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Critical spatiotemporal gait parameters for individuals with dementia: A systematic review and meta-analysis

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Instrumented gait analysis allows for the identification of walking parameters to predict cognitive decline and the worsening of dementia. The aim of this study was to perform a meta-analysis to better clarify which gait parameters are affected or modified with the progression of the dementia in a larger sample, as well as which gait assessment conditions (single-task or dual-task conditions) would be more sensitive to reflect the influence of dementia. Literature searches were conducted with the keywords "quantitative gait" OR "gait analysis" AND "dementia" AND "single-task" AND "dual-task," and for "quantitative gait" OR "gait analysis" AND "dementia" AND "fall risk" on PubMed, EMBASE, the Cochrane Library, Scopus, and Web of Science. The results were used to perform a systematic review focussing on instrumental quantitative assessment of the walking of patients with dementia, during both single and dual tasks. The search was performed independently by two authors (C. R. and C. M.) from January 2018 to April 2020 using the PICOS criteria. Nine publications met the inclusion criteria and were included in the systematic review. Our meta-analysis showed that during a single task, most of the spatiotemporal parameters of gait discriminated best

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between patients with dementia and healthy controls, including speed, cadence, stride length, stride time, stride time variability, and stance time. In dual tasks, only speed, stride length, and stride time variability discriminated between the two groups. In addition, compared with spatial parameters (e.g. stride length), some temporal gait parameters were more correlated to the risk of falls during the comfortable walking in a single task, such as cadence, stride time, stride time variability, and stance time. During a dual task, only the variability of stride time was associated with the risk of falls.

Keywords: Gait; analysis; dementia; task performance; falls.

Introduction

Motor and cognitive functions share neuroanatomical structures and psychological processes.[1,2] Therefore, people with dementia not only have memory and cognitive dysfunctions, but also movement and executive disorders, which seem to follow a retrograde progression, according to the phenomenon of "retrogenesis."[3]

Observational gait analyses of patients with dementia grossly show slowness, static and dynamic instability, abnormal posture, and a wide basis of support. Instrumented gait analysis using optoelectronic systems or wearable technology allows for a more precise estimation of dementia-related modifications in walking.[4,5]

Some studies suggest that modifications of gait parameters are relevant for predicting cognitive decline and the worsening of dementia, and this information could be used to develop specific interventions to prevent further functional decline and falls, as well as to follow rehabilitation progress of patients.[4,5] In addition, specific profiles of gait impairment have been related to the stage and type of cognitive impairment.[6] Therefore, instrumented gait analysis seems to be a useful tool for obtaining more specific and subclinical information about the progression of dementia.

Performing dual tasks could modify the postural balance and the fluidity of gait. Thus, modifications of the gait characteristics of patients with dementia could be used to identify those who are suffering from deficient executive function and a higher risk of falls.[7,8] Furthermore, gait analysis could provide an early assessment of the risk of falls and of the dynamic instability, especially during the execution of dual tasks.[9–11]

The most frequently analyzed spatiotemporal parameters in the current literature are related to variables reflecting gait rhythm, pace, and variability.[4,5,12–18] The parameters reflecting gait rhythm are temporal variables of the duration of gait phases relative to the gait cycle, such as the swing time, stance time, stride time, and cadence. The pace domain includes parameters related to walking speed and displacement in the sagittal plane, such as gait speed and stride length.

Gait variability (CV) is measured as the coefficient of variance and is defined as the fluctuation in spatiotemporal characteristics between steps. Gait variability is a sensitive indicator of mobility deficits and risk of falls.[19] The parameters most used for gait variability in the current literature are stride length CV, swing time CV, and stance time CV.[4,5,14,15,18]

However, kinetic and kinematic data have been studied less, due to the technical difficulties in obtaining recordings from patients. In this regard, only a few studies have been devoted to investigating the kinematic data in terms of joint excursions of the hip, knee, and ankle.[20,21]

We systematically reviewed the literature on gait analysis and dementia from January 2003, when the last review on the same topic was performed,[22] to April 2020. In this period, several studies were examined both walking alone (single task)[4,5,12–18] and walking while performing another action (dual task).[4,12–14,17] More recently, spatiotemporal parameters assessed by gait analysis under dual-task conditions were introduced. In the review from 2003,[22] only one article evaluated the effect of performing dual task among seven people with dementia.

The dual-task condition could be used as a screening tool for detecting Alzheimer's dementia at an early stage,[4] although other studies and clinical trials are needed. However, it is not fully understood which gait parameters are actually correlated to dementia and can be considered as predictive signs of cognitive decline and worsening of disease.

Therefore, the aim of this study was to perform a meta-analysis to better clarify which gait

parameters are affected or modified with the progression of the disease in a larger sample, as well as which gait assessment conditions (single-task or dual-task conditions) are more sensitive to reflect the influence of dementia. All of this information could be interesting for both to identifying gait abnormalities and developing specific rehabilitation interventions to better control postural instability and reduce the risk of falls.

Methods

Search strategy

A search was performed on the following electronic medical databases: PubMed, EMBASE, the Cochrane Library, Scopus, and Web of Science. The reference lists of the related articles were also used to search for other eligible papers. The search strategy was conducted from January 2018 to April 2020. We searched for the following terms and keywords: "quantitative gait" OR "gait analysis" AND "dementia" AND "single-task" AND "dual-task," and for "quantitative gait" OR "gait analysis" AND "dementia" AND "fall risk."

Selection criteria and data extraction

From 2003 to 2020, the database searches yielded 751 references from the first search, 1426 from the second search, and 71 from the third research. The titles and abstracts of these studies were screened and 209 selected papers remained for full text screening. The eligibility of the studies for inclusion was assessed independently.

Nine publications met the inclusion criteria and were included in the meta-analysis, and 187 articles were excluded for the following reasons: 24 examined neurological disorders other than dementia or the diagnosis of dementia, 89 were on preclinical stages of dementia and mild cognitive impairment, 28 did not include gait analysis as an instrumental assessment, and 46 presented results that were not useful for the meta-analysis (Fig. 1). We included original articles published in English about gait analysis on subjects with a confirmed diagnosis of dementia who underwent gait analysis obtained by instrumented systems (i.e. electronic walkways, wearable sensors, and stereophotogrammetric systems). We excluded animal studies and those regarding preclinical stages of dementia and mild cognitive impairment.

We included studies that compared mild cognitive impairment with dementia. Furthermore, studies were excluded if they had participants with

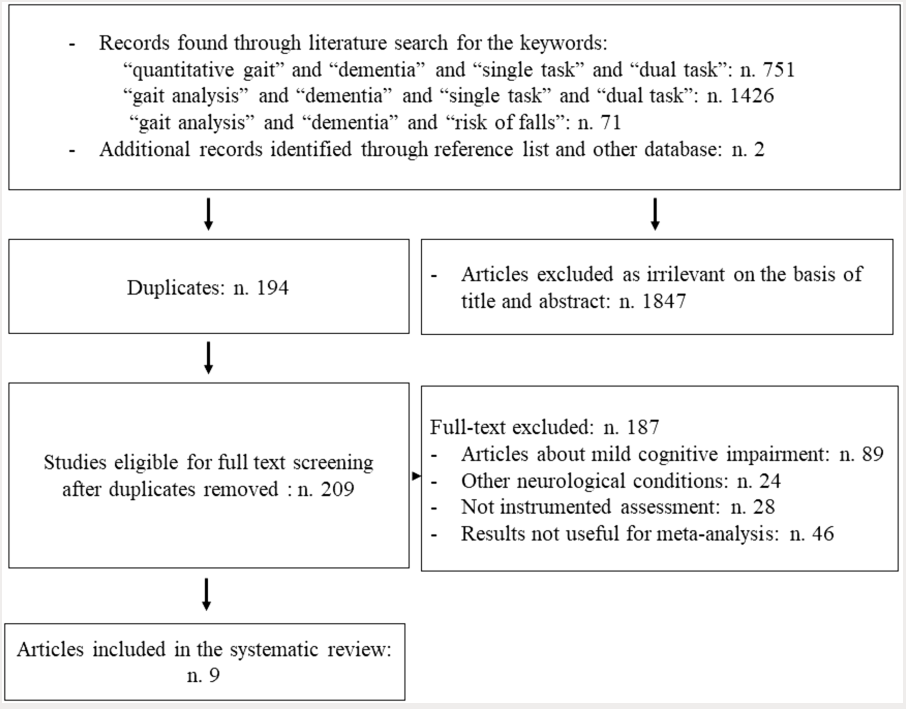

Fig. 1. Flowchart of the process of initial literature search and extraction of studies meeting the inclusion criteria.

other neurological diseases and comorbidity gait disorders (e.g. Parkinson's disease). The other exclusion criteria were the use of qualitative results and arbitrary units, such as symmetry and regularity, and the use of statistical values without the mean values of each parameter, that is, we excluded articles that did not provide data useful for the meta-analysis (i.e. the mean and standard deviation). We also excluded all of the duplicate studies and unpublished data.

