recorded by a tri-axial digital magnetic sensor

V. Marcianò[1], S. Bertuletti[2], T. Bonci[3], C. Mazzà[3], N. Ireson[3], F. Ciravegna[3], S. Del Din[4], E. Gazit[5], A. Cereatti[1]

[1] Politecnico di Torino, Turin, Italy; [2] University of Sassari, Sassari, Italy; [3] The University of Sheffield, Sheffield, UK; [4] Newcastle University, Newcastle upon Tyne, UK; [5] Tel Aviv Sourasky Medical Center, Tel Aviv, Israel.

INTRODUCTION

The increased use of wearable devices (WDs) for monitoring daily-life activities has led to the development of different location-driven applications. The first fundamental distinction is between indoor and outdoor environments. The most intuitive approach is the analysis of GPS coordinates or Wi-Fi signals [1] but both solutions are power consuming. In this study, we proposed and tested the use of deep learning techniques for indoor/outdoor discrimination based on local magnetic field properties of the specific environment during free-living activities.

METHODS

Eight participants were recruited in four different centres (Turin, Italy; Sheffield, UK; Newcastle upon Tyne, UK; Tel Aviv, Israel) and were equipped with the INDIP system [2] (including four magneto-inertial units attached to each foot, lower back, and non-dominant wrist), a smartphone (running the Aeqora mobile application) and were monitored during 2.5-hours of daily free-living activities. Magnetometer data was used to train a deep learning model, while indoor/outdoor probability based on GPS coordinates was provided by the Aeqora app and used as a reference. For each WD, the following features were extracted: x, y, z components and norm of the magnetometer and the 10-sample moving average (0.1s window) of the latter features as a "contextual" rating. A bi-layer long short-term memory structure with a linear layer as a tail and with a gaussian error linear unit as activation unit has been implemented [3]. To achieve a lower-bias training and a more robust model, the network has been validated by exploiting a leave one subject out validation approach. In addition, the classification is based on two different observation timeframes: windows of length equal to the magnetometer data acquisition period (0.01s) and 1s windows.

RESULTS

The average accuracy of the model, across participants, in the classification of indoor/outdoor environments while using as input one WD at a time and all WDs together is reported in Table 1.

Table 1. Summary of the model performance metrics in the indoor/outdoor classification.

		Average Accuracy (%)	
		0.01s window	**1s window**
Wearable device	Wrist	88.3	89.3
	Lower back	91.7	92.2
	Left foot	90.8	92.1
	Right foot	90.0	91.5
	All	93.4	94.1

DISCUSSION

Based on this preliminary analysis, the model seems suitable for discerning indoor from outdoor environments with an average accuracy score higher than 88.3% in participants spread through three countries (different morphology of the territory, culture, lifestyle, etc.). With this respect, considering a longer observation time (1s vs. 0.01s) has resulted in increasing of the accuracy for all conditions. Overall, the best performances were obtained by using the whole INDIP system, with a 94.1% score. However, very similar performances were obtained when only one WD is considered. The effect of the experimental setup (e.g., the number and position of the WDs) and the input of the model (e.g., the length of the time-observation window) on the performance metrics require further investigations.

ACKNOWLEDGMENTS

This work was supported by the Mobilise-D project (IMI2 JU grant agreement No. 820820, this JU receives support from the European Union's Horizon 2020 and EFPIA).

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Machine Learning Approach to Support the Detection of Parkinson's Disease in IMU-BasedGait Analysis.

D. Trabassi [1], M. Serrao [1], T. Varrecchia[2], A. Ranavolo[2], G. Coppola[1], R. De Icco[3,4] C.Tassorelli[3,4] S.F.Castiglia[1,4]

[1]*Department of Medical and Surgical Sciences and Biotechnologies, "Sapienza" University of Rome, 04100 Latina, Italy,*

[2]*Department of Occupational and Environmental Medicine, Epidemiology and Hygiene, INAIL, Monte Porzio Catone, 00078 Rome, Italy,*

[3]*Headache Science & Neurorehabilitation Center, IRCCS Mondino Foundation, 27100 Pavia, Italy,* [4]*Department of Brain and Behavioral Sciences, University of Pavia, 27100 Pavia, Italy*

INTRODUCTION

Recent advances in data analysis and wearable sensors for human movement monitoring can promote objective and accurate clinical evaluation of neurological symptoms and improve outcome measures in clinical trials [1-3].

The aim of this study was to combine modern technique of data analysis and wearable sensors to determine which supervised machine learning (ML) algorithm can most accurately classify people with Parkinson's disease (pwPD) from speed-matched healthy subjects (HS) based on a selected minimum set of IMU-derived gait features.

METHODS

Twenty-two gait features were extrapolated from the trunk acceleration patterns of 81 pwPD and 80 HS, including spatiotemporal, pelvic kinematics, and acceleration-derived gait stability indexes. After a three-level feature selection procedure, seven gait features were considered for implementing five ML algorithms: support vector machine (SVM), artificial neural network, decision trees (DT), random forest (RF), and K-nearest neighbors. Accuracy, precision, recall, F1 score, AUC and generalization error were calculated.

RESULTS

SVM outperformed the other ML algorithms in terms of classification metrics (test accuracy = 0.86; F1 score = 0.85; AUC = 0.85) and generalizability (generalization error = 2.95%) in classifying the gait impairment of pwPD compared with speed-matched healthy subjects, using a selected dataset of gait features based on lower trunk acceleration data. Although significantly lower than SVM, tree-based algorithms revealed good classification performances with low generalization errors (RF: test accuracy = 0.86; F1 score = 0.85; AUC = 0.85), and lower computational demand than SVM. ANN was similar to DT in terms of classification metrics but showed significantly higher generalization error (7.26%) than tree-based algorithms and SVM and higher computational demand than the other ML algorithms. Even though KNN showed the fastest time performance, its classification metrics were the lowest.

DISCUSSION

We proposed a feature selection procedure based on the combination of filter, wrapper, embedded, and domain-specific methods that was effective in lowering the risk of overrepresenting multicollinear gait features in the model, resulting in a lower risk of overfitting in the test performances by increasing the explainability of the results at the same time. Because of their accurate results, their simplicity of understanding, and explanability, DT and RF algorithms could represent useful tools for the comprehension of gait disorders by making clinicians participate in the decision process. This is the first time that the accuracy and generalizability of the most performed ML algorithms in classifying pwPD gait abnormalities based on gait data from a single lumbar-mounted IMU have been compared. The findings of this study could be used to incorporate machine learning algorithms into software that processes gait data from lumbar-mounted IMUs. Future research could focus on finding the best tree-based model for classification and prediction problems in gait analysis.

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Detecting Parkinson's disease through an upper limb reaching task and a machine learning approach.

G. Cesarelli[1,2,‡] and L. Donisi[1,2,‡], F. Amato[1], M. Romano[1], M. Cesarelli[1,2], G. D'Addio[2], A.M. Ponsiglione[1,§] and C. Ricciardi[1,2,§]

[1] *University of Naples Federico II, 80125 Naples, Italy*

[2] *IRCCS ICS Maugeri SPA SB, 82037 Telese Terme, Benevento, Italy*

[‡] *These authors (G.C and L. D.) equally contributed to the work*

[§] *These authors (A.M.P. and C. R.) equally contributed to the work*

INTRODUCTION

Among the neurodegenerative diseases, Parkinson's disease (PD) is the most common movement disorder. In the literature, different approaches to analyse both upper and lower limbs motion patterns have been proposed [1-2]. Referring to our previous work [3], we demonstrated, after a statistical analysis, several features, extracted from upper limb reaching movements acquired through goniometric sensors, confirmed helpful in discriminating healthy controls and PD patients. Following these encouraging results, in this work we explored the possibility of using such features as input to two different machine learning (ML) algorithms and assessed their capability to distinguish healthy controls and PD patients.

METHODS

Twelve subjects (six health controls and six PD patients), who were admitted at the Institute of Care and Scientific Research of Telese Terme of ICS Maugeri SPA SB (Telese Terme, Italy), performed a kinematic task – made up of four movements through the upper limb – twice. The signals of such movements (consisting in an angular displacement) were acquired through a goniometric sensor. Later, thirteen statistical features were extracted through the custom-made software described in [3]. They were given as input to J48 and K Nearest Neighbour (KNN) and a leave one out cross-validation was implemented. Algorithms performance was assessed in terms of accuracy, sensitivity, specificity and Area Under the Curve Receiver Operating Characteristics (AUC-ROC).

RESULTS

The classification algorithms achieved promising results, with metrics that overcame the value of 90%. The tree-based algorithm J48 achieved higher accuracy and sensitivity (91.7% and 100% respectively), while KNN achieved the highest specificity and AUC-ROC (91.7% and 0.94). Table 1 summarizes the results achieved by the algorithms.

Table 1. Evaluation metrics (%) of J48 and KNN in classifying patients into healthy and PD.

Algorithms	Accuracy	Sensitivity	Specificity	AUC-ROC
J48	91.7	100	83.3	0.83
KNN	87.5	83.3	91.7	0.94

DISCUSSION

This paper answers to the need of defining measurable, repeatable, and reliable indicators to monitor the effectiveness of a training program over time; moreover, the paper provides a quantitative measure of the rehabilitation outcome, which is a necessary step towards the design of personalized treatment programs. The results obtained in this investigative research are promising and allow us to think about additional ML algorithms to be considered in further studies and to enlarge the ML approach by considering/investigating additional features to extract.

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Machine learning approach to diabetic foot risk classification with biomechanics data

A. Guiotto[1], G. Bortolami[1], A. Ciniglio[1], F. Spolaor[1], G. Guarneri[2], A. Avogaro[2], F. Cibin[3], F. Silvestri[1], Z. Sawacha[1,2]

[1] BiomovLab, Dept. of Information Engineering, University of Padua, Padova, Italy, [2] Dept. of Medicine, University of Padua, Italy, [3] BBSoF s.r.l., Padova, Italy.

INTRODUCTION

Diabetic foot wound onset, recurrence and healing are globally considered a challenge [1]. In particular, the prevention topic is pursued through several recommendations, however, it is desirable to classify the risk of ulceration before their occurrence, to prevent severe ulcers and subsequent amputations [1]. With regard to the biomechanical properties of the diabetic foot, diabetic patients showed higher load on the push-off associated with lower dorsi-plantar flexion of the ankle during stance and the push-off phase [2]. The aim of this study was to automatically define a risk index of the diabetic foot ulceration by applying machine learning (ML) algorithms to a dataset of standard gait analysis, musculoskeletal modelling and finite element modeling data and of routine diabetic neuropathy screening scores [4].

METHODS

The study included retrospectively the data of 80 subjects (26.3% healthy subjects, 37.5% diabetics without neuropathy and 36.3% diabetics with neuropathy). Diabetic patients were clinically assessed according to the ADA guidelines [3] as reported in [4]. Kinematic, kinetic and electromyographic (EMG) data were acquired through a modified version of the IORgait protocol [3,5] while subjects were walking several gait cycles at self selected speed. Muscle forces were estimated with the Opensim gait 2392 model and internal stresses were determined using a foot finite element model [6]. Joint angles and moments, ground reaction forces, plantar pressures, EMG envelopes and timing of activation, muscular forces and internal stresses were considered for the ML algorithm. For what regards the clinical features, presence or absence of peripheral and autonomic neuropathy, retinopathy, microalbuminuria, vasculopathy, knee-hallux-toes deformities, plantar callosity were selected for the ML algorithm. MongoDB was chosen as database program and data extractions were performed through the library Pandas. Regarding the ML algorithm, the values of different gaits were merged using an arithmetic mean, in order to obtain a narrower dataset and more stable values of the features. Due to the size of the dataset, 'simple' and linear models were adopted, and, among these, Logistic Regression, Linear Model and Perceptron were chosen. For completeness, some more complex classifiers like Kernel Support Vector Machine, Random Forest, Gradient Boosting Tree and eXtreme Gradient Boosting Tree were also adopted but showed lower performances.

RESULTS

Logistic Regression with the adoption of 4 features achieved the best result: 83% of precision and 83% of accuracy (Figure 1). Once the model was developed, a React Native mobile application was implemented with a relative Application Protocol Interface (API) to produce an environment to host and exploit the model. Diabetic foot risk classification according to ADA [3] was used as comparison for the results of the ML approach.

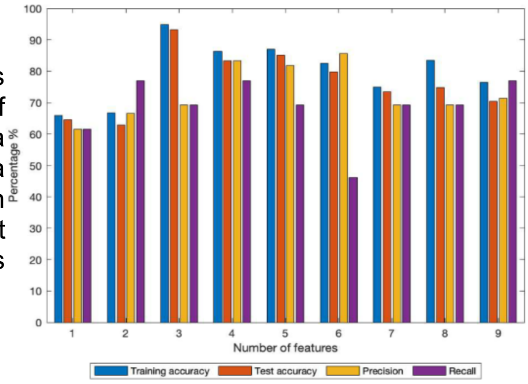

Figure 1. Logistic Regression - Accuracy, Precision and Recall vs n. of features.

DISCUSSION

The performance of the model is not considered to be optimal, but the results are encouraging from a diabetic foot risk point of view. Future development includes the expansion of databases and the exploration of other ML algorithms.

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Gait analysis to quantitatively classify Ataxia and Parkinson's disease patients: a pilot study using tree-based Machine Learning algorithms

G. Cesarelli [1], L. Donisi [1], A. Biancardi [2], B. Lanzillo [2], G. D'Addio [2], M. Cesarelli [1]
[1] University of Naples "Federico II", Naples, Italy, [2] ICS Maugeri SPA SB, Telese Terme, Italy

INTRODUCTION

Posture and gait anomalies investigations have demonstrated to improve to date the rehabilitation programs and patients' outcome for several types of disorders [1,2]; however, the diagnosis and progression of some illnesses, such as Ataxia and Parkinson's Disease (PD), still rely on "gold standard" (clinical) methodologies, which hardly ever allows to fully distinguish the two pathologies. Consequently, the objective of this paper is to provide a new strategy to classify Ataxia and PD subjects using quantitative gait analysis tools.

METHODS

For this purpose, two cohorts of 43 PD and 22 ataxic patients were enrolled. Each patient underwent an Instrumented Stand and Walking [3] test using a microelectromechanical system equipped by a series of inertial measurement units (OPAL, ADPM Inc.) capable to extract – from the raw data acquired – ten posture and gait parameters. A Machine Learning (ML) approach, considering tree-based algorithms fed with the aforementioned features, was implemented in KNIME Analytics Platform (version 4.1.3, KNIME AG) to assess the degree of separability among the two classes of patients.

RESULTS

Table 1 summarizes the results of the preliminary ML analysis conducted using three tree-based algorithms.

Table 1. ML results to distinguish PD and Ataxic patients' groups.

Algorithm	Sensitivity	Specificity	Accuracy
Decision Tree	0.682	0.837	0.785
Gradient Boost	0.682	0.791	0.754
Rotation Forest	0.500	0.860	0.738

DISCUSSION

This paper presents a potential strategy to distinguish quantitatively – through ML – patients affected by Ataxia and PD. Despite the unbalanced patients' cohorts (PD subjects are double respect to Ataxia ones), ML tree-based algorithm demonstrated to discriminate the two classes achieving quite fair scores. Further research will involve a deeper evaluation of patients and additional/more informative kinematic parameters to better corroborate the preliminary results of this study.

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Sessione Clinical Poster 2

Efficacy of treatment with botulinum toxin on posture and gait in pisa syndrome

M. Bacchini[1], G. Chiari[1], M. Rossi[1], C. Bacchini[1], C. Rovacchi[1]
[1]Don Carlo Gnocchi Foundation - Onlus - S. Maria ai Servi Center, Parma, Italy

INTRODUCTION

The trunk dystonia in idiopathic Parkinson's disease, characterized by marked flexion of the thoraco-lumbar spine, is often referred to as Pisa syndrome (PS) [1]. Patients with PS show an important reduction of hip extension during the stance phase, pointing out a flexed pattern for all the gait cycles. The knee joints show a flexed position during the stance phase and a reduction of knee peak flexion during the swing phase. The ankle joints revealed an important reduction of plantarflexion during the pre-swing phases. If dynamic electromyography records hyperactivity of ipsilateral paraspinal muscles, injection of botulinum toxin into these muscles is reported to be effective [2].