Our meta-analysis focussed on gait parameters that were reported in more than one article.

We included studies that investigated the abnormal parameters in gait analysis in people with dementia conditions, including Alzheimer's disease,[4,5,12–16] frontotemporal dementia,[17] and other types of dementia, such as vascular dementia.[5,18]

In order to identify the eligible studies, the reviewers (C. R. and C. M.) independently screened the titles and abstracts from the initial search. In cases of conflicting opinions, consensus was reached after discussion between the authors. Selected full texts were then reviewed and included in the systematic review in accordance with the PRISMA protocol,[23] the MOOSE checklist,[24] and the PICOS[25] (population, intervention, comparison, outcome, and study design) criteria. As shown in Table 1, the participants were aging adults; the interventions were based on rehabilitation in dementia; and comparator could be any comparator. The outcomes included clinical assessments, diagnostic scales, and gait analysis parameters, and the study designs were RCTs and observational studies.

The gait data were obtained during the first evaluation (at zero time) of comfortable walking, without assistive devices or other signs and symptoms, such as extra-pyramidal signs, which could have influenced gait performance. The gait data included spatiotemporal gait variables such as gait speed, step length, stride length, stride length CV, and cadence, as well as stability parameters such as swing, stance time, and CVs of stance and swing time.

Allali *et al.*[17] compared gait parameters of a group of patients with Alzheimer disease with a group of healthy controls. They also compared a group of patients affected by frontotemporal dementia with a control group. Both samples were analyzed separately and assessed twice in the meta-analysis. Lin *et al.*[4] and Muir *et al.*[14] assessed gait with some additional cognitive tasks. The dual-task condition used by Lin *et al.*[4] consisted of walking while counting backwards by one and counting forward, whereas Muir *et al.*[14] used naming animals, counting backwards by one and counting backwards by seven. In our study, we assessed gait parameters under different dual-task conditions and analyzed the results of these authors separately.[4,14]

Meta-analysis calculations

The Statistical Package for Social Sciences (SPSS, Version 18.0 for Windows; SPSS Inc., Chicago, IL, USA) was used for data analysis. The outcomes were considered as continuous data measured on the same scale expressed as a mean value and standard deviation (SD) and analyzed using standard mean differences (SMDs). We verified the impact of study heterogeneity on the results of the meta-analysis using the I^2 test for inconsistency (percentages and p-values under 0.05 were considered significant). An I^2 value $< 25\%$ was considered to indicate low risk of heterogeneity. A value between 25% and 50% was considered indicative of a moderate level of heterogeneity, and $> 50\%$ was considered to indicate statistical significance between the included studies.[26] A random-effect model was used to estimate the combined effect sizes (for each study, a study-specific true effect was estimated, while redistributing the study weights, from larger to smaller studies).[27] We calculated the sample-weighted pooled correlation coefficient for the meta-analysis with the random-effects model based on the moderate heterogeneity found in each study. A Forest plot was generated to depict the SMD along with the 95% confidence interval (95% CI) for each study, and the pooled mean difference was obtained by combining all studies.

The scale recommended by the Cochrane Collaboration[25] was used to assess the methodological quality of the identified studies and the risk of bias of the individual studies included. The major criteria of the checklist were randomization, double blinding (both the patients and the researchers/assessors), comparability of groups, and availability of follow-up information. Publication bias was also examined using funnel plots, to examine the symmetry of study effect-size variation around a meta-analytic effect size (asymmetry can indicate bias).

A sensitivity analysis was conducted for each study individually to evaluate the quality and consistency of the results. For consistency with the

Table 1. Demographic characteristics of patients with dementia: Review of the studies.

Study	Study design	No. of pt, type of dementia	Mean age ± SD	Instruments	Single-task parameters	Dual-task parameters	Dual task
Allali *et al.*[17]	Cross-sectional study	19 AD	76.3 ± 8.9	SMTEC system	Speed	Speed	CB
		22 HC	71.0 ± 0.5		Stride time	Stride time	
Allali *et al.*[17]	Cross-sectional study	19 FTD	62.1 ± 9.6	SMTEC system	Speed	Speed	CB
		22 HC	71.0 ± 0.5				
Allali *et al.*[5]	Cross-sectional study	177 AD	83.9 ± 5.6	GAITRite system	Speed	Speed	CB3, CF3
		91 HC	83.3 ± 5.2		Stride time CV Stance time Stride length Stride length CV Swing time Swing time CV		
Gillain *et al.*[12]	Case–control study	6 AD	73.6 ± NS	Locometrix system	Speed	Speed	CB
		14 HC	73.5 ± NS		Stride length	Stride length	
Lin *et al.*[4]	Case–control study	10 AD	74.0 ± 8.6	Vicon MX system	Speed	Speed	CB, CF
		10 HC	73.8 ± 6.1		Cadence Stride time Stride time CV Stride length Stride length CV	Stride time CV Stride length Stride time	
Maquet *et al.*[13]	Case–control study	6 AD	74.0 ± 4.0	Locometrix system	Speed	Speed, Stride length	CB
		14 HC	74.0 ± 5.0		Stride length		
Muir *et al.*[14]	Case–control study	23 AD	77.5 ± 5.0	GAITRite System	Speed	Speed	NA, CB, CB7
		22 HC	71.0 ± 5.0		Stride time Stride time CV	Stride time CV Stride time	
Van Lersel *et al.*[15]	Case–control study	39 D NOS	78.3 ± NS	Not specified electronic walkway	Speed		
		46 HC	73.8 ± NS		Stride time CV Stride length CV		
Verghese *et al.*[18]	Cohort study	12 AD	82.6 ± 5.7	GAITRite system	Speed		
		17 VD 4 D NOS 36 HC	78.9 ± 4.7		Cadence Stance time Stride length Stride length CV Swing time Swing time CV		
Webster *et al.*[16]	Case–control study	10 AD	77.6 ± 5.7	GAITRite system	Speed		
		10 HC	72.4 ± 6.5				

Notes: D NOS, dementia not otherwise specified; AD, Alzheimer's disease; FTD, frontotemporal dementia; VD, vascular dementia; HC, healthy controls; *N*, number; Pt, patients; CF, counting forward; CB, counting backward; CB7, counting backwards by sevens; CB3, counting backwards by 3 digits; CF3, counting forward by 3; NA, naming animals; SD, standard deviation; CV, variability; NS, not specified.

primary objective, we focussed on quantitative gait analysis and dementia when the information was explicitly disclosed in the publications. $p < 0.05$ was considered to indicate a statistically significant difference.

Results

Description of the studies

The numbers of studies yielded at each stage of the search of the systematic review are shown in Fig. 1. A total of nine studies were included in the meta-analysis. The sample characteristics and details of the designs of each included study are displayed in Table 1.

Characteristics of patients

All study groups were homogeneous for general clinical features, such as age, clinical presentation, and duration of disease (Table 1). There was variation in other features, such as the duration of the disease, the electronic devices, and the kinds of gait parameters used.

There were four case–control studies,[4,12,14,15] one cohort study,[13] three cross-sectional studies,[5,17,28] and one longitudinal prospective study.[16]

Type of dementia

The analysis assessed different types of dementia. There was no homogeneity among the types of dementia and the severity. Lin *et al.*[4] and Maquet *et al.*[13] assessed subjects with mild Alzheimer's disease. Allali *et al.*,[5] Gillain *et al.*,[12] and Muir *et al.*[14] reported about patients with moderate Alzheimer's disease. Webster *et al.*[16] assessed patients with mild-to-moderate Alzheimer's disease. Another recent study by Allali *et al.*[17] considered patients with moderate frontotemporal dementia and moderate-to-severe Alzheimer's disease. In the study by Verghese *et al.*,[18] patients were affected by mild (62%), moderate (35%), and severe (2%) dementias.

According to several studies, there was a direct relationship between the severity of dementia and the presence of gait abnormalities in cases of Alzheimer's disease,[4,5,12–16] frontotemporal dementia,[17] and other types of dementia, including vascular dementia.[5,18] Most of the studies focussed on the interaction of Alzheimer's disease and gait analysis,[4,5,12–16] and two of them compared people with moderate dementia to healthy controls.[15,16] Four studies additionally examined the differences in gait pattern between people with Alzheimer's disease and those with mild cognitive impairment and healthy controls.[5,12–14] Another study compared gait parameters in dementia-free people at baseline and after developing dementia.[18]

Because of the heterogeneous clinical presentation of the different types of dementia, as well as the difficulty in defining the characteristics of gait for each type, it could be important to identify which parameters are specific for both the kind of dementia and the disease stage.

Gait parameters

There was no homogeneity among the studies reporting gait parameters in cases of dementia. The most frequently studied spatiotemporal parameters, such as speed, made the results of the meta-analysis more accurate, whereas the less reported parameters, such as cadence, increased the difficulty of relating consistent findings.

Significant differences in spatiotemporal parameters of people with dementia with respect to healthy people during a single task of comfortable walking were evident in the decreases of gait speed ($n = 9$),[4,5,12–18] cadence ($n = 2$),[4,18] stride time ($n = 3$),[4,14,17] and stance time ($n = 2$).[5,18] However, stride time CV ($n = 4$),[4,5,14,15] stride length CV ($n = 4$),[4,5,15,18] and swing time CV ($n = 2$)[5,18] were increased.

During dual tasks, gait parameters were different for reduced speed ($n = 5$)[4,12–14,17] and increased stride time ($n = 3$)[4,14,17] and stride time CV ($n = 2$).[4,14] Stride length was examined in five studies for a single task[4,5,12,13,18] and in three studies for dual-task conditions.[4,12,13] Overall, the spatiotemporal parameters were significantly reduced, except in two studies that reported insignificant differences.[12,13]

According to four investigations, temporal domains such as cadence, stride time, stride time variability, and stance time were more affected dementia-related gait parameters than spatial parameters (e.g. stride length).[29–32] Impairment in the ability to maintain a steady gait, with minimal stride-to-stride variations, was closely related to instability and fall risk and was independent of gait speed.[32] In addition, two studies[29,32] highlighted that a dual-task activity, such as walking while

Table 2. The effect of dementia on gait parameters during single-task condition.

Study	Type of D	Speed (m/s)	Cadence (steps/min)	Stride time (s)	Stride time CV (%)	Stance time (s)	Stride length (cm)	Stride length CV (%)	Swing time (s)	Swing time CV (%)
Allali *et al.*[17]	AD	110.6 ± 9.9		1.1 ± 0.1						
Allali *et al.*[17]	FTD	118.5 ± 9.0		1.2 ± 0.1						
Allali *et al.*[5]	AD	61.8 ± 20.3			5.7 ± 4.1	0.9 ± 0.1	79.6 ± 20.3	7.1 ± 4.0	0.40 ± 0.1	0.001 ± 9.9
Gillain *et al.*[12]	AD	102.0 ± 36.0					113.0 ± 45.0			
Lin *et al.*[4]	AD	90.0 ± 30.0	97.0 ± 17.2	1.3 ± 0.2	5.2 ± 1.9		110.0 ± 20.0	6.7 ± 5.3		
Maquet *et al.*[13]	AD	74.0 ± 26.0					100.0 ± 42.0			
Muir *et al.*[14]	AD	110.8 ± 13.7		1.0 ± 1.1	2.6 ± 1.0					
Van Lersel *et al.*[15]	D NOS	61.0 ± 30.0			5.0 ± 2.3			6.5 ± 2.2		
Verghese *et al.*[18]	AD VD D NOS	79.5 ± 23.0	95.3 ± 11.8			0.8 ± 0.1	99.3 ± 33.0	5.56 ± 2.4	0.45 ± 0.1	0.04 ± 2.0
Webster *et al.*[16]	AD	102.0 ± 30.0								
p		< 0.001	< 0.001	0.014	< 0.001	0.023	< 0.001	0.048	0.568	0.047

Notes: D, dementia; FTD, frontotemporal dementia; AD, Alzheimer's disease; D NOS, dementia not otherwise specified; VD, vascular dementia; s, seconds; m, meters; CV, coefficient of variation; cm, centimeters; min, minutes.

reciting random numbers or counting down numbers, exhibited a greater risk of falls and increased variability of stride time, which is a temporal measure that is associated with fall risk.[29,32]

Meta-analysis of gait parameters

The data showed that patients with dementia generally had the following gait features: slower gait speed and cadence, reduced stride time and stance time, shorter stride length, and greater stride time CV and stride length CV than healthy elderly subjects. Tables 2 and 3 show what gait parameters provided significantly better discrimination between people with dementia and healthy controls during a single task or dual task. During single tasks, these parameters were speed, cadence, stride length, stride time CV ($p < 0.001$), stride time, stance time, and stride length CV ($p < 0.05$). During dual tasks, the parameters were stride time CV ($p < 0.001$) and stride length ($p < 0.05$). In contrast, we did not observe significant differences for swing time and swing time CV during a single task or for stride time during a dual task

Table 3. The effect of dementia on gait parameters during dual-task condition.

Study	Type of D	Dual task	Speed (m/s)	Stride time CV (%)	Stride length (m)	Stride time (s)
Allali *et al.*[17]	AD	CB	88.9 ± 10.0			1.3 ± 0.2
Allali *et al.*[17]	FTD	CB	89.4 ± 10.0			1.3 ± 0.2
Gillain *et al.*[12]	AD	CB	74.0 ± 26.0		1.0 ± 0.4	
Lin *et al.*[4]	AD	CB	80.0 ± 4.0	5.8 ± 5.0	1.0 ± 0.3	1.4 ± 0.4
Lin *et al.*[4]	AD	CF	70.0 ± 3.0	9.9 ± 3.8	1.0 ± 0.3	1.5 ± 0.4
Maquet *et al.*[13]	AD	CB	74.0 ± 26.0			
Muir *et al.*[14]	AD	CB	96.4 ± 22.8	4.8 ± 2.7		1.0 ± 0.2
Muir *et al.*[14]	AD	NA	81.0 ± 24.7	9.0 ± 8.9		1.2 ± 0.3
Muir *et al.*[14]	AD	CB7	67.9 ± 28.5	12.4 ± 12.3		1.1 ± 0.6
p			< 0.001	< 0.001	0.040	0.067

Notes: D, dementia; FTD, frontotemporal dementia; AD, Alzheimer's disease; ±, standard deviation; NA, naming animals; CB, counting backwards by ones; CB7, counting backwards by sevens; CF, counting forward; s, seconds; m, meters; CV, coefficient of variation.

Table 4. Forest plot illustrating the effect of dementia on single-task speed when compared with cognitively healthy controls.