METHODS

94 patients with PS (58 females and 36 males with an average age of 72 years) participated in this study. 9 tests were performed for each patient with the optoelectronic system EL.I.TE. 3-D SMART (BTS, Milan, Italy) following the DAVIS protocol. The patients were subjected to clinical evaluation with TDDS (Trunk Dystonia Disability Scale) [2], Rx, and gait analysis on two moments: at inclusion and 1 month after botulinum toxin injection. The measurements were performed "on" conditions 1 h after theregular morning antiparkinsonian drug administration. Dynamic EMG showed a pattern of abnormal tonic hyperactivity of the paraspinal muscles on the bending side, whereas activity was markedly reduced in both muscles on the opposite side. We injected botulinum toxin (Dysport, 500 U in 2.5 mL saline), under electromyographic guidance, into the ipsilateral paravertebral muscles at the flexion sideat four sites using 50 U at each site. The patients performed a rehabilitation program that included individual sessions of 90 minutes per day, 5 days per week for 4 consecutive weeks.

RESULTS

After treatment, TDDS showed a 6-point improvement. A significant decrease was observed in the Rx degree of lateral trunk flexion (15.2°+-4.3° versus 26.8° +- 5.7°) and mean axial rotation along the spine (8.9°+-2.7°versus 12.4°+-3.6°). Kinematic: resumption of the pelvic sinusoidal trend in the sagittal plane (Fig. 1) and pelvic lateral tilt in the frontal plane; an increase of the range of pelvic obliquity correlating with an increase of the flexor range of the hip in the stance, whose average range is 54° against 41° in pre-treatment controls. Kinetics: a "temporal" concentration of the hipextensor moment in the final stance phase is recorded, with an average value of 1.2 Newton x meter/kg, against 1.4 of the pre-treatment controls; increase of the extensor moment peak at knee ipsilateral the bending site, with an average value of 0.47 Newton x meter/kg, against 0.43 of the pre-treatment controls; increase of the power generated at the ankle at the push off with average value 0.8 Watt/kg, compared with 0.6 before treatment.

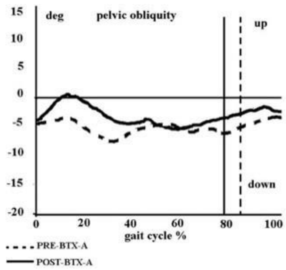

Figure 1. recovery of pelvic rhythm.

DISCUSSION

The kinematic alterations could be a compensative strategy for the reduction of unbalance caused by the trunk position in PS. In our experience, we have found hyperactivity in the lumbar paravertebral muscles on the bending side. These findings suggest that parkinsonian patients with lateral trunk flexion are part of a subgroup in need of a specific and personalized therapeutic program. The patients with trunk dystonia show axial rigidity, kinematic and kinetic alterations, and reduced response to Levo-dopa treatment. For this, they probably fall into a selective form of PD, which will also benefit more from an integrated treatment strategy of botulinum toxin and appropriate physiotherapy [3].

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An innovative integrated platform of telerehabilitation for patients with chronic diseases: development and initial implementation

A. Nardone [1,2,3], M. Mirando [2], V. Tibollo [4], M. Terzaghi [4], M. Piastra [4]

[1] *Department of Clinical-Surgical, Diagnostic and Paediatric Sciences, University of Pavia, Pavia, Italy*
[2] *ICS Maugeri IRCCS, Centro Studi Attività Motorie of Pavia Institute, Pavia, Italy*
[3] *ICS Maugeri IRCCS, Neurorehabilitation and Spinal Units of Pavia Institute and NeurorehabilitationUnit of Montescano (PV) Institute, Italy*
[4] *Department of Industrial and Information Engineering, University of Pavia, Pavia, Italy*

INTRODUCTION

Although physical exercise is recommended to maintain health and to counteract the deleterious effects of chronic diseases, home exercising is rarely performed autonomously by patients. Hence, there is urgency to introduce and validate rehabilitation protocols based on a combination of technological solutions and specific health requirements in order to guarantee continuity and quality of care to patients with chronic diseases [1]. The aim of this presentation is to describe the development and initial implementation of an integrated platform of telerehabilitation, based on information and communication technologies. The platform is the product of a Lombardy Region grant (Regione Lombardia, Programma Operativo Regionale 2014-2020, "Bando Call HUB Ricerca e Innovazione") to Istituti Clinici Scientifici Maugeri IRCCS.

METHODS

Preliminary results have been obtained in five healthy subjects testing the feasibility of the integrated platform in a lab setting (Fig. 1). The platform includes an @home fully-integrated kit composed of: 1) wearable inertial devices, 2) digitally-controlled resistance band, 3) time-of-flight range camera 4) mini-PC with exergames. The @home kit is connected with: 4) cloud-based software systems for programming and monitoring exercises, 5) intelligent conversational agents (chatbot) and virtual coach on personal smartphones. The exergames are based on Otago-inspired exercises [2], including strength, balance, aerobic and cognition. The hardware of the exergames consist of a mini-PC, to be connected to a home TV set, eight inertial measurement units (IMUs, two for proximal and distal part of each limb), providing both accelerometer and gyroscope assessments, a 3D motion range camera, and an extensible band with programmable resistance, exerted by an electric motor. This arrangement allows to detect and record the movement patterns of the subjects. A Digital Support System (DSS) in cloud allows the remote definition and supervision of exercising programs on a deferred basis, thus reducing operator time. An assisted interaction with subjects is allowed through a chatbot and a smartphone app allowing not only to monitor completed activities and achieved progresses but also to receive reminders and advice for the upcoming planning activities.

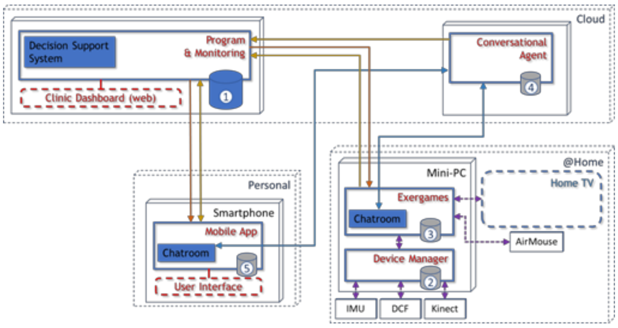

Figure 1. Architectural schema of the integrated platform showing the interconnections between the patient (@home kit), the cloud-based systems and the intelligent conversational agents. IMU, inertial measurement unit; DCF, digitally-controlled resistance band.

RESULTS

The game interface and an avatar of the subject, detected by a range camera, are shown on a TV screen. Operating together, IMUs and the range camera can not only track the movement, but also assess it (as speed and joint range of motion). The DSS operates in an asynchronous mode allowing the continuous remote supervision of the rehabilitation activities, with the possibility to modify the rehabilitation program and progressively adapting it to subject's performance. The chatbot and the smartphone app allow continuous and assiduous first level contact with the subject.

DISCUSSION

The prototype of the platform is innovative as it is based on algorithms both for evaluations and classification of the results data on a deferred basis at variance with the existing telerehabilitation devices. The platform provides also rehabilitation assistance and advice, likely reducing the need of repeated consultations with the physiotherapist. Finally, this intervention technology might take part in the creation of a standardized evaluation and rehabilitation prescription system, leading to better quality of healthcare assistance.

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Instrumental-assisted vs overground gait training: what is the best way to improve gait in neurological patients? A systematic review and meta-analysis.

M. Godi[1], M. Giardini[1], I. Arcolin[1], S. Corna[1]
[1] *Istituti Clinici Scientifici Maugeri Spa SB, IRCCS, Department of Physical Medicine and Rehabilitation, Veruno (NO), Italy*

INTRODUCTION

Gait disorders represent one of the most disabling features for people affected by neurological disease and recovery of walking function is one of the main goals of gait rehabilitation. However, to date, there is a lack of agreement on which is the most beneficial type of gait training in neurological subjects. International guidelines offer conflicting recommendations on instrumental gait rehabilitation: some recommend the use of instrumental methods [1,2], some advice against them [3,4], while others recommend instrumentation only for research purposes or for non-ambulatory persons [5,6]. Our aim was to compare the outcomes of instrumental-assisted vs overground gait training in patients with neurological disorders.

METHODS

The research was performed through several databases (PubMed, Scopus, Embase, Central). Eligibility criteria were studies of adults with neurologic disorders performing instrumental vs overground gait training. Outcomes were measures of gait, balance and independence in daily activities. We included randomized controlled trials in which intervention protocols included gait training performed with treadmill or Lokomat, while control group was trained by overground walking for the same experimental group's amount of time. Quality of the included trials was evaluated with the Cochrane Collaboration's tool for assessing risk of bias.

RESULTS

Of the 1059 records identified, only 25 studies were included in this systematic review. Studies included 1075 patients in total, of whom 530 were trained by instrumental-assisted walking training and 545 by overground walking. 747 subjects (69.4%) had sequaele of stroke; 174 (16.2%) multiple sclerosis; 104 (9.7%) Parkinson's disease; 30 (2.8%) with spinal cord injury; 20 (1.9%) with traumatic brain injury. The overall weighted mean age was 60 (range, 31-74) yrs in the instrumental group and 61 (range, 32-73) yrs in the overground one. Results showed that instrumental and overground gait training similarly improved comfortable gait speed, walking distance, balance and independence in daily activities (Table 1). However, biases assessment showed high or unclear risk of bias in more than 50% of the studies.

Table 1. Meta-analysis between instrumental and overground gait training.

	N. studies	Total sample	MD*/SMD	95%CI	p	I^2
Gait speed	20	763	0.00*	−0.05 to 0.05	0.90	50%
Walking distance	16	606	0.10	−0.07 to 0.26	0.25	0%
Balance measures	15	552	-0.02	−0.22 to 0.18	0.82	25%
Independence measures	11	415	-0.05	−0.25 to 0.14	0.70	0%

DISCUSSION

Due to the current quality of the literature, it was not possible to achieve firm conclusions about the most effective type of gait training. Indeed, the instrumental rehabilitation did not reveal more benefits compared to overground walking training in any of the analysed outcomes. Therefore, higher-quality RCTs with larger sample sizes in different populations are needed for stronger conclusions.

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Posture and gait in the early course of schizophrenia

V. Presta[1], F. Paraboschi[2], F. Marsella[3], V. Lucarini3, D. Galli1, P. Mirandola1, L. Ambrosini1, C. Marchesi[3], M.L. Arcari[1], M. Vitale[1,4], M. Tonna[2], G. Gobbi[1]

[1]*Department of Medicine and Surgery, Human Anatomy, University of Parma, Parma, Italy*
[2]*Department of Mental Health, Local Health Service, Parma, Italy*
[3]*Department of Neuroscience, Psychiatric Unit, University of Parma, Parma, Italy*
[4]*Movement Analysis Laboratory (LAM)-Parma University Hospital, Parma, Italy*

INTRODUCTION

Information on motor dimension in schizophrenia are scarce in literature [1, 2], and no data on their onset are available yet. The aim of this study was i) extensively investigate gait and posture parameters in patients with schizophrenia and, in a secondary analysis, ii) to look across patients to capture a possible motor profile for the early detection of the disorder.

METHODS

Body composition, posture and gait parameters were assessed in 30 subjects with schizophrenia and compared to 25 healthy subjects. Based on time from first hospitalization, the schizophrenia group was subdivided in three subgroups: ≤5 years, 6–14 years, ≥15 years from the first hospitalization.

RESULTS

Sway area was significantly higher in the schizophrenia group showing a visual-independent behavior when maintaining the upright posture. Gait cadence and speed were significantly lower in patients with schizophrenia. Similarly, in the early stages of disease sway area was significantly higher and gait cadence and speed were reduced. The increased sway area and gait cadence reduction differentiated between early and adult-onset patients.

DISCUSSION

The combination of an increased sway area and a gait cadence reduction might be considered peculiar postural and gait profile characteristic of early schizophrenia, and a link with the disruption of bodily-self dimension.

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Stiff Knee Gait in post stroke patients: a cross sectional analysis of kinematic data

D. Anastasi[1], **C. Crippa**[1], **C. Durante**[1], **A. Castagna**[1]
[1] *IRCCS Fondazione Don Carlo Gnocchi, Milan, Italy*

INTRODUCTION

Stiff Knee Gait (SKG) is one of the most typical patterns of abnormal gait in post stroke which characterized by reduced knee flexion during the swing phase. The main reported causes are lack of efficient ankle power at push-off. [1] Few studies report the kinematic pathological pattern linked to SKG, which is a fundamental information to address the rehabilitation program, tailored on the single patient. We assume that the swing knee flexion is influenced by the pelvis movement in pre-swing phase and his position at toe-off (TO), [2] according to pendula model of the leg and an incorrect position of the pelvis induces worse knee flexion, regardless of the ability to product an efficient push-off power. The aim of this study is to profile walking pattern in patients after stroke with SKG and to compare with patients without SKG (NSKG) having low push-off power.

METHODS

We retrospectively analyzed the gait kinematics of 85 adult stroke patients (46 male and 44 female, age 54.1±14.8years), available in the database of our laboratory, acquired using the Smart-D system (BTS Bioengineering, Milan, Italy). We identified SKG when knee flexion during fly phase is lower than 40°. Moreover, we identified subjects with low push-off power if less than 1 W/Kg. We analyzed differences between SKG and NSKG subjects in general parameters (i.e. gait speed, stride length, cadence) and in specific kinematic variables, as knee flexion during swing, pelvis elevation and pelvis rotation at TO and distance on horizontal plane between foot and hip at TO. Statistical comparisons between groups were performed using t-test.

RESULTS

We found that 55 subjects (62%) of our sample showed SKG. of which 48 subjects showed low push-off power (0.383±0.282 W/Kg); A control subgroup of 33 subjects NSKG, 15 showed a low push-off power (0.464±0.244 W/Kg, p=0.21). We found statistically differences in the two groups regarding gait speed, stride length, knee flexion and pelvis elevation and distance on horizontal plane between foot and hip at TO (table 1).

Table 1. Means (SD) of general parameters and kinematic variables in subjects with SKG and without (NSKG).

	SKG	**NSKG**	**P Value**
N (%F)	48 (37.5%)	15 (60.0%)	0.21
Age (years)	59.7 (13.4)	57.3 (13.9)	0.34
BH (cm)	167 (11.5)	166 (8.31)	0.66
BW (Kg)	72.3 (16.6)	70.8 (13.7)	0.77
Push-off power (W/Kg)	**0.383 (0.282)**	**0.464 (0.244)**	**0.21**
Knee Flexion@swing (deg)	25.2 (12.0)	45.5 (5.40)	<0.001*
Gait speed (m/s)	0.324 (0.194)	0.461 (0.231)	0.03*
Cadence (step/min)	66.0 (20.4)	73.8 (23.8)	0.132
Stride Length (%BH)	33.3 (13.2)	43.1 (11.8)	0.0128*
Pelvis Rotation at TO (deg)	-13.4 (9.00)	9.30 (5.95)	0.0951#
Pelvis Elevation at TO (deg)	2.09 (3.89)	-0.152 (3.24)	0.0328*
Pelvis-foot at TO (mm)	4.67 (6.63)	9.13 (4.41)	0.0243*

* statistically difference with p≤0.05, # statistically difference with p≤0.10

DISCUSSION

We analysed subjects with SKG in comparison with subjects without SKG having similar push-off power, but different knee flexion during swing phase.

Moreover, we found statistically significant differences between the two groups in gait speed and stride length, highlighting the influence of an adequate knee flexion and a physiological pelvic kinematic on a more performing gait.

Finally, the two groups showed different kinematic pattern of pelvis movement, highlighting the need to setting a tailored rehabilitation program, focused on pelvis movement in the pre-swing phase of gait to improve a better knee flexion in swing.

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In-vivo kinematics evaluation of total ankle replacement through dynamic radiostereometric analysis: a prospective study

R. Zinno [1], S. Caravelli [2], S. Di Paolo [1], F. Santillozzi [1], E. Vocale [2], S. Massimi [2], M. Mosca [2], L. Bragonzoni [1]

[1] *Department for Life Quality studies, University of Bologna, Bologna, Italy,* [2] IRCCS *Rizzoli Orthopaedic Institute, Bologna, Italy*

INTRODUCTION

In the last few years, total ankle replacement (TAR) kinematics has undergone many changes, and critical issues that led to the improvement of prosthetic designs have been highlighted. A considerable effort has been made with the implementation of the dynamic model-based radiostereometric analysis (dMBRSA), which allows to study in vivo, under load and with active muscular action, the biomechanical behavior of the prosthetic components [1]. The aim of this prospective study was to perform a kinematical evaluation in vivo and in weight-bearing conditions of an ankle prosthetic implants and a clinical and quality-of-life (QoL) evaluation of people with TAR.

METHODS

A cohort of 11 patients (8 male and 3 female) with a mean age of 60±10.3 suffering from ankle osteoarthritis were enrolled in this study. The patients riceved an ankle prosthesis (5 right and 6 left) with a mobile insert (Exactech Vantage) and anterior access. The clinical evaluation was carried out through the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Score, and the QoL was assessed through the Short Form survey (SF-12) at T0 (before the surgery) and 9 months after surgery. SF-12 was divided into 2 domains: physical and mental. Kinematical data were obtained in vivo through dMBRSA 9 months after surgery during a motor task: from plantar flexion to maximum dorsal flexion in weight bearing condition. For each patient kinematical data were calculated (Grood and Suntay decomposition): Internal-External rotations, Anterior-Posterior (AP) translations, and Varus-Valgus rotations of the Tibial component with respect to the Talus component during ankle flexion.

RESULTS

During the motor task, the kinematical results obtained 9 months after surgery showed a dorsi-flexion excursion of 9.14°, varus-valgus rotations range of 2.63°, internal-external rotations range of 2.21°, and anterior-posterior translations range of 10.42 mm (Table 1). After surgery the AOFAS significantly improved (from 31.9±14.4 to 82.3±8.1, $p<0.001$). Moreover, the physical SF-12 scores significantly improved ($p<0.001$) from pre- (34.2±7.3) to post-surgery (47.8±3.8). Otherwise, the improvement of the mental SF-12 scores (from 49.2±8.3 to 5 2.9±5.4) was not significant ($p>0.05$).

Table 1. Kinematical data of the ankle prosthesis

	Maximum Peak	Minimum Peak	Range
Ankle flexion (°)	9.14°	-10.55°	19.69°
Varus-Valgus rotation (°)	2.02°	-0.61°	2.63°
Internal-External rotation (°)	-0.91°	-3.12°	2.21°
Anterior-Posterior translation (mm)	3.33 mm	-7.09 mm	10.42 mm

DISCUSSION

The present prospective study showed that there was an improvement of clinical score and QoL in people after the TAR. The evaluation of joint range of motion with dMBRSA allowed to describe the movements of tibial component with respect to the talus component, excluding other joints.

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A randomised controlled clinical trial in people with foot drop after stroke. The gait analysis to evaluate walking impairment and spasticity in subjects wearing a dynamic Ankle Foot Orthosis.

M.G. Viva [1,2], G. D'Addio [1,4], G. Pagano [1,4], G. Nitti [1], I. Petrosino [1], I. Scarola [1], P. Calia [1] P. Fiore [1,3], S. De Trane [1]
[1] Neurological Rehabilitation and Spinal Unit IRCCS Maugeri Bari, Bari, Italy; [2] Sapienza University of Rome, Rome, Italy; [3] University of Foggia, Foggia, Italy; [4] University of Naples Federico II, Naples, Italy

INTRODUCTION

Regaining gait ability after stroke represents the most important goal of neurorehabilitation in order to improve independence in the activities of daily living [1]. Spasticity is a common consequence of stroke limiting a patient's mobility [2]. In hemiparetic patients, hypertone of plantar flexors and weakness of dorsiflexors can result in a foot-drop pattern which negatively impacts on gait [3]. In such cases a rigid ankle foot orthosis (rAFO) is commonly applied, providing ankle stability, improving the toe clearance and counteracting triceps surae spasticity. However, cutaneous afferent stimuli, generated by the contact of the rigid AFO on the skin, may also trigger spasticity and spasms making the tolerance of the device quite challenging for the patients. The dynamic-AFO (DAFO) is a less known device which does not go into the shoe, it keeps the ankle in a neutral position during the stance phase without limiting ankle dorsiflexion. To date there are no objective studies evaluating the effects of DAFO on gait analysis (GA), LL range of motion (ROM), spasticity and muscles strength. The aim of this study was therefore to evaluate through the use of GA and EMG the effects of the use of a DAFO prescribed early in the rehabilitation phase when compared to movement based rehabilitation program alone. Secondary objective was to evaluate the changes in LL muscle strength and ankle ROM over time in patients using the orthosis compared to the control group.

METHODS

This is a pilot randomised controlled clinical trial. 30 adults with a diagnosis of a recent stroke were enrolled. All subjects had walking impairment and experienced spasticity in plantar flexors. At baseline patients were assessed for eligibility, then randomised in a 1:1 ratio. At V1 outcome measures (OMs) were recorded, these included clinical and objective measures such as the Modified Ashworth Scale (MAS) for spasticity, the Muscle Power Scale (MRC) for LL, the Goniometry for the passive and active ROM for the ankle, GA, using the OPAL inertial accelerometer system, to detect the kinematic parameters of the LLs and trunk during walking, EMG to study the activation patterns of the medial and lateral gastrocnemius, soleus and anterior tibial muscles. At V1 The active group underwent GA with and w/o the DAFO on, while the control group performed the GA w/o the DAFO. Both groups followed a personalised weekly training schedule, consisting in 60 minutes treatment, twice a day, 6 days a week, for 4 weeks. Exercises focused on trunk and LL passive and active movements, strength, balance and coordination exercises, muscular stretching, walking and ADL independence training. Active group wore the DAFO during the trial. At 4 weeks (V2) OMs were repeated as per V1. Termination visit included surveys to assess patients' satisfaction and tolerability of the DAFO. Homogeneity between the basal values in the two groups was verified. A second analysis was conducted in order to separately test the effects of the rehabilitation outcome in the two groups. A third phase of variance analysis was conducted to verify the differences in OMs achievement in the two different arms of the study.

RESULTS

Preliminary data for this pilot study are not yet available. Protocol has been submitted and positively evaluated by the CTS group. Recruitment will start in September.

DISCUSSION

This study can be used to help predict response to the use of the DAFO based on patient's clinical features, it will also give an idea on whether this tool, prescribed early in the rehabilitation path, may improve rehabilitation outcomes for patients after stroke, when compared to a late prescription.

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Motion capture analysis of dominant arm trajectories in subclinical patients with Multiple Sclerosis vs healthy controls: an explorative study

A. Bellinvia[1], G. Pasquini[2], F. Gerli[2], G. Fransvea[2], L. Truppa[3], A. Mannini[2], F. Vannetti[2], E. Portaccio[1], A. Uccelli[4], M.P. Amato[1,2]
[1]*University of Florence, NEUROFARBA Department, Florence, Italy*
[2]*IRCCS Fondazione Don Carlo Gnocchi, Florence, Italy*
[3]*Scuola Superiore Sant'Anna, Pisa, Italy*
[4]*Scientific Direction IRCCS Ospedale Policlinico San Martino Genoa Italy*

INTRODUCTION

To examine differences in motion capture analysis parameters of dominant arm in early Relapsing-Remitting Multiple Sclerosis (RRMS) patients with no evident neurological deficits compared with healthy controls (HCs).

METHODS

A motion capture analysis of the dominant upper limb was performed for 42 subjects via the Smart DX motion capture system (BTS Bioengineering), synchronized with a grid of 8 proximity sensors (Witty Sem by Microgate). Each subject was equipped with 6 markers placed on the following anatomical landmarks: both the shoulders, C7, elbow, ulnar styloid and second metacarpal caput.

RRMS Patients, with Expanded Disability Status Scale (EDSS)1 ≤ 1.5, enrolled in the project NET-2018- 12366666 funded by Italian Minister of Health, were included and compared with age- and sex-matched HCs. The subjects had to perform two tasks: the first one involved the achievement of 50 light stimuli (a green "F") in random sequential while the second, more difficult, included the addition of distractors (i.e., different green letters and numbers). The following parameters were analyzed for both the tasks: time to perform the task, entropy, spectral arc length, speed metric and log dimensionless jerk (LDJ). A Wilcoxon signed-rank test was performed to compare the two tasks within each group. Interaction between within-subjects factor (task) and between- subjects factor (group) on the dependent variable were evaluated by a two-way mixed ANOVA. Significance threshold was set at $\alpha = 0.05$.

RESULTS

Twenty RRMS patients and 22 HCs were included in the analysis. Wilcoxon test showed that there is a significant difference between single and dual task for all the tested variables ($p<0.05$). The latter holds for both the healthy and the pathological cohort. Furthermore, from a mixed-ANOVA analysis, LDJ (median [IQR] HCs: first task - 6.08 [0.38], second task -6.89 [0.48]; RRMS: first task -6.75 [0.86], second task -7.09 [0.72]) resulted significantly different between the two groups ($p=0.016$) and between tasks ($p<0.001$).

DISCUSSION

Motion capture analysis of upper limbs is a largely unexplored area in Multiple Sclerosis. In this explorative study, we have searched for useful parameters that can distinguish HCs from RRMS that did not exhibit noticeable disability on neurological examination. The LDJ parameter, a variable used to quantify the smoothness of movement2, appeared significantly worse in RRMS compared with HCs.

Motion capture analysis of superior limb movements in scaling difficulty conditions might be useful to detect subclinical deficits in RRMS patients. These preliminary results need to be confirmed by validation on a larger, multicentric cohort.

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Effects of the Virtual Reality Rehabilitation System on trunk and lower limb motor impairment in people with severe polyneuropathy: A prospective observational study in a clinical setting.

M.G. Viva[1,2], D. Macchiarola[1,2], M. Ditillo[2], G. Pagano[2], P. Battista[2], I. Scarola[2], B. Minafra[2], P. Fiore[2,3], S. De Trane[2].
[1] Department of Anatomy, Histology, Legal Medicine and Orthopedics, Sapienza University, Rome, Italy
[2] Neurorehabilitation Unit, Clinical and Scientific Institutes Maugeri, IRCCS of Bari, Bari, Italy
[3] Department of Physical and Rehabilitation Medicine, University of Foggia, Foggia, Italy

INTRODUCTION

Paraparesis, postural imbalance and gait disorders are common features of peripheral neuropathies[1], which affect the 1-8% of the general population. Etiologies are varies, including metabolic, toxic, nutritional, inflammatory, and hereditary.[2] Virtual reality rehabilitation (VRR) is gaining a growing interest in the rehabilitation of motor disorders. It provides immediate visual feedback of the body movements, allowing for modulation of exercises based on the person's abilities through a fine regulation of the sensibility.[3] VRR System (VRRS), Khymeia, is a relatively new medical device used for rehabilitation training and tele-training. It is equipped with a kinematic magnetic acquisition system that exploits augmented feedback and motor imagery in order to develop motor and functional learning throughout the awareness of the results and the quality of the movements. The aim of this study is to evaluate the effects of the use of VRRS on trunk stability and lower limb motor impairment in inpatients with a diagnosis of polyneuropathy, admitted to the Neurorehabilitation Unit of Maugeri Institute IRCCS of Bari, Italy.

METHODS

This is a prospective observational cohort study, in a clinical setting. All participants were suffering from lower limb weakness, balance disorder, and walking impairment secondary to severe polyneuropathy. Subjects underwent a rehabilitation program using VRRS Khymeia for 1 hour a day and including 6 exercises aiming at the neuromotor control of the trunk, hip flexion, knee extension, ankle dorsiflexion, and load transfer exercise from a standing position. This was combined with the traditional physical exercise training consisting in 2 hours a day of passive mobilization, muscle strengthening, and proprioceptive exercises. Treatment lasted 60 days and was conducted for 6 days a week. Subjects were assessed at baseline, after 30 and 60 days of rehabilitation treatment. Medical history and clinical assessments were performed, outcome measures scores were also recorded (OMs): 1) MRC scale for muscle strength, 2) TIS for trunk control, 3) Berg scale for balance, 4)TUG test, for mobility and fall risk, 5-6) Barthel and FIM scales for the level of disability 7) PTPSQ for compliance and patient satisfaction, as well as the measure of the body sway of the vertical center of mass (CoM) and the center of pressure (CoP) quantified by using VRRS Khymeia.

RESULTS

So far 4 patients took part in this study, (3 males), aged between 24 and 49 years. 3 had a diagnosis of Guillain Barrè Syndrome while one had an acute motor-sensory axonal neuropathy in severe thiamine deficiency with Wernicke's encephalopathy. Preliminary data showed a relevant improvement recorded at 30 days on the OMs concerning disability (Barthel +25%, FIM +23%), trunk control (TIS +46%), and muscle strength, especially in proximal lower limbs muscles and hip flexors (iliopsoas and quadriceps bilaterally). Furthermore, all patients perceived satisfaction with the VRRS training, defining it as suitable and engaging.

DISCUSSION

Augmented reality is gaining more ground in rehabilitation. Although our data recording as well as the definitive statistical analysis are still ongoing, these preliminary results are promising, suggesting that VRRS is a valid rehabilitation tool, which combined with the traditional approach, can reduce disability in people with paraparesis, improving function. Furthermore, patients reported the customized training to be engaging, which increased patients' compliance.

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Turning Performance during an instrumented Timed-Up-and-Go test to distinguish fallers and non-fallers in chronic stroke patients

S. Spina [1], S. Facciorusso [2], P.Fiore [3] , A. Santamato [1]

1 *Physical Medicine and Rehabilitation Section, Policlinico Riuniti Hospital, University of Foggia, Foggia, Italy.*
2 *Villa Beretta Rehabilitation Center, Valduce Hospital, Costa Masnaga, Lecco, Italy.*
3 *Neuroriabilitazione Universitaria, IRCCS Maugeri, Bari*

INTRODUCTION

Falls are a well-known complication of mobility impairment in patients after stroke[1]. Stroke patients frequently experience falls while turning, likely because turning is more difficult and demanding than linear gait as it requires more neural resources to plan and coordinate postural transitions, more coupling between the balance and gait control systems, and more spatial coordination between limbs[2]. As such, turning assessments may be more predictive of future falls than gait assessments alone. The Timed-Up-and-Go (TUG) could provide some information about turning movement and technological advancements have matched the need to improve the parameterization of the TUG test, resulting in the development of an instrumented version of the test[3]. We propose to consider turning parameters measured by an inertial wearable sensor during TUG as new indicators to evaluate the risk of fall after stroke. Thus, the aim of this study was to analyze if these turning metrics can distinguish between fallers and non-fallers.

METHODS

This is a cross sectional observational study including 48 chronic stroke patients (26 male; mean age 60,87 ± 11.46). Turning performance was evaluated during the execution of an instrumented TUG wearing an inertial sensor on the lower back (First Sacral Vertebra S1). All turning parameters such as duration, average angular (AA) and peak angular (PA) speed for both mid (MT) and end turning (ET) were registered. The occurrence of falls within the 6 months after the measurements was assessed by a declarative fall questionnaire administered by phone call to patients or relatives.

RESULTS

In the exploration of fall incidence, we found that 42% of patients fall and 58% did not fall after 6 months. A comparison of fallers and non-fallers in the stroke group revealed significant differences ($p<0.001$) in iTUG total duration, mid and end turning duration and all speed parameter with the exception of PA MT.