Study	Type of D	N HC	N D	Mean HC	Mean D	SMD	SE	95% CI Lower limit	95% CI Upper limit	t	P	Weight (%) Random	Weight (%) Fixed	Heterogeneity	
Allali *et al.*[17]	AD	19	22	118.5 ± 11.7	110.6 ± 9.9	0.719	0.317	0.077	1.36			10.60	8.01	DF	9
Allali *et al.*[17]	FTD	19	22	118.5 ± 11.7	111.8 ± 9.0	0.636	0.315	0.001	1.273			10.62	8.12	Significant level	$p < 0.0001$
Allali *et al.*[5]	AD	177	91	104.7 ± 22.2	61.7 ± 20.3	1.987	0.155	1.683	2.292			11.92	33.70	I^2	86.93%
Gillain *et al.*[12]	AD	6	14	140.0 ± 13.0	102.0 ± 36.0	1.161	0.502	0.106	2.215			8.70	3.20	95% CI for I^2	77.93–92.26
Lin *et al.*[4]	AD	10	10	150.0 ± 20.0	90.0 ± 30.0	2.254	0.557	1.083	3.424			8.14	2.60		
Maquet *et al.*[13]	AD	6	14	130.0 ± 14.0	74.0 ± 26.0	2.302	0.592	1.058	3.547			7.79	2.30		
Muir *et al.*[14]	AD	23	22	135.7 ± 24.0	110.8 ± 13.7	1.245	0.321	0.597	1.892			10.57	7.82		
Van Lersel *et al.*[15]	D NOS	39	46	65.0 ± 31.0	61.0 ± 30.0	0.130	0.216	−0.299	0.560			11.50	17.29		
Verghese *et al.*[18]	AD VD D NOS	33	36	94.1 ± 23.6	79.5 ± 23.0	0.630	0.244	−0.133	1.107			11.27	13.53		
Webster *et al.*[16]	AD	10	10	140.0 ± 20.0	102.0 ± 30.0	1.427	0.484	0.410	2.444			8.89	3.44		
Total fixed effects		342	287			1.180	0.089	1.004	1.357	13.148	**< 0.001**	100.00	100.00		
Total random effect		342	287			1.188	0.271	0.656	1.720	4.384	**< 0.001**	100.00	100.00		

Notes: D, dementia; FTD, frontotemporal dementia; AD, Alzheimer's disease; D NOS, dementia not otherwise specified; VD, vascular dementia; HC, healthy controls; N, number; ±, standard deviation; SE, standard error; SMD, standardized mean difference; CI, confidence intervals; I^2, inconsistency.

Table 5. Forest plot illustrating the effect of dementia on dual-task speed when compared with cognitively healthy controls.

Study	Type of D	Dual task	N HC	N AD	Mean HC	Mean AD	SMD	SE	95% CI Lower limit	95% CI Upper limit	T	P	Weight (%) Fixed	Weight (%) Random	Heterogeneity	
Allali *et al.*[17]	AD	CB	19	22	102.3 ± 12.4	88.9 ± 10.0	1.176	0.333	−1.830	−0.484			17.62	14.12	DF	8
Allali *et al.*[17]	FTD	CB	19	22	102.3 ± 12.4	89.4 ± 10.0	1.132	0.331	−1.783	−0.445			17.82	14.13	Significant level	p < 0.0001
Gillain *et al.*[12]	AD	CB	6	14	130.0 ± 14.0	74.0 ± 26.0	2.302	0.661	−4.343	−1.567			5.58	12.29	I^2	88.91%
Lin *et al.*[4]	AD	CB	10	10	140.0 ± 3.0	80.0 ± 4.0	16.252	2.605	−21.725	−10.779			0.29	2.74	95% CI for I^2	81.16–93.47
Lin *et al.*[4]	AD	CF	10	10	130.0 ± 3.0	70.0 ± 3.0	19.153	3.058	−25.579	−12.727			0.21	2.10		
Maquet *et al.*[13]	AD	CB	6	14	130.0 ± 14.0	74.0 ± 26.0	2.302	0.661	−4.343	−1.567			5.58	11.98		
Muir *et al.*[14]	AD	CB	23	22	129.0 ± 27.0	96.4 ± 22.8	1.279	0.323	−1.929	−0.628			18.84	12.29		
Muir *et al.*[14]	AD	NA	23	22	122.9 ± 30.4	81.0 ± 24.7	1.495	0.332	−2.159	−0.818			17.71	14.18		
Muir *et al.*[14]	AD	CB7	23	22	115.9 ± 25.4	67.9 ± 28.5	1.749	0.346	−2.438	−1.044			16.35	14.12		
Total fixed effects			139	158			1.545	0.140	1.269	1.820	11.036	**< 0.001**	100.0	100.0		
Total random effects			139	158			2.377	0.477	1.439	3.316	4.985	**< 0.001**	100.0	100.0		

Notes: D, dementia; FTD, frontotemporal dementia; AD, Alzheimer's disease; HC, healthy controls; N, number; ±, standard deviation; SE, standard error; SMD, standardized mean difference; CI, confidence intervals; I^2, inconsistency; NA, naming animals; CB, counting backwards by ones; CB7, counting backwards by sevens; CF, counting forward.

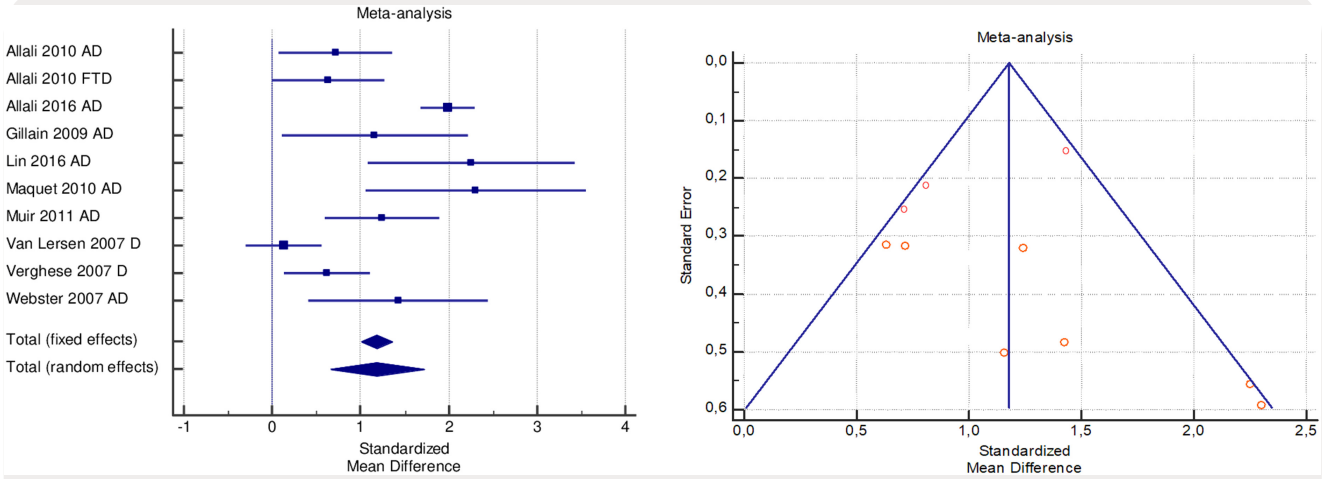

Fig. 2. Figure related to Table 4.

($p > 0.05$). Tables 4 and 5 show that speed, one of the parameters more frequently reported, discriminates significantly between dementia and healthy controls in both single and dual tasks ($p < 0.001$) (Figs. 2 and 3).

Heterogeneity and publication bias

The heterogeneity between studies was high (I^2 between 86.93 and 88.91%), as shown in Tables 4 and 5. The funnel plot (Figs. 2 and 3) showed that there was symmetry between the studies, and no significant publication bias was seen. However, there was a small study effect, but it was insignificant. The sensitivity analysis also showed the absence of an excessive influence of individual studies.