Table 1. Mann- Whitney between fallers and non-fallers

Parameter	Non Fallers (n 28)	Fallers (n 20)	p-value
Duration (s)	20,45 ± 10,28	30,12 ±11,73	0,001
Sit to Stand (s)	1,56 ± 0,53	2,07 ± 0,74	0,003
Forward Gait (s)	5,46 ± 4,86	8,10 ± 4,12	0,005
Mid Turning (s)	3,94 ± 1,34	6,04 ± 2,56	0,001
Return Gait (s)	4,76 ± 3,74	7,25 ± 5,26	0,02
End Turning (s)	2,88 ± 0,96	4,56 ± 2,11	0,001
Stand to Sit (s)	1,87 ± 0,79	2,10 ± 0,70	0,088
AA Speed (°/s) MT	49,65 ± 18,60	31,68 ± 10,66	0,001
PA Speed(°/s)	110,28 ± 37,62	81,01 ± 19,95	0,005
AA Speed (°/s) ET	56,63 ± 19,65	33,35 ± 10,17	0,000
PA Speed (°/s)	125,31 ± 41,37	80,58 ± 15,31	0,000

DISCUSSION

Our results confirmed that turning speed during iTUG with a single inertial sensor on the lower back could be useful for discriminating fallers from non-fallers in stroke patients. Fallers spent more time turning and turned with slower average and peak angular speeds. Further research should investigate which cut-off values of speed turning could better differentiate among fallers and non-fallers in stroke patients.

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New frontiers in pain medicine. The potential role of kinematic assessment

G. Bongiorno[1,3], A. Tomasi[2], L. Miceli[3]

[1]Rehabilitation center Friuli Riabilitazione, Roveredo in Piano (PN), Italy; [2]Orthopaedic surgery, Hospital Papa Giovanni XXIII, Monastier (TV), Italy; [3]Pain Medicine, IRCCS CRO di Aviano, Aviano (PN), Italy

INTRODUCTION

We are used to thinking that analgesic therapy is a tool used only to reduce the patient's pain, usually expressed through a numerical value (Numeric Rating Scale) [1]. However, since 2001, medicine has been progressing from the ICD (International Classification of Diseases) classification system to the ICF (International Classification of Functioning, Health, and Disability) system [2]. The combination of modern analgesic techniques and recent methods of kinematic assessment of movement can lead to a personalized rehabilitation project, based on the impairment of the individual patient rather than on the individual pathology.

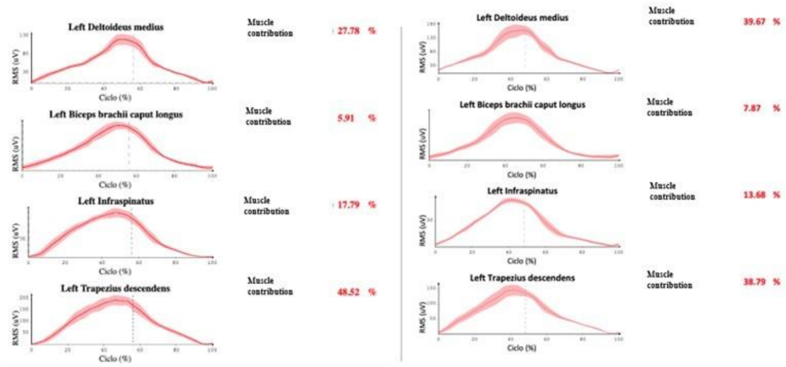
METHODS

Female patient, 51 years old, with diabetes, suffering from adhesive capsulitis of the left shoulder came to the institute because of continuous, severe pain (NRS 8(10) in the left shoulder, with significantly associated ankylosis. She is offered and performed a single treatment with pulsed radiofrequency (TherMedico NK 1 radiofrequency lesion generator®Germany) of the left suprascapular nerve. The choice of pulsed radiofrequency, as effective as the intra- articular steroid [3], was preferred due to the subject's diabetic pathology. The patient was simultaneously subjected to kinematic and surface electromyographic evaluation before the procedure and three weeks later.

RESULTS

After 15 days of the treatment, a substantial reduction in pain has been recorded (NRS decreased from 8 to 2). Many improvements emerged from the non-invasive analysis conducted with an accelerometer and surface electromyograph (G-sensor and Freemg 1000 BTS bioengineering® Garbagnate, Italy). There was a clear improvement in the angles of movement, a better fluidity of the movement itself expressed by the Jerk index (the lower the value of this coefficient and the greater the fluidity) [4], and more correct muscle activation with a lower contribution of the trapezius muscle to the advantage of the other extrinsic muscles of the shoulder. See Table 1 EMG results.

Table 1. Surface electromyographic values of left shoulder muscle before and after the pulsed radiofrequency procedure in the abduction movement of the arm, in which there is less involvement of the trapezius muscle in favour of the ipsilateral deltoid muscle.



DISCUSSION

This approach has allowed us to detect and quantify the effect of only the treatment of the pain symptom on the quantity and quality of a patient's movement or on her ability to restore a function with objective and periodically repeatable data in a non-invasive way during the rehabilitation treatment.

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Longitudinal functional assessment of a transfermoral amputee patient treated with osseointegration surgery

L. Bragonzoni[1], S.Di Paolo[1], D. Alesi[2], A. I. Mirulla[1], Emanuele Gruppioni[3], G. Barone[1], Stefano Zaffagnini[2]

[1]Università degli Studi di Bologna, Bologna, Italy; [2]IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy; [3]Centro Protesi INAIL Vigorso di Budrio, Bologna, Italy

INTRODUCTION

The socket-type prosthesis is the treatment of election for the lower-limb transfemoral amputation. However, patients often report skin abrasions, skin sweating, lack of balance, and walking difficulties [1,2]. The osseointegration technique is an alternative treatment for amputee patients that limits the socket-related problems and provides a more physiological mechanical loading [1].

After surgery, a critical functional recovery and dedicated rehabilitation phase is required. Little functional assessment of these patients has been reported in the literature. The purpose of the present study was to provide the functional assessment of a transfemoral amputee patient before osseointegration surgery and after rehabilitation by means of wearable sensors.

METHODS

A transfemoral amputee patient (male, 47 years, time from amputation 18 years) scheduled for osseointegration surgery was enrolled. The patient was able to walk without aids and performed a gait test the day before surgery with his standard socket-type prosthesis, consisting in 10-meters walking in a hospital indoor hall, two at self-selected speed and two at the fastest speed possible. The test was repeated 3 months after surgery (after the clearance from the rehabilitation, 3M FU), and 6 months after surgery (6M FU).

A set of 15 wearable inertial sensors (Awinda, Xsens Technologies) was used to collect full body kinematics. Complete gait cycles were isolated and spatiotemporal and kinematical parameters were extracted. The differences between the amputee (AL) and the sound (SL) limb among the follow-ups were reported. One-way ANOVA with post-hoc comparisons was conducted in Spm1D ($p<0.05$).

RESULTS

Shorter step length and longer swing phase were found for the AL at pre-op, with greatest differences in the midstance. Also, hip abduction and rotation, pelvis forward tilt and obliquity, trunk forward tilt, and lateral bending on the AL were also noticed. At follow-ups, symmetry index progressively improved (1.14, 1.09, 1.06 at pre-op, 3M FU, and 6M FU, respectively). Asymmetries in hip abduction, hip rotation, and pelvis rotation decreased at follow-ups and no more trunk forward and lateral tilt were found.

DISCUSSION

The altered spatiotemporal and kinematical parameters found preoperatively were in line with the current literature [1]. After rehabilitation, the patient showed higher time spend on the AL and lesser kinematical asymmetries. The osseointegration surgery showed to progressively restore a physiological kinematics in the transfemoral amputee patient.

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Spinal and whole-body kinematics assessed by 3D gait analysis using DB-Total protocol in Late Onset Pompe Disease and healthy populations

Paolo De Blasiis[1] Allegra Fullin[1], Mario Sansone[2], Davide Mazzoli[3], Giorgia Bruno[4], MariarosaAnna Beatrice Melone[4], Simone Sampaolo[4]

1 University of Campania "Luigi Vanvitelli", Department of Mental and Physical Health and Preventive Medicine, Section of Human Anatomy, Naples, Italy

2 University "Federico II" of Naples, Department of Electrical Engineering and Information Technology, Naples, Italy.

3 Gait and Motion Analysis Laboratory, Sol et Salus Hospital, Rimini, Italy

4 University of Campania "Luigi Vanvitelli", Department of Advanced Medical and Surgical Sciences, 2nd Division of Neurology, Naples, Italy.

INTRODUCTION

The Late Onset Pompe Disease (LOPD) is characterized by postural abnormalities mainly due to involvement of paraspinal lumbar and abdominal-pelvic muscles. Previous studies quantitatively analysed static upright posture, time-distance of gait cycle and kinematic angles without considering sagittal whole-body kinematics. Aim of our study was to evaluate kinematic whole-body parameters during walking in LOPD adult respect to healthy, in order to better characterize abnormal postural patterns.

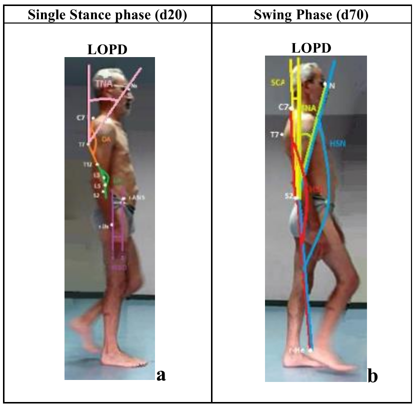
METHODS

Seven LOPD siblings were assessed by 3D-Stereophotogrammetry using DB-Total protocol. Fourteen age and sex-matched healthy individuals were used as controls.

RESULTS

LOPD group showed a longer gait cycle duration, stance phase and double support, and a shorter swing phase, cadence, gait speed and stride length. About kinematic-parameters, a significant increase was found in Gait Profile Score (GPS) and Gait Variable Score (GVS) of pelvis tilt, whole hip ROM and knee flex-extension. Moreover, analysis of additional sagittal whole-body values showed a flattening of the spinal curvatures, with a head, neck and trunk posteriorization respect to sacrum, a significant increase of anterior convexity in Heel-S2-Ns/C7 angles, a rear-position of upper limbs respect to pelvis and a trend of elbow extension during walking.

Figure 1. Representation of significant DB-Total parameters during walking in LOPD patients [two exemplary frames taken in the single stance (d20-a) and swing phase (d70-b) of right lower limb during gait cycle].



DISCUSSION

The present study highlighted abnormal sagittal whole-body kinematics of LOPD patients compared to healthy controls during walking. This typical postural pattern, resembling "back falling man", reveals a biomechanical compensation strategy to maintain the balance against the instability of trunk-pelvic district, kinematically verified by a significant increase of excursion range in most sagittal parameters. The analysis of these new additional kinematic parameters might be useful to diagnostic suspicion, monitoring and rehabilitation project of this rare disease.

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Clinical and biomechanical evaluation of an adaptive poly-articulated myoelectric hand prosthesis: A case series.

M.G. Viva[1], M. Mangone[1], A. Bernetti[1], F. Agostini[1], M. Paoloni[1].
[1] *Department of Anatomy, Histology, Legal Medicine and Orthopedics, Sapienza University, Rome, Italy*

INTRODUCTION
Upper limb amputations are about 5% of all amputations, and the most common cause consists of trauma. 2% can instead be traced to congenital agenesis [1]. The loss of upper limb function is an important cause of disability, as the features in particular of the hand are numerous and complex. To date, the use of myoelectric prostheses allows a partial recovery of the amputated limb, but despite the constant research to increasingly meet the aesthetic and functional needs of the amputee individual, at the moment no prosthesis is able to accurately replicate the movements of the upper limb. [2]. Adam's Hand®, produced by BionIT Labs S.R.L., is a poly-articulated adaptive hand prosthesis based on an innovative technology, which uses a single motor to move all the fingers, automatically adapting to the shape and size of the objects grasped, without selecting any grip pattern. This feature makes the prosthesis light and much easier to use, allowing it to be used even by less experienced users.
To date, the evaluation of prostheses has often taken place through questionnaires on usability and patient satisfaction [3]. The analysis of the basic tasks with objective methods is lacking in the literature. The aim of this study is to evaluate through movement analysis and clinical tests the movement patterns during basic goal-oriented movements and the impact on daily living activities of the use of an innovative adaptive myoelectric prosthesis.

METHODS
This is a case series observational study for evaluation of the feasibility of a subsequent clinical trial.
Due to the infrequency of upper limb amputations, at the moment only 3 patients have been recruited, all suffering from transradial amputation secondary to trauma or agenesia. Additional patients will be added during the work. Patients were initially evaluated by clinical examination, which included clinical and objective measures including the Muscle Strength Scale (MRC) and the goniometric measurement for the passive and active ROM of trunk and upper limbs. Then an evaluation with an optoelectronic system and EMG was performed, using an upper limb protocol, during the execution of 3 basic movement tasks (Grasping, Pointing and Hand to Mouth), in order to evaluate movement and muscle activation patterns of the trunk and upper limbs and identify any compensatory movement. To examine the impact of the use on daily living activities, subjects were also evaluated through validated tests specific for upper limb prostheses (Box and Blocks test, Manual Dexterity Test, Southampton Hand Assessment) and questionnaires for upper limb disability (DASH) and prosthesis use (TAPES-R).

RESULTS
Preliminary data for this pilot study are not yet available. Recruitment has already begun and preliminary evaluations of the first patients have been carried out.

DISCUSSION
This study represents the first clinical evaluation of Adam's Hand adaptive prosthesis. It can be an important reference for the biomechanical evaluation of myoelectric prostheses and the impact of their use on daily living activities. It will also allow to identify any compensatory movements that could lead in the long term to overuse pathologies. The evaluations carried out will on the one hand help to better understand the mechanisms of the new prosthesis and the issues to focus on to improve prosthetic use and, on the other hand, the protocol set can be used as a possible reference for similar studies. It can also be useful to identify objective parameters to consider when comparing different types of upper limb prostheses.

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Influencing factor of stability during gait the main determinants of individuals' risk of falling

Carmela Conte[1], Stefano Filippo Castiglia[2,3], Enrica Di Sipio[4], Chiara Iacovelli[5], Cristiano Pecchioli[6], Andrea De Rosis[7], Eduardo Palermo[7], Marco Germanotta[8], Irene Aprile[8], Mariano Serrao [1,2]

[1] Policlinico Italia, Laboratorio di Analisi del Movimento, Piazza del Campidano 6, Roma, Italia, [2] Dipartimento di Scienze e Biotecnologie medico-chirurgiche, Latina, Italia, [3] Dipartimento di Scienze del Sistema Nervoso e del Comportamento, Università di Pavia, [4] CoRehab, Riabilitazione, Trento, Italia,[5] UOC Riabilitazione e Medicina Fisica, Dipartimento di Scienze dell'Invecchiamento, Neurologiche, Ortopediche e della Testa-Collo, Fondazione Policlinico Universitario Agostino Gemelli IRCCS,Largo F. Vito n.1 – 00168 Roma (IT), [6] Department of Neuroscience and Neurorehabilitation, IRCCS San Raffaele Pisana, 00167, Rome, [7] Sapienza, Dipartimento di meccanica e ingegneria aerospaziale, Roma, Italia,[8] IRCCS Fondazione Don Carlo Gnocchi, Firenze, Italia

INTRODUCTION

The presence of small kinematic disturbances induces people to loss equilibrium and lead them to fall. Dynamic stability is fundamental prerequisite to ensure safe and efficient locomotion. If the Center of Mass, CoM, is maintained or reallocated within the Base of Support (BoS), the system is usually considered "stable" (Hof et al .2005). Bruijn and colleagues describe different types of gait stability dealing with small internal (internal nose) and external perturbations (unstable surface) (Bruijn et al. 2013). Measures generated from induced internal and external disturbance were assessed in this study to establish the main determinants of individuals' risk of falling.