Discussion

Summary of collected data

To our knowledge, this is the only systematic review in the last 15 years that provides a comprehensive overview and meta-analysis of studies devoted to a quantitative evaluation of gait dysfunctions in dementia, including Alzheimer's disease and frontotemporal and vascular dementia. During single and dual tasks, dementia is associated with impairment of gait speed, cadence, and stride length, but not swing time, and these data are significant even in the presence of a high CV.

The prevalence of mobility dysfunction, motor impairments, and falls is higher in people with dementia than cognitively healthy older adults. Gait abnormalities have been reported in 16% and

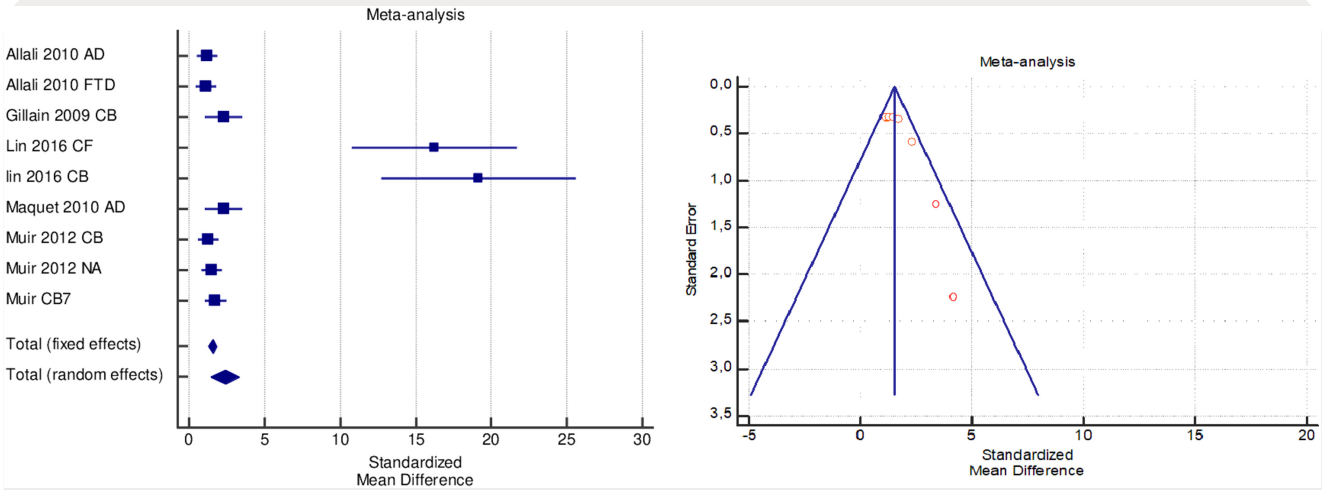

Fig. 3. Figure related to Table 5.

32% of patients with moderate and severe disease, respectively.[28,33,34] Thus, gait assessment seems to be a useful tool for monitoring the progression of the disease with the aim of identifying and preventing postural instability.

Patients with dementia and mild cognitive impairment (the stage between the expected cognitive decline of normal aging and the more serious decline of dementia) walk more slowly and have more variability (CV) in their gait under single- and various dual-task conditions than patients without cognitive impairment.[35]

Comparing studies: Gait parameters

We observed that the most studied parameter was gait speed, which was reported by nine papers[4,5,12–18] and by five other papers during a dual-task activity.[4,12–14,17] Cadence was recorded in only two papers[4,18] and stride length was recorded in five studies for single-task conditions,[4,5,12,13,18] whereas three reported it for dual-task conditions.[4,12,13] Both the parameters are important because modifications of speed are physiologically due to an increase or decrease of cadence or stride length. Therefore, based on the obtained data, we can say that speed is the main abnormal gait parameter of patients with dementia. Among all gait parameters, for the relation between speed and executive function, speed could be a very important marker of the extent of involvement of motor areas of the brain in diffuse brain disease.[36] Gait speed is a holistic parameter that includes all others. Moreover, when speed is increased, it means that the locomotor system is at its maximal efficiency. Usual gait speed is associated with executive function, but maximum speed is more closely associated with cognition than usual speed. In this regard, Perry *et al.*[36] showed that there is a statistical correlation between gait velocity and the clinical condition of people with stroke. They showed that more affected hemiplegic patients walked significantly slower ($< 0.4\,\mathrm{m/s}$) than those who were affected ($> 0.8\,\mathrm{m/s}$). Similar findings can be found for people with Parkinson's disease[37] and multiple sclerosis.[38] The studies that investigated the association between gait speed and cognition only used the participants' usual gait speed and did not carry out a direct comparison of different gait speeds. It could be interesting to compare the severity of dementia with the degree of difficulty when walking faster. We propose following the changes in speed in people with dementia as an objective indicator of disease progress. Our meta-analysis highlighted how slow gait and subjective cognitive decline are part of a motoric cognitive risk syndrome, with a high-risk status for the development and the worsening of dementia.

Gait parameters showed an association with various cognitive domains.[5,18] Allali *et al.*[5] concluded that higher stance time CV appears as a motor phenotype of cognitive decline. Verghese *et al.*[18] reported that swing time could predict decline in the memory domain, whereas stride length could predict decline in the executive domain. They highlighted that gait parameters can predict cognitive decline and dementia, independently from cognitive performance.[18]

Correlation between gait parameters and types of dementia

According to De Cock *et al.*,[39] the balance and gait quality change differently between distinct types of dementia. The different types of dementia showed similar gait characteristics to those of Alzheimer's disease.[5,17,18] Patients with Alzheimer's dementia were characterized by significant differences in stride time and stride width variability with respect to adults without neurological impairment or dementia.[16,40]

In patients with frontotemporal dementia, worse motor performance was evident during walking in single-task conditions, in contrast to patients with Alzheimer's disease who showed only slight gait impairment in the same conditions. In frontotemporal dementia, gait was significantly slower, as suggested by the reduction of speed, stride length, and cadence with respect to patients with Alzheimer's disease. Among gait parameters, patients with frontotemporal dementia had higher stride time CV than patients with Alzheimer's disease and healthy controls during single and dual tasks. Stance time was modified in both cases of frontotemporal dementia and Alzheimer's disease, indicating a dynamic instability.[17]

Studies on spatiotemporal gait analysis in Lewy body dementia and Alzheimer's dementia showed that single-task walking changed similarly in both kinds of dementia in comparison with cognitively normal people. Velocity and stride length decreased, and double support (two feet simultaneously touching the floor) increased in both

groups of demented patients.[41] The distinction between patients with Alzheimer's disease and those with subcortical lesions was related to gait speed.[42]

Allali *et al.*[5] examined the spatiotemporal gait parameters in mild and moderate dementia. They assessed a group with Alzheimer's dementia and another with non-Alzheimer's dementia.[5] Patients with mild non-Alzheimer's dementia had significantly worse walking than patients with Alzheimer's disease in terms of stride length variability.[5] Patients with moderate non-Alzheimer dementia presented significantly more disturbed gait parameters than patients with dementia in terms of walking speed, stride length, and stance time.[5]

Verghese *et al.*[18] included 12 patients with Alzheimer's disease, 17 with vascular dementia, and 4 with other kinds of dementias that were not specified. None of the gait parameters predicted a specific kind of dementia, and only the pace factor predicted the risk of vascular dementia.[18]

De Cock *et al.*[39] proposed that a decrease of step width could differentiate Alzheimer and frontotemporal dementia from vascular dementia and Lewy body dementia, in the mild dementia stage, according to the Clinical Dementia Rating.