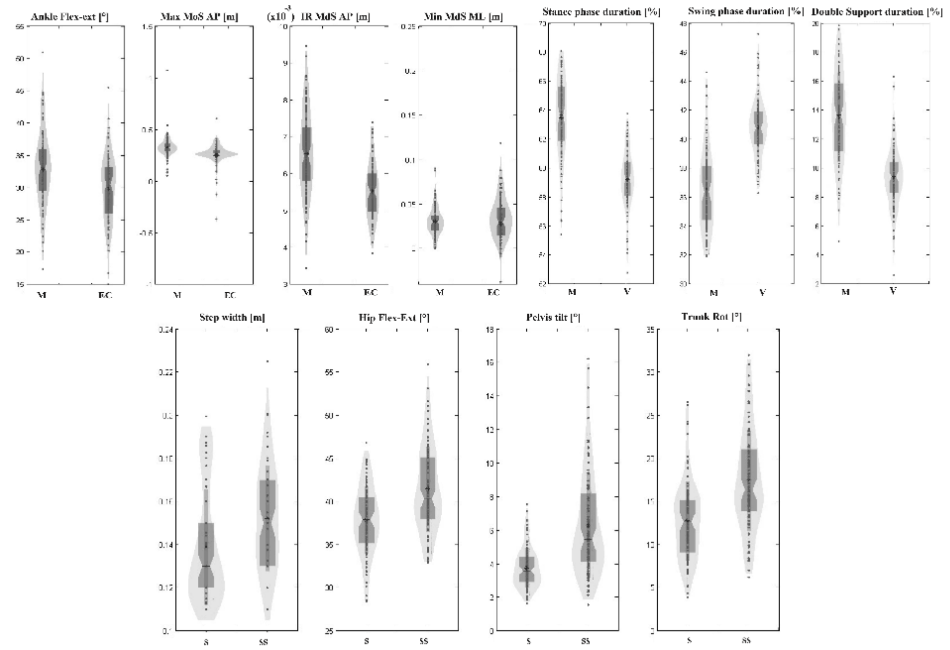
METHODS

Nineteen subjects aged between 23 to 45 years old, (mass 63.6 ± 12.1 kg, height 1.70 ±0.1 m, BMI 22.1 ± 2.1) were recorded. The movement of thirty passive spherical markers placed over prominent bony landmarks was detected using an optoelectronic motion analysis system (SMART-D, BTS, Milan, Italy). Each participant was evaluated on a slippery floor (coated with soap and water) (SS); with eyes-closed (EC) and finally after vestibular stimulation (V). Slow, fast and comfortable walking tasks were also acquired in order to match the gait speed with those of unstable tasks. Spatio-temporal and stability variables were calculated using a 15-segment, full-body biomechanical model.

RESULTS

The Kruscall-Wallis non-parametric test was used to evaluate differences between the tasks. The post-hoc results were show in figure 1.

Figure 1. Results of the gait variables that significantly affect the tasks.



DISCUSSION

Because perturbations occur during gait from both internal and external sources, the likelihood of falling is determined not only by the individual's neuromusculoskeletal capacity, but also by external factors such as the type and magnitude of perturbations encountered in daily life. Our findings showed that, regardless of gait speed, factors such as poor vision may induce people to use ankle strategies, whereas internal perturbations affect influences spatiotemporal and kinematic parameters.

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Gait analysis, trunk movements, and electromyographic patterns after minimally invasive spine surgery for lumbar instability: an observational prospective study

Massimo Miscusi [1,2], Mariano Serrao [1,3], Luca Ricciardi [2], Carmela Conte [3], Stefano Filippo Castiglia [1,4], Giorgio Ippolito [1], Gianluca Coppola [1], Stefano Forcato [5], Alba Scerrati [6], Antonino Raco [2]

[1] Department of Medical and Surgical Sciences and Biotechnologies, Sapienza, University of Rome – Polo Pontino, Corso della Repubblica 79, 04100, Latina, Italy
[2] Department of NESMOS, Sapienza University, via di Grottarossa 1035-1039, Rome, Italy
[3] Movement Analysis LAB, Policlinico Italia, Piazza del Campidano 6, 00162, Rome Italy
[4] Dipartimento di Scienze del Sistema Nervoso e del Comportamento, Università di Pavia
[5] UO di Neurochirurgia, Pia Fondazione di Culto e Religione Cardinale G. Panico, Via San Pio X 4, 73039, Tricase, Italy
[6] Dipartimento di Morfologia, Chirurgia e Medicina Sperimentale, Università di Ferrara, via Luigi Borsari 46, 44121 Ferrara, Italy

INTRODUCTION

More than 80% of the working adult population in the world complains of Low Back Pain (LBP), which is a major cause of disability (Rubin, 2007). More than half of subjects with LBP present segmental spine instability (Panjabi, 2003). Minimally Invasive Surgery (MIS) has been proposed as an alternative to conventional surgery for many different conditions affecting the spine (Miscusi et al., 2015)
The aim of the present study was to investigate trunk kinematics and spine muscle activation during walking after minimally invasive surgery in patients suffering from lumbar instability (LI).

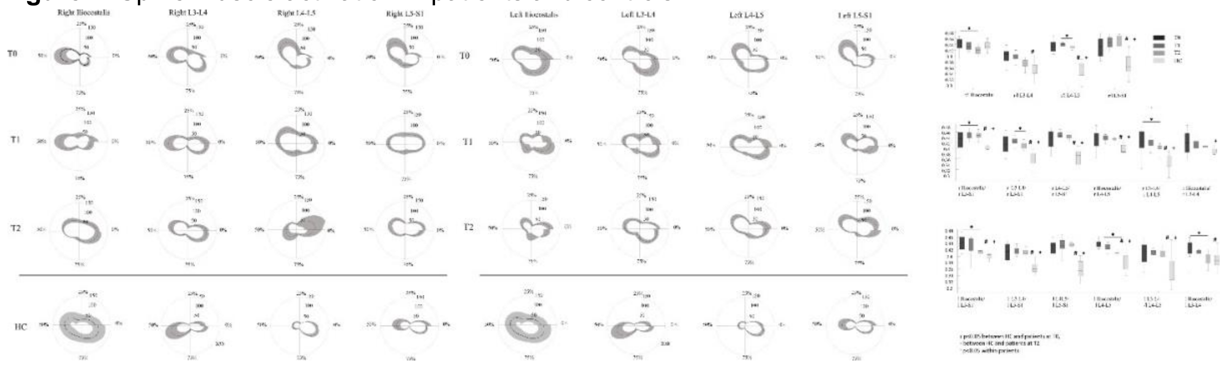
METHODS

Eleven patients suffering from LI and 13 healthy controls (HC) were enrolled in the present investigation. Trunk kinematics and spine muscle activation (left and right lumbar iliocostalis and longissimus dorsi muscles from L3 to S1) patterns during walking were collected using a stereophotogrammetric system equipped with a portable electromyography device. Maximal trunk ranges of motion in the three-dimensional were also recorded from standing position.
Assessments were performed pre-operatively (T0), 1 month (T1) and 3 months (T2) after MIS.

RESULTS

We found significant improvement in spine muscle activation during walking at T2 compared to T0, mainly involving right/left symmetry at the operated level (L4-L5) and up-down synchronization from L3 to S1 (Figure 1).

Figure 1. Spine muscle activation in patients and controls.



DISCUSSION

Our results suggest that MIS may improve some biomechanical parameters, including muscle activation symmetry and synchronization, as well as trunk rotation during walking, at early follow-up. These biomechanical parameters could represent novel tools for monitoring the effect of surgery in LI and preventing impaired spine mobility and muscle activation.

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Variability of Postural Stability and Plantar Pressure Parameters in Healthy Subjects Evaluated by a Novel Pressure Plate

A.Fullin [1], P. Caravaggi [2] , P. Picerno [3] , M. Mosca [4], S. Caravelli [4] , A. De Luca [1] , A. Lucariello [5] and P. De Blasiis [1]

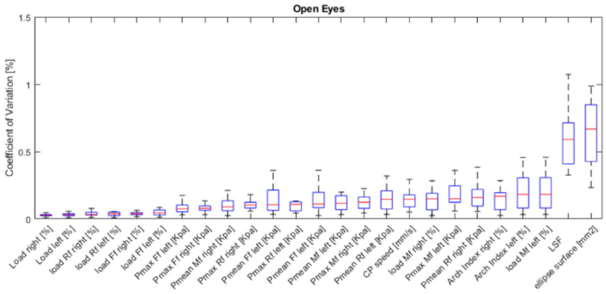
1 Department of Mental and Physical Health and Preventive Medicine, Section of Human Anatomy, University of Campania “Luigi Vanvitelli”, 80138 Naples, Italy; allegrafullin92@hotmail.it (A.F.); antonio.deluca@unicampania.it (A.D.L.)
2 Movement Analysis Laboratory, IRCCS Istituto Ortopedico Rizzoli, 40136 Bologna, Italy; paolo.caravaggi@ior.it
3 SMART Engineering Solutions & Technologies (SMARTEST) Research Center, Università telematica “e Campus”, 22060 Novedrate, Italy; pietro.picerno@uniecampus.it
4 II Clinic of Orthopaedics and Traumatology, IRCCS Istituto Ortopedico Rizzoli, 40136 Bologna, Italy; massimiliano.mosca@ior.it (M.M.); doct.car@gmail.com (S.C.)
5 Department of Sport Sciences and Wellness, University of Naples “Parthenope”, 80100 Naples, Italy; angela.lucariello@gmail.com1

INTRODUCTION
Postural stability and plantar pressure parameters can be assessed by baropodometry; nevertheless, they are often affected by low repeatability. The aim of the study was to test the accuracy and repeatability of a novel resistive sensor pressure plate and to establish the most reliable baropodometric parameters.

METHODS
Accuracy and repeatability of the FM12050 BTS-Bioengineering plate measurements were assessed by using different weights in static conditions across three sessions. Subsequently, 20 healthy subjects were assessed by 30-s stabilometric analysis in bipedal standing with open eyes across four trials in two sessions, morning and afternoon.

RESULTS
Pressure plate repeatability in measuring the static weights was very high, and plate measurements were correlated to the scale measurements (Pearson’s coefficient = 0.99). Percentage of load distribution between left and right foot and in rearfoot and forefoot regions showed the largest repeatability (Coefficient of variation < 5%) across trials. Eventually, median and percentiles (25–75%) were reported for each parameter.

Figure 1. Boxplot of inter-subject Coefficient of Variation [%] of stabilometric and pressure parameters sorted in ascending order to median values.



DISCUSSION
This study helped to assess the accuracy and repeatability of a novel pressure plate in static conditions and to define the most reliable parameters for the assessment of postural stability and foot morphology. The present healthy-subject stabilometric dataset may be used as reference data in the evaluation of pathological populations.

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EEG-based neuroplasticity analysis procedure for longitudinal assessment of post-stroke patients following robot-assisted upper-limb rehabilitation.

M.C. Mauro[1], A. Mazza[2], M. Germanotta[1], L. Cortellini[1], A. De Liso[3], A. Comanducci[2], I. Aprile[1], and E. Guglielmelli[2,3]
[1] *IRCCS Fondazione Don Carlo Gnocchi, Florence, Italy;* [2] *IRCCS Fondazione Don Carlo Gnocchi, Milan, Italy;* [3] *Università Campus Biomedico, Rome, Italy;*

INTRODUCTION

Stroke is the world's second leading cause of death and the leading cause of disability. Robotic therapy is a well-established approach for the rehabilitation of the upper limb, as a way to increase the amount and intensity of the therapy and standardize the treatment [1]. In recent years, robot-assisted bilateral upper-limb training has grown abundantly for stroke rehabilitation, and an increasing number of end-effector robots have been developed [2], while only one exoskeleton allows a similar treatment. Along with the clinical evaluation, the monitoring of electrical brain activity with Electroencephalography (EEG) has emerged as a widely accessible and versatile instrument for the longitudinal assessment of stroke patients. The goal of this study is to assess recovery in post-stroke patients following unilateral or bilateral robot-assisted upper limb rehabilitation by using a novel high-density EEG-based index.

METHODS

For this study, 6 subacute stroke patients (mean time since the stroke onset 3±2 months) have been recruited. The subjects underwent a 30-session upper-limb neurorehabilitation program using the Arm Light Exoskeleton Rehab Station (ALEx RS). Each patient was randomly assigned to either the experimental group (bilateral treatment) or the control group (unilateral treatment). A 64-channels hd-EEG was recorded at the following time-points: before the beginning of the first game session (T0), right after the end of the first game session (T1), at the end of 30 treatment sessions (T2), and at 1-week follow-up (T3). From the EEG data, the Spectral Exponent (SE) index [3], a metric that reflects EEG slowing and quantifies the power-law decay of the EEG Power Spectral Density (PSD), has been computed. A preliminary statistical analysis was conducted on the whole group of patients, to evaluate the changes in brain activity induced by the rehabilitation treatment. Specifically, the SE index values obtained before (T0) and after the intervention (T2) were compared by using a Wilcoxon test, for the Affected and the Unaffected Hemisphere, and in eyes open and closed conditions, separately.

RESULTS

The results of the statistical analysis are reported in Figure 1. As expected, in the eyes closed condition, a significant increase in the SE index (meaning an overall renormalization), was found solely in the affected hemisphere ($p=0.028$, Figure 1A) but not in the unaffected one ($p=0.116$, Figure 1B). In eyes open condition, a similar trend, though not significant, was detected for both affected ($p=0.173$) and unaffected hemisphere ($p=0.173$).

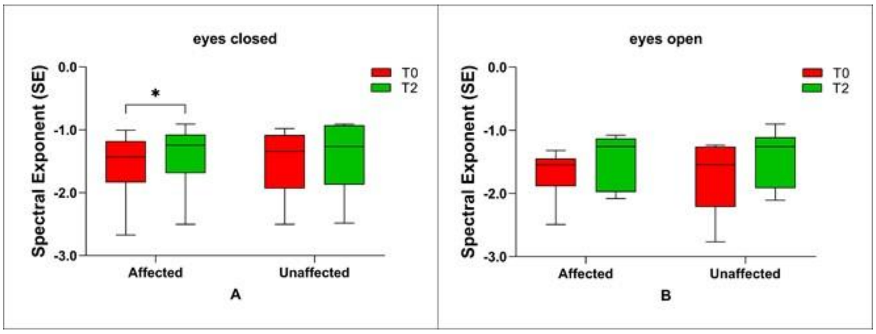

Figure 1 – Spectral Exponent (SE) index before (T0) and after (T2) the rehabilitation treatment.

DISCUSSION

These early findings support the responsiveness of the index to the intervention, supporting its use to better investigate the neuronal mechanisms involved in stroke rehabilitation.

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Using the HoloLens 2 position to improve the MIMU-based estimation of the foot position during level walking

I.G. Porco [1], A. Lazich [2,3], S.M.G. Solinas [1], C. Pes[1], M. Notarantonio [2], N. Balletti [2], S. Bertuletti [1], A. Cereatti [4], U. Della Croce [1]

[1] Department of Biomedical Sciences, University of Sassari, Italy, [2] Italian Joint Veteran Defense Center (Centro Veterani della Difesa), Rome, Italy, [3] DIAG, Sapienza University of Rome, Italy, [4] DET, Politecnico di Torino, Torino, Italy

INTRODUCTION

Magneto-inertial measurement units (MIMUs) have been extensively used to estimate temporal and spatial parameters of gait [1]. While temporal parameters are relatively easy to estimate, spatial parameters estimation is more challenging mostly due to the errors originating from the double integration of the linear accelerations recorded by the MIMUs. The determination of the integration initial conditions is one of the challenges that need to be faced to estimate the position of the MIMU. While an efficient method for the determination of the initial velocity was proposed in [2], the determination of the initial position of the MIMU remains an open issue.

The Microsoft HoloLens 2 is a mixed reality visor featuring a set of cameras and an embedded MIMU for reconstructing the surrounding space. By means of proprietary sensor fusion algorithms, the HoloLens 2 provides the position and orientation of the subject's head in the 3D space. In an augmented motor rehabilitation environment in which subjects wear the HoloLens 2 and two MIMUs on the feet, the determination of the instant in which the antero-posterior (AP) coordinate of the head and of each foot is coincident, makes possible the determination of the AP initial condition for the integration of the velocity so that the AP foot position could be estimated. In this work we identify the above-mentioned stance phase instant.

METHODS

Four healthy participants, wearing a HoloLens 2 and two MIMUs positioned on their feet, walked three times along a straight 10-meter walkway at three different speeds (slow, comfortable, and fast). In addition, four markers were attached to the HoloLens 2 (front, back and sides) and three markers were attached on each MIMU. A 12-camera stereophotogrammetric system (Vicon, Oxford, UK), including two video cameras, was used as reference (sampling frequency=100Hz). The AP position of the front HoloLens 2 marker ($HEAD_{AP}$) and the AP position of the centroid of the MIMU markers ($FOOT_{AP}$) were extracted from each trial. Heel strike and toe off timings were obtained from the visual analysis of the relevant recorded videos. Stride and stance durations of the middle gait cycle were therefore determined. The instant of stance in which $HEAD_{AP}$ and $FOOT_{AP}$ positions were coincident was also determined.

RESULTS

Table 1 shows the subject average over trials and sides of the stance percentage when $HEAD_{AP}$ and $FOOT_{AP}$ are coincident.

Table 1. Subject average stance percentage of equal head and MIMU AP position

walking speed / subject no.	1	2	3	4	**average**
Slow	34.6	36.8	34.1	35.2	**35.2**
Comfortable	35.9	36.9	35.6	36.6	**36.2**
Fast	36.0	37.9	34.9	35.9	**36.2**

DISCUSSION

The results of this study allow for the estimation of the AP coordinate of a MIMU on the foot during level walking while wearing a HoloLens 2. The value of the $HEAD_{AP}$ position at about 35%-36% of the stance phase can be used as the initial condition of the integration of the $MIMU_{AP}$ velocity obtained from the integration of the $MIMU_{AP}$ acceleration signal, to obtain the $MIMU_{AP}$ position throughout the gait cycle.

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The effectiveness of a soft passive trunk exoskeleton on the motor coordination in patients with cerebellar ataxia

A. Tatarelli[1,3], **M. Serrao**[2], **C. Casali**[2], **E. Cioffi**[1], **L. Fiori**[3,4], **T. Varrecchia**[3], **G. Chini**[3], **F. Draicchio**[3], **B. Montante**[5], **R. Ciancia**[5], **M. Michieli**[5], **M. Rupolo**[5], **A. Ranavolo**[3]

[1] *Department of Human Neurosciences, Sapienza University of Rome, Rome, Italy*

[2] *Department of Medico-Surgical Sciences and Biotechnologies, Sapienza University of Rome, Italy*

[3] *Department of Occupational and Environmental Medicine, Epidemiology and Hygiene, INAIL, Monte Porzio Catone, Rome, Italy*

[4] *Department of Physiology and Pharmacology, Sapienza University of Rome, Rome, Italy*

[5] *Oncology Reference Center (CRO), IRCCS, Aviano, Italy*

INTRODUCTION

Cerebellar ataxia's motor features show that mobility is substantially impaired due to incoordination between the head, trunk, and limbs, inability to make the necessary adjustments for balance control and coordination at the polyarticular level [1]. The aim of this study was to analyze the effectiveness of a soft passive trunk exoskeleton on motor coordination in patients with cerebellar ataxia.

METHODS

We collected data samples from 6 subjects with cerebellar ataxia. They performed walking tests at self-selected speed in laboratory with six infrared cameras optoelectronic motion analysis system. Twenty-six passive spherical markers were placed on prominent bony landmarks, according to a modified Davis' protocol [2]. We recorded sEMG signals from four muscles of the trunk and twelve of the right lower limb. The walking tests were performed in three conditions: without exoskeleton and with a more flexible and a less flexible exoskeleton. We calculated the muscle coactivation and the following synthesis parameters: Full Width at Half Maximum (FWHM) and the within subject Coefficient of Multiple Correlation (CMC_{WS}). We also calculated the Total Energy Consumption (TEC) and the fraction of mechanical energy recovered (R-step).

RESULTS

Figure1 shows the values obtained for the parameters calculated in the three conditions for the trunk and lower limb. The statistical analysis did not reveal statistically significant differences but it is possible to detect a trend.

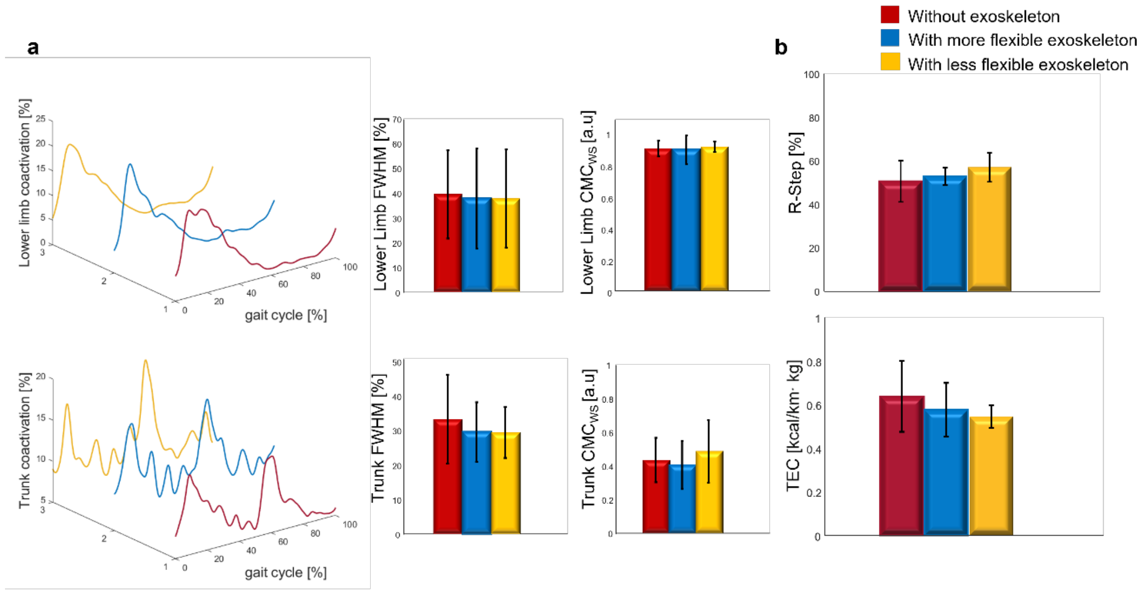

Figure 1. **a**: muscle coactivation curves in the three conditions and respective synthesis parameters for trunk and lower limb; **b**: R-Step and TEC parameters in the three conditions.

DISCUSSION

The results demonstrated the device's effectiveness, with the reduction in FWHM demonstrating that it can lower the amount of time that muscle co-activation persists over 50% of its maximum value. Moreover, the presence of the device allows the subject to have a similar muscular behavior in different walks, to recover more and spend less in terms of mechanical energy expenditure. As a result, the findings of this preliminary study confirm the effectiveness of the exoskeleton and allow its application in a rehabilitation route to be explored.

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Feasibility of interleaved stimulation in peroneal stimulators: the effect of surface electrode configuration on foot kinematics

M. Carbonaro[1], G. Agostinelli[1], G.L. Cerone[1], A. Botter[1]
[1] *LISiN, Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Torino, Italia*

INTRODUCTION

A peroneal stimulator is a neuroprosthetic device based on functional electrical stimulation (FES). It induces ankle dorsiflexion in the swing phase in patients affected by foot drop [1]. A well-known limitation of FES is the increased muscle fatigability due to the non-physiological motor unit (MU) activation. A possible approach to limit this issue is to interleave electrical pulses delivered to the muscle (*mstim*) and to the nerve (*nstim*) to distribute the stimulation among different MU groups [2], thus reducing the activation frequency of each group (interleaved stimulation). The practical applicability of this approach to peroneal stimulators requires that both *mstim* and *nstim* induce foot dorsiflexions (DFs) with minimal in-/eversion and ab-/adduction for all the knee angles within the swing phase. While for *mstim* knee rotations are not critical, changes in knee angle may modify the relative position between *nstim* electrodes and peroneal nerve, resulting in foot rotations outside the sagittal plane. Here we investigate the effect of *nstim* electrode positioning on induced foot rotations to identify the configuration leading to foot DF maximally similar to the voluntary ones for the entire knee ROM.

METHODS

We compared the electrically-induced foot movement for five nstim electrode positioning and four knee joint angles (0°, 20°, 40° and 60°, being 0° full knee extension) in ten healthy subjects. A grid of five cathodes was placed between fibular head and the tibial tuberosity (Figure 1A) while a large anode (56 cm^2) was located on the patella. For each knee angle, electrical stimulation was delivered at the five stimulation sites (pulse duration: 200 µs, frequency: 20 Hz) and foot rotations were quantified with an IMU positioned under the foot. Foot in-/eversion and ab-/adduction were compared with those measured during voluntary DFs at each angle

RESULTS

Figure 1B shows the ab-/adduction (Y-axes) and in-/eversion (X-axes) angles for each stimulation site (color-coded) and for the four knee angles in a representative subject. Red-dotted line delimits the acceptability area confining the angles obtained during voluntary DFs from all participants. All the points (stimulations) inside this area were regarded as producing a foot kinematic comparable to a voluntary DF. Figure c shows the number of subjects inside the acceptability area for all the stimulation configurations and knee angles. Collectively, configurations A and C included 7 out of 9 subjects, whilst for configurations D and E no subjects were inside the acceptability area for all knee angles.

DISCUSSION

We identified a common *nstim* electrode configuration that induced, in the majority of the participants, foot (DF) with minimal eversion and inversion for the knee angles within the swing phase. This is a necessary condition to ensure the applicability of stimulation strategies based on distributed nerve/muscle stimulation (interleaved stimulation) aimed at reducing muscle fatigue in FES-based foot drop treatments.

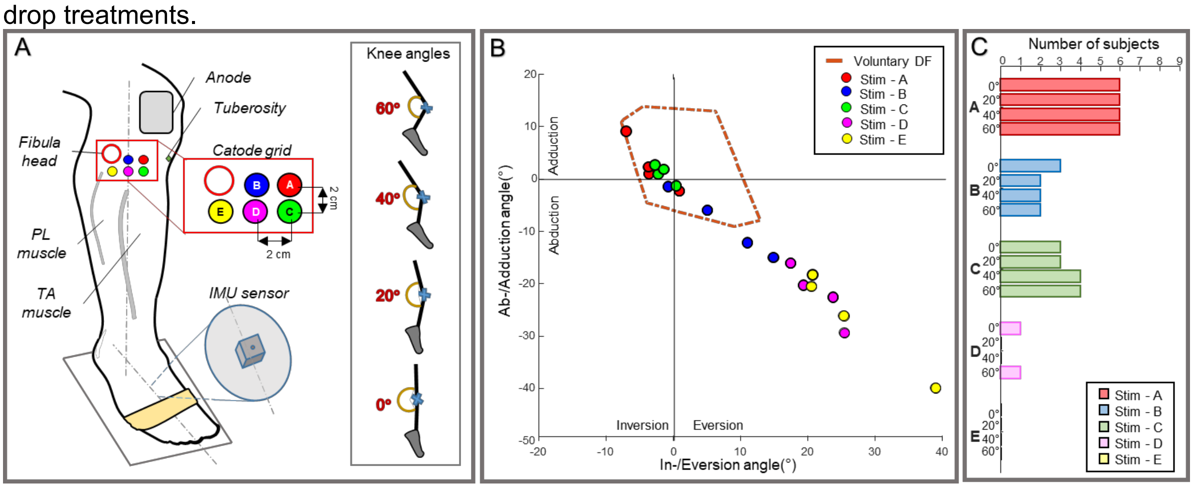

Figure 1. A. Experimental setup; B. Results from a representative subject. C. Group results.

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Use of inertial sensor system for upper limb motion analysis in obese subjects: preliminary setting and analysis

R. Monfrini[1], V. Cimolin[2], M. Galli[2], N. F. Lopomo[1]
[1]University of Brescia, Brescia, Italy; [2]Politecnico di Milano, Milano, Italy

INTRODUCTION

Obesity has been demonstrated to be a physical condition which heavily affects the possibility to realize daily activities, including not only walking but also trunk and upper limbs movements; in obese subjects (BMI > 30 kg/m2), the excessive mass could in fact limit/alter the capability of movement [1]. In this picture, quantitative analysis of human motion provides accurate measurements of both postures and movements, allowing to detect any biomechanical alterations due to overweight. At present, this assessment is usually performed by means of marker-based optoelectronic systems used within experimental environments; nonetheless, wearable equipment, like inertial measurement units (IMUs), might facilitate examinations in more ecological and daily-life conditions [2]. Although IMU performance has been highlighted in several applications related to human motion analysis, their use in obese subjects is still under discussion.

METHODS

In order to verify the agreement among the IMU-bases and marker-based systems, the procedure was preliminary tested on a control group of normal-weight subjects (15 women and 14 men, average age 23 years, BMI is 22.2 kg/m2); all the subjects gave their informed consent and the study was approved by the local IRB. Focusing on upper limbs, flexion and abduction movements were specifically acquired while performed at normal velocity and repeated six times for two trials. The acquisition was simultaneously performed by using an IMU-bases system (Awinda, Xsens, Netherlands) and a marker-based optoelectronic system (Smart DX400, BTSBioengineering, Italy). MVN and modified plug-in-gait protocol were exploited to obtain motion information [3]. Acquired data were specifically analyzed by using dedicated routines (Matlab, The Mathworks, US) to obtain coherent information. For each gesture the maximum and the minimum values of the angles were found, and the ranges of motion were computed. Statistical evaluation by t-test, Pearson's correlation and Bland-Altman plot was undertaken.

RESULTS

The curves representing the joint angles acquired with the systems look similar; their overall values are coherent with the movements under analysis (Figure 1). However, several differences were highlighted in terms of ranges – above all considering the shoulder joint -, thus leading to limited values of correlation and agreement.

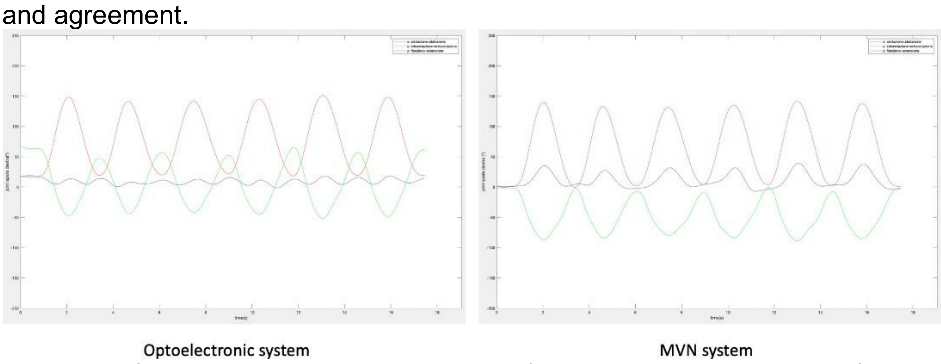

Figure 1. Euler angles of the shoulder during the abduction of the arm. The curves on the left were measured by means of an optoelectronic system, whereas the curves on the right with inertial measurement units.

DISCUSSION

Several differences were underlined between the two systems. This might be, above all, due to the complexity of the shoulder joints and to the kinematic model at the basis of the MVN system. Furthermore, several discrepancies in the definition of the anatomical references were highlighted and should be compensated. For these reasons, further analyses are required in order to use the IMU-based system in the application on obese subjects..

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Kinectome: an example of the network theory applied to motion analysis

E. Troisi Lopez[1], P. Sorrentino[2], M. Liparoti[3], R. Minino[1], A. Polverino[4], A. Romano[1], E. Amico[5], G. Sorrentino[1]
[1] Department of Motor Sciences and Wellness, University of Naples "Parthenope", Naples, Italy
[2] Institut de Neurosciences des Systèmes, Aix-Marseille Université, Marseille, France
[3] Department of Developmental and Social Psychology, University "La Sapienza" of Rome, Italy
[4] Institute for Diagnosis and Care, Hermitage Capodimonte, Naples, Italy
[5] Institute of Bioengineering, Center for Neuroprosthetics, EPFL, Geneva, Switzerland

INTRODUCTION
Human movement originates from a hierarchical and multisystemic organization, where the brain plans and regulates the activation of different muscles. Hence, body elements create movement patterns based on their kinematic mutual relationship. Consequently, an adequate movement analysis should account for those multiple synergies to capture kinematics patterns. Network science [1] adequately fit for this purpose. Considering body elements and their relationships as nodes and edges (i.e., links) of a network, we set out to build subject-specific network matrices, from which extracting relevant kinematic features.

METHODS
Gait cycles of sixty healthy subjects were recorded through a stereophotogrammetric system, and the changes of acceleration (i.e., jerk) of 21 reflective markers were calculated. The jerk time series of the markers were cross-correlated using Pearson's correlation, obtaining a matrix (that we named kinectome) for each participant, presenting the bone markers (as nodes) on each axis and the couple-interaction between all pairs of nodes as entries. Finally, different mathematical approaches were used to retrieve relevant information from kinectomes. Standard deviation was used to assess kinectomes' variability; data driven modularity analysis [2] was performed to assess anatomical kinematic modules; fingerprint analysis [3] was employed to check the extent to which each kinectome was subject-specific.