Comparing studies: Single- and dual-task conditions

A few studies described the modifications in gait function during single- and dual-task conditions in patients with Alzheimer's disease[4,5] and different types of dementia such as vascular dementia[5] with respect to healthy controls or people with mild cognitive impairment.[12–14] Dual-task conditions were examined in five papers and the type of dual task was different.[4,12–14,17] In three articles, gait analysis was performed while the subjects walked counting backwards.[5,12,13] For the dual-task conditions, other articles used counting backwards by ones, counting forward,[4] counting backwards by one, naming animals, and counting backwards by sevens.[14] Allali *et al.*[5] reported that counting backwards by 3 digits, as the second task during gait performance, revealed more marked modifications in gait parameters than counting forward by 3 digits in elderly people with mild dementia compared with elderly people without dementia. Muir *et al.*[14] revealed a significant increase of stance time CV with larger effects for backwards counting compared with naming animals. Another article additionally found a significant increase in counting forward by one and counting backward.[12]

Correlation between gait parameters and types of dementia in dual-task activity

Montero-Odasso *et al.*[43] and Terney *et al.*[44] showed that the gait performance varied and became worse based on the kind of cognitive dual task used. A working memory test such as the counting-backwards task was more related to frontal lobe dysfunction and to cortical gait modifications in cases of early cognitive decline.[43] A test of semantic verbal fluency and memory, such as the animal-reciting task, was related to temporal lobe dysfunction. Patients with Alzheimer's disease performed better than vascular-dementia patients in verbal fluency.[44]

Implications in rehabilitation

Maintaining the function of gait, decreasing the severity of dementia, and decreasing the risk of falls are the principal objectives of rehabilitation. Preserving the walking status and the correct postural balance in patients with dementia could improve the cognitive function.[45,46] In order to slow down the course of dementia, a rehabilitation project with dual-task activities could be the key to therapeutic success.

Limitations

A lack of uniformity among the study designs (measured parameters, electronic instruments) may have affected the validity of the statistical analysis. Each study assessed different parameters, so that the results of meta-analysis were more accurate for parameters that were more frequently reported (e.g. gait speed). Another limitation is the absence of information about some clinical characteristics that could influence gait parameters, such as comorbidities affecting gait (osteoarthritis, arthrosis, or peripheral neuropathy), the use of drugs, and the presence of prostheses. Furthermore, in some studies, the sample was too small. Several studies did not evaluate the educational status of the participants, which could be a confounding factor and could influence the results.

The articles about dual tasks used different cognitive tasks, thus making the sensitivity of different modalities unclear.

Conclusions

Our systematic review identified the most sensitive parameters related to the different kinds of dementia, assessed by gait analysis. Pooling data within this meta-analysis revealed that several gait spatiotemporal parameters of gait discriminated best between dementia and healthy controls, including speed, cadence, stride time, stride time variability, stance time, stride length during single task and speed, stride time variability, and stride length in dual task.

The temporal parameters could predict the risk of falls more than spatial parameters, such as cadence, stride time, stride time variability, and stance time. They could be markers of full-blown dementia and predictors of functional dependence and risk of falling, especially during dual-task conditions.

Thus, gait analysis could contribute to the diagnosis and prognosis of dementia. The results could be used for the development of preventive interventions to reduce the burden of dementia, as well as specific rehabilitation interventions to better control postural instability and reduce the risk of falls.

Conflict of Interest

The authors have no conflicts of interest relevant to this article.

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The influence of low-intensity resistance training combined with neuromuscular electrical stimulation on autonomic activity in healthy adults: A randomized controlled cross-over trial

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Background: Low-intensity resistance training (RT) combined with neuromuscular electrical stimulation (NMES) is one method of exercise to improve the deterioration of physical function. However, it is unclear whether low-intensity RT combined with NMES (RT + NMES) can be safely implemented.
Objective: This study aimed to examine the influence of low-intensity RT + NMES on autonomic activity and cardiovascular responses in healthy adults.
Methods: This study was an open-label, randomized controlled cross-over trial. The exercise intensity of isometric knee extension RT was set to 40% of the maximum voluntary contraction (peak torque). NMES was adjusted to a biphasic asymmetrical waveform with the frequency maintained at 50 Hz and a phase duration of 300 μs. The difference in the change in autonomic activity and cardiovascular responses was compared by assessing heart rate variability, blood pressure, and heart rate during RT and RT + NMES.
Results: Twenty healthy male college students (mean age 21.0 ± 0.6 years) participated in this study. The ratio of low- and high-frequency components of heart rate variability, systolic blood pressure, and heart rate increased during exercise in the RT and RT + NMES sessions ($P < 0.05$). There were no significant differences in autonomic activity and cardiovascular responses throughout the sessions during RT and RT + NMES.
Conclusion: In conclusion, our results demonstrated that low-intensity RT + NMES was safe and did not induce excessive autonomic and cardiovascular responses in healthy adults.

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Keywords: Autonomic nervous system; cardiovascular system; electrical stimulation; exercise; resistance training; safety.

Introduction

Resistance training (RT) is widely used as one method of exercise to improve the deterioration of physical function and the occurrence of disability in older adults.[1–5] In recent years, RT has also been applied to patients with cardiovascular disease, who are recommended to adopt low-intensity RT in consideration of their physical risks and frailty.[6–9] There is a need for a safe and effective low-intensity RT method that can improve physical function such as increasing muscle strength in frail older patients with physical risks.

The effect of RT depends on the exercise intensity; low-intensity RT has been shown to be less effective than moderate- or high-intensity RT.[10–12] On the other hand, two studies have reported that RT combined with neuromuscular electrical stimulation (NMES) was more effective for the improvement of muscle strength than RT alone in healthy adults.[13,14] Moreover, a randomized controlled trial has shown that low-intensity RT combined with NMES (RT + NMES) can improve mobility, muscle cross-sectional area, and the capacity to perform daily tasks in older adults.[15] We believe that low-intensity RT + NMES could be an effective method of exercise in older patients who can exercise only at low intensities.

It is important to understand an effect of exercise training; however, how to exercise safely should be initially considered. In particular, older adults and patients with any disease for whom low-intensity exercise should be safely performed often have cardiovascular risk,[16] and it is important to reliably measure cardiovascular responses during or before and after exercise. Therefore, it is worthwhile to examine whether RT +NMES has a bad synergistic effect on cardiovascular response even during low-intensity exercise.

Excessive sympathetic activation precipitates arrhythmias, unexpected cardiovascular responses, and sudden cardiac death.[17] In a study that examined the cardiac autonomic activity during exercise, low-intensity RT did not alter cardiac autonomic modulation in patients with peripheral artery disease.[18] On the other hand, NMES was reported to slightly but significantly increase the blood pressure and sympathetic activity in patients with acute myocardial infarction.[19] However, few studies have reported on autonomic activity and cardiovascular responses during RT + NMES, including reports on healthy subjects.

Older adults often have some disease (e.g., hypertension, dyslipidemia), and the disease or drug may affect autonomic activity and cardiovascular response. Therefore, the participants of this study were healthy adults. The purpose of this study is to examine whether low-intensity RT + NMES could be performed without inducing autonomic imbalance and cardiovascular instability in healthy adults.

Methods

Participants

Study participants were students at the Tokyo University of Technology. To be included in this study, participants needed to be age 20 years and older and male. All subjects participated in the study as volunteers, and none of them received monetary compensation. Participants were excluded if they engaged in regular exercise or had a history of smoking, cardiopulmonary disease, or motor dysfunction due to neurological or orthopaedic disease. The participants were instructed to refrain from vigorous activities, maintain their usual sleep patterns, and abstain from caffeine and other autonomic stimulants for one day before starting the study.

Study design

This study was an open-label, randomized controlled cross-over trial. All procedures of this study were performed by the authors who were registered physiotherapists in Japan. Participants were allocated randomly to the RT or RT + NMES session using block randomization. The two sessions were performed at the same time in two consecutive days.[20]

The study protocol was approved by the Ethics Committee of Tokyo University of Technology

(approval number: E17HS - 035). All subjects were informed about the purpose and contents of the study, and personal information management. Written informed consent was obtained. This study was registered at the University Hospital Medical Information Clinical Trials Registry (registration number: UMIN000031069).