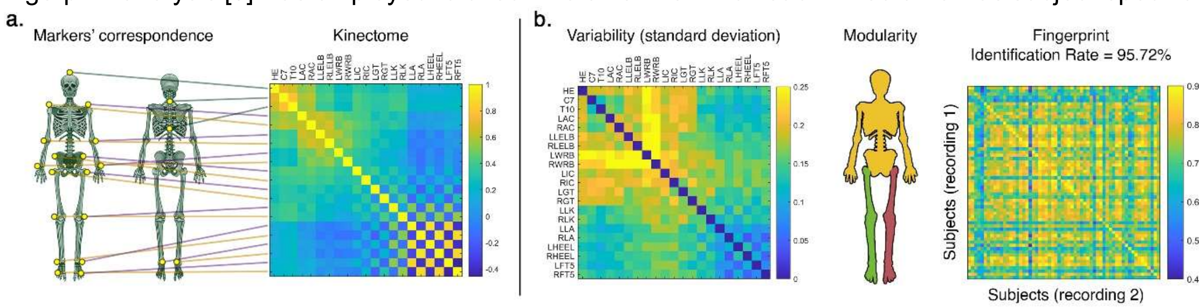

Figure: Kinectome map (a) and network-based analyses (b).

RESULTS
Standard deviation analysis showed that higher variability among participants involved head and arms movement with respect to the whole body. On the contrary, the movement pattern of the lower limbs resulted as the most stable part. Modularity analysis individuated three communities. The first includes the upper body, while the remaining two included the left and the right legs. Finally, fingerprint analysis showed that subjects' identification based on kinectome displayed a success rate above 95% for subject identification.

DISCUSSION
Our study showed that the kinectome is a handy tool on which is possible to apply several well-grounded mathematical approaches, able to reveal specific feature of individuals' movement pattern. We were able to identify which kinematic elements mostly differ among our participants. Furthermore, the modularity analysis highlighted legs and upper body clusters, according to the knowledge of passenger and locomotor units. Finally, the fingerprint analysis showed that each participant exhibited a unique pattern of movement that allows to identify them. We believe that this approach has the potential to find broad application in several fields of movement, from robotics to clinical analysis.

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Sessione 8 – Clinical applications of motion analysis Part 3

The effects of anterior cruciate ligament sacrifice on the behavior of theknee joint, tested through the use of a musculoskeletal model

L. Donno [1], C.A. Frigo [1]
[1] *Movement Biomechanics and Motor Control Lab - Politecnico di Milano, Milan, Italy*

INTRODUCTION

In usual knee joint arthroplasty, the insertion of the prosthetic components requires the removal of the anterior cruciate ligament (ACL), while the posterior cruciate (PCL) is retained. Since the balance of the knee joint ligaments is fundamental for a good functionality of the joint, it is important to know the effects of the ACL sacrifice. In a previous study [1] the tension of the knee joint ligaments was tested by simulating the typical maneuvers (anterior/posterior drawers, varus/valgus and internal/external rotation forcing) applied to a musculoskeletal model. In the present work the tests were repeated in the absence of the ACL, and the changes with respect to the 'all ligaments' condition were analyzed.

METHODS

The dynamic musculoskeletal model was described in previous publications [1, 2]. Briefly, it included femur, tibia and rotula, all collateral ligaments, subdivided in several bundles, and the two cruciate ligaments subdivided in their respective anterior and posterior components. The femoral condyles and the tibial plateaus were in contact and could slide one relatively to the other without penetration. External forces were applied to the tibial tuberosity to reproduce the anterior/posterior drawer. In this case the rotation of the tibia was constrained so that it could only translate. External torques were instead applied to reproduce the varus/valgus and the internal/external rotation maneuvers. The tests were conducted at different knee flexion angles: 0°, 20°, 60°, 90° and 135°.

RESULTS

The force/displacement and the moment/angle curves were analyzed in relation to respectively the anterior/posterior drawer test and the varus/valgus and internal/external rotation maneuvers. According to [3] the curves were separated into three portions: the central one corresponding to 'laxity', and the two extreme parts corresponding to 'stiffening'. In each portion the stiffness (slope of the curve) was computed and compared in the two modelling conditions: 'All ligaments' and 'ACL sacrificed'.
Table 1 reports an example of how the stiffness of the extreme portion of the curve changes during the anterior drawer test. In all the tested conditions the joint stiffness appeared less affected by the lack of the ACL when the knee was either fully extended (0°) or flexed to around 90°. During the drawer test, for angles of 20°, 60° and 135° the anterior stiffness was markedly reduced. Moreover, the laxity of the knee at 135° was about more than doubled during drawer test and doubled in internal/external maneuvers, in which also a strong reduction of the external terminal stiffness was obtained. In terms of medial-lateral stability the major impact of the severed ACL was recorded on valgus and varus terminal stiffness for flexion angles of 90° and 135° respectively.

Table 1. Anterior Terminal Stiffness [10^4 N/m] recorded during anterior/posterior drawer test.

	Knee flexion angle [°]				
	0°	**20°**	**60°**	**90°**	**135°**
ACL sacrificed	6.6	4.1	2.5	3.7	4.6
All ligaments	7.8	6.6	5.1	3.5	10.7
Ratio	0.85	0.62	0.49	1.06	0.43

DISCUSSION

Our results are in a good agreement with those obtained on cadaver studies by [3], and this further demonstrates the validity of the model implemented. The possibility to simulate a complete gait cycle by our musculoskeletal model will permit to extend the analysis to a dynamic condition which, of course, is impossible to reproduce in vitro with anatomical specimens.

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Gait Analysis for the evaluation of rehabilitation otucome in patients with obstructive sleep apnea syndrome

G. Pagano[1], M. Aliani[1], A. Diasparra[1], M. Genco[1], A. Coccia[2], M. Cesarelli[2], V. Proscia[1], G. D'Addio[1]

[1]*Clinical and Scientific Institutes Maugeri SPA SB Pavia, Italy*

[2]*Dept. of Electrical Engineering and Information Technologies University of Naples "Federico II", Naples, Italy*

INTRODUCTION

Obstructive Sleep Apnea (OSA) is a common sleeprelated breathing disorder characterized by discontinuous reduction or cessation of airflow. The OSA syndrome reduces the maximal aerobic capacity, increasing cardiovascular risk and functional limitation. The 6-Minutes Walking Test (6MWT) is used in clinical environment to assess the maximal exercise capacity in OSA patients, and also to monitor other physiological parameters during physical effort. The OSA syndrome reduces the maximal aerobic capacity, and this limitation can be associated with increased cardiovascular risks and reduced survival.

METHODS

Thirteen patients (4 women, 9 men) with obstructive sleep apnea syndrome, admitted for rehabilitation treatment in the Pneumology Rehabilitation Units of ICS Maugeri Institute of Care and Scientific Research in Bari (Italy) were involved in the experimental protocol. Participants underwent an instrumented 6MWT performed using the G-Walk system. The parameters of the instrumented 6MWT considered in the analysis are the following: 6MWT distance (m); symmetry index (%) and walking speed (m/s). Patients repeated the test twice: at baseline (T0) and after (T1) a period of rehabilitation lasting at least 7 days. The paired t-test was used to outline statistically significant difference between the paired samples at T0 and T1. The non- parametric paired t-test was used for the variables whose difference (T1-T0) clearly shows a non-gaussian distribution. The normality was tested by visual analysis of data distribution and through the Shapiro-Wilk normality test.

RESULTS

Table 1 reports data statistics, in terms of mean and standard deviation. The values are reported divided for time of acquisition, T0 or T1 and, limited to values of 6MWT, also pre and post the walking trial. In Table the results of the statistical analysis conducted by means of paired t-test are summarised. To assess the level of statistical significance of the p-values four different α values were considered ($p < 0.05$, $p < 0.01$, $p < 0.001$, $p < 0.0001$). The level of significance is reported in the Table using a different number of stars, while the absence of statistical significance ($p - \text{value} > 0.5$) is reported as ns.
Table 1 details the results of the statistical test performed on data measured pre and post the 6MWT.

Table 1. Data Statistics.

mean±std		**T0**	**T1**	**p-value**	**T0 vs T1**
Instumented 6MWT	Distance (m)	415 ± 89	458 ± 41	Distance (m)	**
	Simmetry Index (%)	91.4 ± 8.2	89.8 ± 12	Simmetry Index (%)	ns
	Walking Speed (m/s)	1.41 ± 0.27	1.37 ± .16	Walking Speed (m/s)	ns

DISCUSSION

The spatio-temporal and kinematic parameters extracted from the instrumented 6MWT show different behaviours.
The 6MWT distance is significantly increased in T1 with respect to the baseline time, while the symmetry index and the mean walking speed do not show significant variations after the rehabilitation period. This suggests that the endurance training has an effect on physical resistance during walking, in accordance with previous findings, but does not significantly affect biomechanics of gait.

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An automatic procedure to classify biomechanical risk classes associated to lifting activities according to the Revised NIOSH Lifting Equation

L. Donisi[1,2], G. Cesarelli[1,2], E. Capodaglio[2], G. Pagano[2], M. Cesarelli[1,2], M. Panigazzi[2], G.D'Addio[2]
[1] *University of Naples Federico II, Naples, Italy,* [2] *IRCCS ICS Maugeri, Pavia, Italia*

INTRODUCTION

In the field of occupational medicine, physical ergonomics studies, aimed at preventing work-related illnesses, have gained importance in recent years since both quantitative/semi-quantitative observational studies and instrumental methods have reported promising results. Among the instrumental methods, wearable devices capable to acquire signals such as acceleration and angular velocity, electromyography (EMG) [1] have potentially proved useful to help assessing – both automatically and more accurately – the work-related risk, which can lead to biomechanical overloading and the development of work-related musculoskeletal disorders (WRMD), especially in the case of workers involved in activities such as material handling and lifting tasks.

METHODS

In this context, a powerful method to monitor workers biomechanical risk is a National Institute for Occupational Safety and Health (NIOSH) quantitative formula (RNLE), which considers factors such as intensity, duration and frequency (together with other geometrical characteristics) of a lifting task [2]. The study was carried out enrolling 13 healthy subjects with no signs of musculoskeletal disorder wearing an inertial sensor (Opal, APDM Inc.) on the chest. Each subject performed a session based on two trials. Each trial consisted in 20 consecutive lifting of a plastic container. The first trial was performed in a condition with LI < 1 which corresponds to the No-risk class while the second trial was performed in a condition with LI > 1 which correspond to the Risk class. LI of 0.5 and 1.3 were derived from the RNLE by variously combining height, frequency and weight of lifting tasks. The collected acceleration and angular velocity signals along the three axes were filtered and then segmented to extract the region of interest (ROI) corresponding to the lifting by means of the Savitzky-Golay filter. For each ROI several features in the time and frequency domains were extracted and feed to machine learning algorithms to evaluate the discriminative power of these features to classify risk classes according to the RNLE.

RESULTS

Table 1 shows the results of the machine learning (ML) analysis by means of some evaluation metrics using different ML algorithms. The ML analysis was carried out on a dataset composed of 520 instances (13 subject x 40 lifting), 114 features (19 features x 6 axes) and two classes (No-risk, risk).

Table 1. Metrics' scores using hold-out validation and hyperparameters optimization.

Algorithms	**Accuracy**	**F-measure**	**AucRoc**
Random Forest	0.91	0.91	0.97
Decision Tree	0.87	0.87	0.88
k-nearest neighbors	0.88	0.88	0.93
Naïve-Bayes	0.80	0.79	0.85

DISCUSSION

The goal of this research was to develop an automatic procedure - based on algorithms for digital signal processing and ML algorithms fed with appropriate time and frequency domains features extracted from sternum inertial data – able to classify lifting biomechanical risk classes according to the RNLE. The results of the ML analysis, especially Random Forest, showed high scores in evaluation metrics. The presented methodology could represent a valid integration to the conventional protocols used in ergonomics to evaluate the biomechanical risk more quickly and easily. These results are of direct practical relevance for occupational ergonomics, as they present the opportunity for automatic, economic and non-invasive (by placing an IMU on the sternum) detection of the risk associated with lifting. Future investigation on enriched dataset that will involve several scenarios and risk classes could confirm the potentiality of the proposed methodology.

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Effects of Cerebellar Transcranial Alternating Current Stimulation on Gait and Balance inHealthy Subjects

V.Sveva[1], A. Guerra[2,3], G. Cusolito[1], E. Di Lorenzo[1], L. Del Vecchio[1], M. Mangone[1], A. Berardelli[2,3], M.Bologna[2,3], M.Paoloni[1]

[1]Department of Anatomical and Histological Sciences, Legal Medicine and Orthopedics, Sapienza University, Piazzale Aldo Moro 5, 00185 Rome, Italy; [2]Department ofHuman Neurosciences, Sapienza University of Rome, Viale dell'Università 30, 00185 Rome, Italy; [3]IRCCS Neuromed, Via Atinense 18, 86077 Pozzilli, IS, Italy.

INTRODUCTION

Transcranial Alternating Current Stimulation (tACS) is a non-invasive brain stimulation technique [1] able to modulate neural oscillatory activities, including those linked to the cortico-cerebello-thalamo-cortical network [2, 3]. In this double-blind sham-controlled study, we aimed to investigate the effects of cerebellar tACS delivered at theta and gamma frequencies on gait and balance in healthy subjects, as assessed by kinematic techniques.

METHODS

In a group of young healthy subjects, we applied tACS over the dominant cerebellar hemisphere during the execution of three different motor tasks: 1) standing (both with eyes open and closed); 2) gait initiation (assessed both for the dominant and non-dominant lower limb); 3) 5-meter walk test (5MWT) (Figure 1). tACS was delivered in a random order at the theta (5 Hz, theta-tACS) and gamma (50Hz, gamma-tACS) frequencies, and sham-tACS was used as a control condition. The stimulation intensity was set at 1,5mA and the stimulation duration lasted as long as the motor task was accomplished. Kinematic data were obtained using a force platform and an optoelectronic system. The data analysis was conducted using a dedicated software.

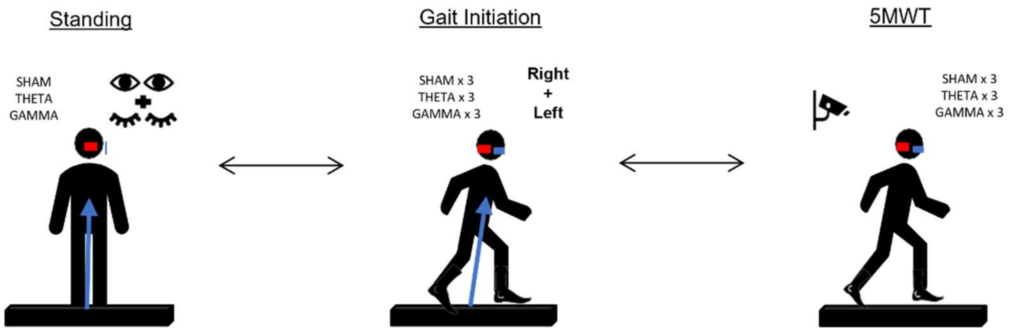

Figure 1. Experimental Design. tACS montage: one electrode was centered 1 cm below and 3 cm lateral to the inion over the dominant cerebellar hemisphere (red) and the other was placed over the ipsilateral buccinator muscle (blue). Three tasks were recorded and averaged for each stimulating condition. we waited at least twice the duration of the stimulation time before conducting the task in a different stimulation condition. 5MTW, 5-meter walk test.

RESULTS

Theta-tACS induced a significant reduction of the Centre Of Pressure (COP) displacement during standing with eyes closed compared to sham- and gamma-tACS (mean radius displacement: theta-tACS 4.65±0.74mm, gamma-tACS 5.58±1.26mm, sham-tACS 5.99±2.12mm). A similar, though weaker, trend was present in the eyes open condition. Furthermore, stride width during 5MWT resulted tighter during theta-tACS compared to sham- and gamma tACS.