Outcome measures

The peak torque of isometric knee extensor strength was assessed using a dynamometer (Biodex Multi-Joint System 3, Biodex Medical, Shirley, NY, USA). The knee extensor strength is widely used as a representative of lower limb muscle strength and is strongly related to various physical functions from young to older adults.[21,22] We chose this dynamometer because this dynamometer shows acceptable mechanical reliability and validity,[23,24] and is capable of quantifying exercise intensity using measured muscle strength. The non-dominant lower extremity was chosen for the assessment. Participants were seated in an upright posture with the knee flexed to 60°.[13,23] Before testing, all participants received instructions from the examiner regarding the appropriate evaluation of muscle strength. Participants were asked to push against the dynamometer pad by attempting to straighten their knee for a period of 5 s and to increase the force gradually to maximum voluntary effort. The isometric knee extensor strength was measured three times with a 2 min break between each measurement. The highest value of the maximum voluntary contraction was used to decide the exercise intensity.

The systolic blood pressure, diastolic blood pressure, and heart rate were measured as parameters of the cardiovascular response. The systolic blood pressure and diastolic blood pressure were measured using an automatic sphygmomanometer (TM-2572, A & D, Saitama, Japan). The heart rate was measured using a chest-worn monitoring device (Actiheart, CamNtech, Cambridge, United Kingdom).

The heart rate variability was assessed as autonomic activity using RR intervals obtained at a temporal resolution of 1 ms from the digitized Actiheart recorder.[25] It is reported that this recorder is technically reliable and valid to sense the heart rate.[26,27] The power spectra of the low-frequency component (LF; 0.04–0.15 Hz) and high-frequency component (HF; 0.15–0.40 Hz) were analyzed by power spectrum analysis of heart rate fluctuations using the exclusive software (Actiheart Software version 4.0.116, CamNtech, Cambridge, United Kingdom). The LF/HF ratio was calculated by dividing the LF component by the HF component. The power spectra of the HF component and LF/HF ratio were used as parameters reflecting cardiac parasympathetic and sympathetic activities, respectively.[28,29]

The psychological stress throughout the session was assessed because the psychological stress has been shown to affect the blood pressure and heart rate variability.[30,31] The rating of perceived exertion of the lower extremity was measured using the original Borg scale (6–20).[32] The perceived pain level of the lower extremity was assessed using the numerical rating scale.[33]

Study protocol

The study was performed between 10:00 and 16:00 in an air-conditioned room kept at 23–25°, 2 or more h after lunch. Participants rested for 10 min (pre-exercise phase), exercised for 6 min (3 min in the first half of the exercise phase and 3 min in the second half of the exercise phase), and then rested again for 10 min (post-exercise phase). The systolic blood pressure, diastolic blood pressure, Borg scale, and numerical rating scale were measured at four points: 9 min into the pre-exercise phase, 2 min into the first half of the exercise phase, 2 min into the second half of the exercise phase, and 1 min into the post-exercise phase. The heart rate, LF, HF, and LF/HF were measured throughout the session; the mean values were calculated in each phase because at least a 2-min sample is required to calculate the outcomes of heart rate variability.[29]

For the RT session, the participants performed the isometric knee extension exercise using the dynamometer. They flexed the non-dominant knee to 60° and the process was repeated as 6 s of muscle isometric contraction and 6 s of rest, for a total of 30 repetitions (6 min). The exercise intensity (as low-intensity) was set to 40% of the maximum voluntary contraction (peak torque), as referred to in a previous report.[11] For the RT + NMES session, NMES was applied simultaneously with muscle exercise (contraction) described above. During the RT, the participants were given the feedback of 40% of the maximum voluntary contraction, looking at a monitor that showed the exerted torque in real-time.

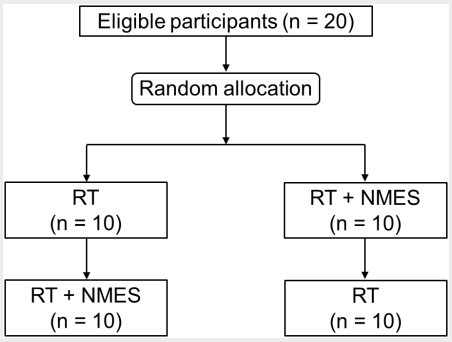


Fig. 1. Flow chart of the study.
NMES: neuromuscular electrical stimulation, RT: resistance training.

Neuromuscular electrical stimulation

NMES was applied to the *rectus femoris* and *vastus medialis* of the non-dominant lower extremity.[34] Self-adhering surface electrodes 50 × 90 mm (PALS, Axelgaard, Fallbrook, CA, USA) were placed on four areas of the skin: the motor points of the *rectus femoris*/*vastus medialis* and the point approximately 5 cm distal to the other electrodes. NMES was performed with a duty cycle of 6 s stimulation and 6 s rest simultaneously with muscle voluntary contraction using a portable electrical stimulation device (NM-F1, Ito, Tokyo, Japan). A biphasic asymmetrical waveform with a frequency maintained at 50 Hz and a phase duration of 300 μs was used. Stimulus intensity was set to the intensity beyond the motor threshold to evoke visible muscle contractions.

Statistical analyses

Sample size calculation was performed using the pilot data of the LF/HF ratio in our pre-study. We calculated a target sample size of 20 participants to provide 80% power to detect a 2.0 difference between the RT and RT + NMES sessions, with a two-sided alpha level of 0.05 using a standard deviation of 3.0.

Data were expressed as means ± standard deviations or medians (25th, 75th percentiles). The changes in cardiovascular responses and autonomic activity were analyzed using two-way analysis of variance (ANOVA) for repeated measures (group vs. time course) and post-hoc analysis with the Bonferroni test. The changes in the Borg scale and numerical rating scale were analyzed using Friedman's test and Wilcoxon signed-ranks test with Bonferroni correction. The Statistical Package for the Social Sciences (SPSS version 21.0, SPSS, Chicago, IL, USA) was used for analyses, and a P value less than 0.05 was considered statistically significant.

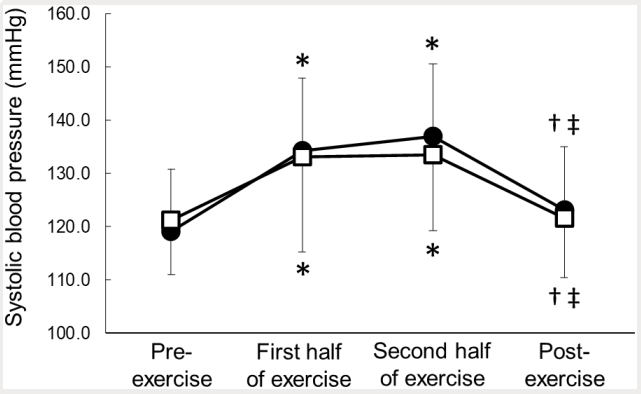
Results

A flow chart of the study is shown in Fig. 1. Twenty subjects (mean age 21.0 ± 0.6 years, mean height 172.8 ± 6.0 cm, mean body weight 63.5 ± 7.5 kg, mean body mass index 21.2 ± 1.8 kg/m^2) were enrolled in this study. Their maximum isometric knee extensor strength (peak torque) was 208.8± 43.5 Nm. All participants completed both experimental sessions without any injuries, and no participants dropped out.

Changes in the cardiovascular responses are shown in Fig. 2. The results of the two-way ANOVA showed no significant group or time interaction effect for systolic blood pressure, diastolic blood pressure, and heart rate. There were no significant differences in systolic blood pressure, diastolic blood pressure, and heart rate throughout the session between the RT and RT + NMES sessions. The systolic blood pressure was significantly increased during the first half and second half of exercise as compared with the pre-exercise levels in both sessions ($P < 0.05$, respectively). The heart rate was significantly increased during the first half and second half of the exercise, and post-exercise as compared with pre-exercise readings in both sessions ($P < 0.05$, respectively).

Changes in autonomic activity are shown in Fig. 3. The results of the two-way ANOVA showed no significant group or time interaction effects for LF, HF, and LF/HF. There were no significant differences in LF, HF, and LF/HF between the RT and RT + NMES sessions throughout a single session. The LF and LF/HF were significantly increased during the first half of and second half of the exercise when compared to the pre-exercise levels in both sessions ($P < 0.05$, respectively).