DISCUSSION

Boosting theta oscillations in the cerebellum through tACS improves balance during standing and gait in healthy subjects. This effect may rely on the modulation of the activity of cerebellar neurons resonant to the theta rhythm. This non-invasive neuromodulation approach could be applied in neurological conditions characterized by ataxia to possibly ameliorate the imbalance and reduce the risk of falling.

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Muscle activation timing and knee biomechanics during single leg hop in subjects with and without anterior cruciate ligament reconstruction: a case study

A.Baldazzi [1], C.Bosio [1,2], L. Rum [1], H. Pillet [2], F. Margheritini [1], A. Macaluso [1], E. Bergamini [1]
[1] University of Rome "Foro Italico", Rome, Italy, [2] Arts et Métiers ParisTech, Paris, France

INTRODUCTION

The Single Leg Hop test (SLHT) is commonly performed to determine readiness to return to sport (RTS) after anterior cruciate ligament (ACL) injury and reconstruction [1]. Usually, the between-limb symmetry of hop distance is considered as a criterion to clear the athletes to RTS. However, athletes may pass this criterion despite ongoing biomechanical and neuromuscular deficits. Several works developed an instrumented approach of the SLHT to assess biomechanical parameters associated to ACL injury risk [1]. Although it is known that muscle pre-activation timing during landing can be altered in patients with ACL reconstruction (ACLR) [2], thus exposing them to a reinjury risk, very few studies have related biomechanical parameters with electromyographic (EMG) signals of the involved muscles. The aim of this preliminary study is to assess muscle pre-activation timing prior to SLHT landing in both ACLR and HC athletes and to associate this information with ACL injury-related kinematic and kinetic parameters.

METHODS

Two male soccer athletes (Tegner Activity Score ≥ 6) participated in the study, one healthy (HC) and one with ACLR (12 months before the test; injured limb: left). They performed three SLHT landing on a force plate (AMTI, USA, 1000 Hz) after standardized warm-up. The 3D trajectories of 52 markers were measured by an optoelectronic system (Vicon, 200 Hz) [3]. Eight wireless bipolar EMG electrodes (MiniWave, Cometa, Italy) were placed on Vastus Medialis (VM), Vastus Laterialis (VL), Semitendinous (ST) and Biceps femoris (BF) on both limbs according to the SENIAM guidelines [4]. All instruments were electronically synchronized. Foot-force plate contact was identified by setting a threshold of 20 N on the vertical GRF (vGRF) [5]. EMG onset prior to landing was identified according to [2]. A set of ACL injury risk-related parameters were then extracted: peak vGRF ($vGRF_{peak}$), peak knee flexion and abduction moment ($KMflex_{peak}$ $KMabd_{peak}$), and knee flexion at initial contact (KflexIC). Also, for each SLHT, the hop distance was assessed (SLH_{dist}). The Limb Symmetry Index (LSI) was then calculated for each parameter. For each athlete and each limb, the SLH with the greater hopping distance was considered for further data processing.

RESULTS

Muscle pre-activation timing was shorter in ACLR subject than HC in all muscles (Table 1). ACLR subject also showed higher values in peak knee moments, especially in the injured limb, as well as greater asymmetry for most of the investigated parameters, especially knee angles and moments.

Table 1. Distance, Kinematic, Kinetic and EMG parameters assessed during landing

		SLHdist (cm)	vGRFpeak (N/kg)	KMflexpeak (Nm/kg)	KMabdpeak (Nm/kg)	KflexIC (°)	EMG onset prior landing (ms)			
							VM	VL	BF	ST
ACLR_01	**R**	**173,0**	**4.2**	**4.0**	**0.9**	**24.4**	**166**	**162**	**118**	**126**
	L	156,5	4.1	6.3	1.8	18.7	146	136	116	129
	LSI	90.5	97.6	155.6	200	76.6	88.2	83.7	98,8	103
HC_01	R	130,0	3.6	4.9	0.5	15.9	203	196	175	156
	L	**144,0**	**3.8**	**4.0**	**0.5**	**19.3**	**182**	**176**	**161**	**177**
	LSI	90.3	94.7	122.5	100.0	82.4	111.7	111.4	108.8	88

DISCUSSION

In the ACLR subject, the lower muscle pre-activation timing prior to landing may lead to an uncoordinated movement and to a deficit in muscle force generation to stabilize the joint, thus increasing knee injury risk [2]. This timing was even shorter in the injured limb. From a biomechanical point of view, a greater asymmetry was found in the ACLR subject with respect to the HC in both kinematic and kinetic parameters. On the contrary, hop distance LSI did not show any clear difference between the two participants. These results corroborate the hypothesis that evaluating only hop distance is reductive.

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Kinematic and electromyographic evaluation of forward bending in patients with chronic low back pain

L. Berti[1,2], L. Labanca[1], V. Ghirardo[2], R. Tedeschi[2], E. Cappelli[2], M. Cafalli[3], L. D'Auria[2], L. Bragonzoni[1,2], G. Zuccarello[2], M.G. Benedetti[1,2]
[1] *IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy,* [2] *Università di Bologna, Bologna, Italy,* [3]*Università di Pisa, Pisa, Italy*

INTRODUCTION

Instrumental evaluation of patients with low back pain (LBP) is essential for clinical assessment. Forward bending is a very common movement in the activities of daily living and is strongly related to pain. Patients with LBP show abnormalities in kinematics during the performance of forward bending, but there is no agreement on kinematic measures which should be used for clinical assessment [1]. In addition, the abnormalities of lumbar muscles activation need further investigation since a number of electromyographic (EMG) parameters, such as the absence of the flexion-relaxation phenomenon (FRP), have been associated with LBP [2,3]. Thus, the aim of this study was to assess trunk kinematics and lumbar muscles EMG activity during forward bending in patients with chronic LBP.

METHODS

Eight patients, 4 males and 4 females (age: 36.3±11.4 years; body mass: 75.3±7 kg; height: 174±4 cm), with chronic LBP were recruited. Six healthy control participants, 3 males and 3 females (age: 30.7±5.6 years; body mass: 67.7±12 kg; height: 170±5 cm), served as a control group. LBP was quantified by means of a visual analogue scale (VAS). The Schober test was performed to assess the flexibility of the lumbar spine. Kinematics of the trunk and EMG activity of lumbar muscles were recorded while participants were asked to perform a forward bending of the trunk (Figure 1) at a self-selected speed. They were asked to maintain the flexed position for 3 seconds and then to perform a back extension. Wireless EMG probes (Freeemg 1000, BTS Bioengineering) were applied over left and right longissimus dorsi (LD) and multifidus (MF) muscles. An inertial sensor (G-sensor, BTS Bioengineering) was applied between the shoulder blades by means of an elastic belt. The FRP was calculated as the difference between the standing and the maximum flexion 1-second root-mean square of the EMG signals. The flexion relaxation ratio (FRR) was calculated as the difference between the trunk flexion and the maximum flexion 1-second root-mean square of the EMG signals. Finally, the maximum angle of flexion (MAF) was calculated. A one-way ANOVA was used to assess between-group differences.

RESULTS

Patients with LBP showed higher VAS than control participants (6.4 ± 1.1 vs. 0 ± 0; $p < 0.001$). There was a trend to significance for the MAF to be higher in control group than LBP patients (97.2° ± 16.1° vs. 110.8° ± 20.4°; $p = 0.05$). FRP of LD muscle was observed in all the 6 participants of control group and in 4 out of 8 LBP patients, while for the MF muscle was observed in 4 out of 6 participants in the control group and in 2 out of 8 LBP patients. FRR was higher in LD muscle of control group in comparison with LBP patients. No significant differences were found for flexibility of the spine (LBP patients = 4.2 ± 1.5 cm; control group = 5.0 ± 0 cm).

Figure 1. One of the participants performing the forward bending task.

DISCUSSION

Patients with LBP show kinematics and EMG abnormalities during the performance of forward bending of the trunk. The assessment of the reduction of the maximum flexion of the trunk and abnormalities of the FRP and FRR of lumbar muscles by means of inertial sensors and EMG are useful to quantify LBP related impairments in clinical practice. Further investigations with larger sample of participants are needed to confirm these preliminary results.

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Motor inhibition parameters are reflected in the kinetic and kinematic of gait initiation in a step version of the Stop Signal Task

L. Fiori[1,2,3], I. B. Marc[1,2], S. Ramawat[1,2], A. Tatarelli[3,4], T. Varrecchia[3], G. Chini[3], A. Ranavolo[3], F. Draicchio[3], P. Pani[1], S. Ferraina[1], E. Brunamonti[1]
[1]*Department of Physiology and Pharmacology, Sapienza University of Rome, Rome, Italy*
[2]*PhD program in Behavioral Neuroscience, Sapienza University of Rome, Rome, Italy*
[3]*Department of Occupational and Environmental Medicine, Epidemiology and Hygiene, INAIL*
[4]*Department of Human Neurosciences, Sapienza University of Rome, Rome, Italy*

INTRODUCTION

Interacting with a continuously changing environment may necessitate cancelling a programmed movement, such as a step, after an environmental change to avoid errors and possible falls. This cancellation is successful if it occurs during the few milliseconds from the Anticipatory Postural Adjustments (APA) that precede the step onset, a period in which the center of mass (CoM) and the center of pressure (CoP) can still be aligned. Here we studied the inhibition of steps by the means of Stop Signal Task (SST), a behavioral task matched with a theoretical model developed to study the behavioral and physiological correlates of simple response inhibition [1], e.g., pressing a button. Aim of the present work was investigating if and how the inhibition of a complex multi-effectors movement as in step, accomplishes the assumptions of the model developed for simpler movements and if it is they are reflected in the time evolution of CoM and CoP.

METHODS

12 healthy subjects (age: 33.3±7.1 y; weight: 69.3±17 kg; height: 169.7±8.2 cm) were required to initiate 300 walks from a stationary position (Go trials; GT) in response to the onset of an ahead pointing arrow (Go signal) on a pc monitor, and to interrupt the movement when in 30% of the trials (Stop trials; ST), a road stop signal (Stop signal) replaced the arrow after a variable time, determined using a behavioral tracking staircase algorithm [2]. A stereo-photogrammetric motion analysis system (SMART-DX 6000: BTS) and eight dynamometer platforms (Kistler 9286B; Kistler) were used to detect the kinematic and dynamic parameters of gait initiation. Ad-hoc analysis algorithms were developed by the MATLAB software (R2019b 9.7; MathWorks) to track the time evolution of CoM and CoP trajectories and capture the related reaction times (RT) for GT, error stop trials (eST), and correct stop trials (cST), and to conduct the statistical analysis.

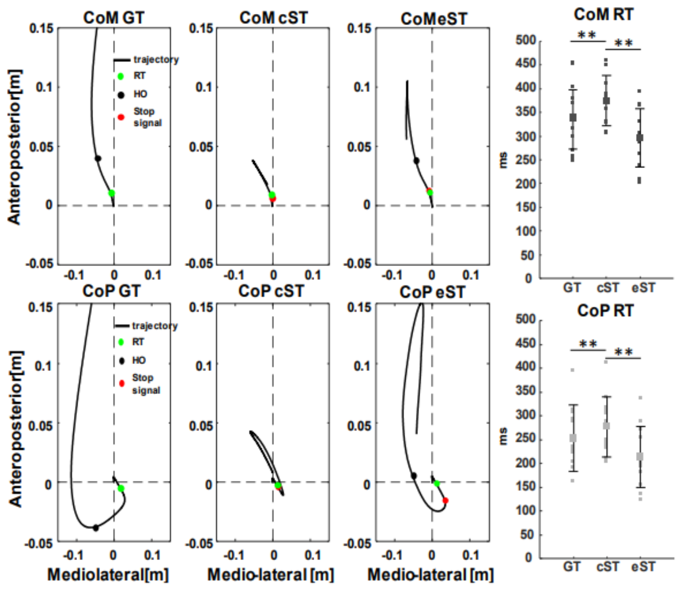

Figure 1 The trajectories CoM and CoP of go trials (GT), error stop trial (eST), and correct stop trial (cST), and corresponding reaction times (RTs).

RESULTS

Figure 1 displays the CoM (left upper panels) and CoP (left lower panels) trajectories in GT, eST, and cST, and the computed corresponding RT (rightmost panels). A repeated measures ANOVA and post-hoc tests detected ($p<0.001$), for both CoM and CoP, a significantly slowest RTs in cST (CoM=375±53ms; CoP=277±64ms), faster RT in GT (CoM=335±62ms; CoP=253±70ms), and the even faster in RT during the eST (CoM=296±61ms; CoP=213±64ms).

DISCUSSION

By tracking the time evolution of CoM and CoP in a step version of the SST we obtained, during APA, a measure of RT, not only in GT and eST trials, but even in cST, a parameter hidden in the typical experimental setup. With these variables, we detected that the outcome of our version of SST complied with the main assumption of the race model: a movement is successfully cancelled when a stop process wins the race being faster than a go process. Accordingly, here we observed the eST were the trials approaching the race with significantly faster RT than cST. These results provide evidence that our version of SST is a valid tool for studying inhibition of complex movements and the associated kinematic variables.

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Characterization of infants' general movements based on a single RGB-Depth camera: a feasibility study

D. Balta [1], H.H. Kuo [2], J. Wang [2], I.G. Porco [3], M.M. Schladen [2], A. Cereatti [1], P.S. Lum [2], U. Della Croce [3]
[1] DET, Politecnico di Torino, Torino, Italy, [2] Department of Biomedical Engineering, The Catholic University of America, Washington, United States of America, [3] Department of Biomedical Sciences, University of Sassari, Sassari, Italy

INTRODUCTION

Movements in infants have age-specific characteristics which could be quantified by extracting specific metrics based on the kinematics of General Movements (GM). For this purpose, a number of metrics have been proposed [1-2]. However the latter have been often obtained using complex and expensive experimental setups. The aim of this study was to evaluate if a simple experimental setup associated (RGB-D camera) with a suitable signal processing (a purposely modified markerless method - MLM) can be used to characterize the GM with the above-mentioned metrics.

METHODS

Data from three typically developing infants sitting in a baby seat were acquired at 3, 4 and 5 months from birth with a single RGB-D camera with depth obtained from a stereoscopic view of two infrared sensors (Intel RealSense D435). Each acquisition lasted three minutes. First, the video and depth data alignment was guaranteed using a purposely developed method, then an automatic tracking algorithm (DeepLabCut [3]) was used to estimate the locations of six points of interest (PoI) for both left and right upper body sides (shoulder, elbow and wrist). The 3D position of PoIs tracked in the RGB images was obtained by exploiting the depth data. Erroneous values were found when one or more of the following situations occurred: 1) a residual spatial misalignment between RGB and depth images, 2) a 'black' area in the depth images caused by the different points of view of the two infrared sensors and 3) PoIs were occluded by a body segment. Such erroneous values were replaced by applying a cubic spline interpolation to obtain the 3D trajectories of the PoIs. The periodicity index of the wrist trajectories, the area in which the wrist velocity profiles fall outside the standard deviation band of their moving average and the skewness of the wrist velocity were then determined [1].

RESULTS

Results are shown in Table 1.

Table 1. Values of the selected metrics for each infant at each timepoint.

Metric / Timepoint	***3 months***			***4 months***			***5 months***		
	Sub1	*Sub2*	*Sub3*	*Sub1*	*Sub2*	*Sub3*	*Sub1*	*Sub2*	*Sub3*
Periodicity Index	0.05	0.05	0.04	0.05	0.03	0.06	0.04	0.04	0.05
Area $[m * frame]$	8.23	15.1	13.3	6.04	7.26	15.4	14.1	8.7	16.7
Skewness	35.2	37.3	23.8	45.5	38.2	20.8	38.9	31.6	37.1

DISCUSSION

This work has shown that the infants' GM could be characterized with a simple experimental setup, therefore giving parents the possibility of performing such evaluations at home with a higher frequency than currently possible in clinical facilities. This would allow an earlier detection of the appearance of GM anomalies. Additional work is needed to streamline the process and reduce the processing time while developing protocols for improving the acceptance and reliability of parents' participation.

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info@siamoc2022.it

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