Changes in the Borg scale and the numerical rating scale are shown in Table 1. There were no significant differences in the Borg scale or the numerical rating scale between the RT and RT + NMES sessions throughout a single session. The Borg scale was significantly increased during the first and second halves of the exercise, and during post-exercise when compared to the pre-exercise readings in both sessions ($P < 0.05$, respectively).



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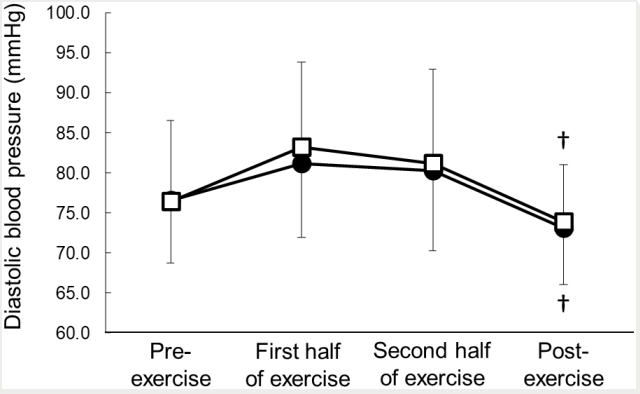

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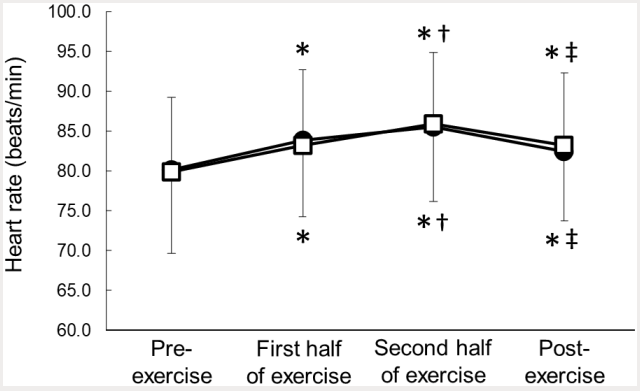
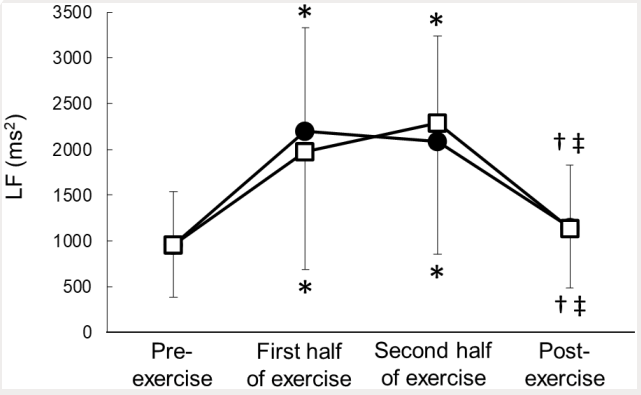
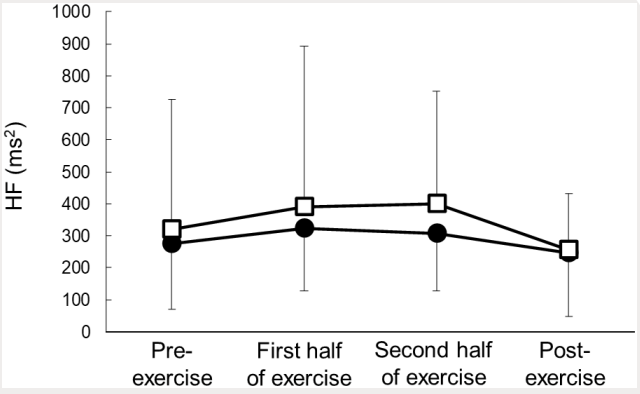


(c)

Fig. 2. Changes in the cardiovascular responses throughout the session (a) Systolic blood pressure, (b) diastolic blood pressure, (c) heart rate. Data are expressed as means ± standard deviations. Closed circles and open squares stand for RT and RT + NMES sessions, respectively. * $P < 0.05$ vs. pre-exercise, † $P < 0.05$ vs. first half of the exercise, ‡ $P < 0.05$ vs. second half of the exercise. NMES: neuromuscular electrical stimulation, RT: resistance training.

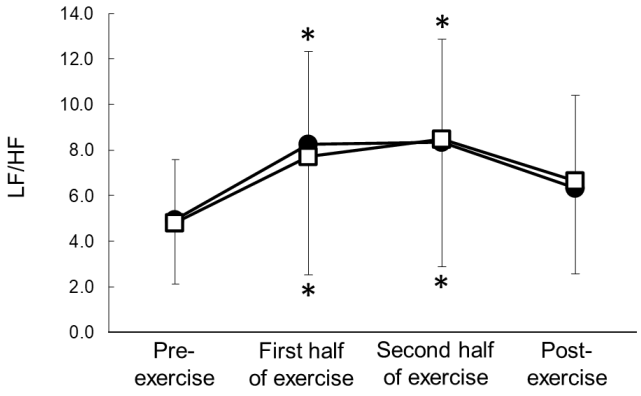


(a)



(b)

Fig. 3. Changes in autonomic activity throughout the session (a) LF, (b) HF and (c) LF/HF. Data are expressed as means ± standard deviations. Closed circles and open squares stand for RT and RT + NMES sessions, respectively. * $P < 0.05$ vs. pre-exercise, † $P < 0.05$ vs. first half of the exercise, ‡ $P < 0.05$ vs. second half of the exercise. HF: high-frequency component, LF: low-frequency component, NMES: neuromuscular electrical stimulation, RT: resistance training.



(c)

Fig. 3. (*Continued*)

Table 1. Changes in the Borg scale and the numerical rating scale.

		Pre-exercise	First half of exercise	Second half of exercise	Post-exercise
Borg scale	RT	7 (6, 9)	9 (7, 11)*	10 (8, 13)* †	10 (7, 13)*
	RT + NMES	7 (6, 9)	9 (7, 11)*	11 (7, 12)* †	10 (8, 11)*
Numerical rating scale	RT	0 (0, 1)	0 (0, 2)	0 (0, 2)	0 (0, 1)
	RT + NMES	0 (0, 0)	0 (0, 2)	1 (0, 2)	0 (0, 1)

Notes: Data are expressed as medians (25th, 75th percentiles). The numerical rating scale represents the perceived pain level of the lower extremity. * $P < 0.05$ vs. pre-exercise, † $P < 0.05$ vs. first half of exercise. NMES: neuromuscular electrical stimulation, RT: resistance training.

Discussion

This study investigated autonomic activity and cardiovascular responses during low-intensity RT +NMES in healthy adults. The results showed that changes in autonomic activity and cardiovascular responses showed no differences between RT and RT + NMES sessions; however, a significant increase in LF/HF (sympathetic activity), systolic blood pressure, and heart rate were observed during exercise. Therefore, the results illustrated that the addition of NMES to RT did not compromise the safety of low-intensity RT.

Previous reports showed that RT + NMES improves physical function without causing adverse events; however, few studies have reported on autonomic activity and cardiovascular responses during the pre-exercise, in-exercise, and post-exercise periods.[35,36] In contrast, several studies have suggested changes in autonomic activity and cardiovascular response when subjects performed RT or NMES alone.[18,19,37] This study did not show that adding NMES to RT elicited a worse response to autonomic activity or cardiovascular response compared to RT alone. The results from this study support the safety of RT + NMES, as shown in the results of previous studies investigating RT or NMES alone from the aspect of evaluating autonomic activity and cardiovascular response.

Observing the intensity of RT was very important in this study. After measuring the peak torque of knee extensor, 40% of the maximum voluntary contraction was calculated. A monitor was set up in front of the participants, and the monitor displayed a bar graph that moved up and down when power was applied and a line indicating 40% of maximum voluntary contraction. The participant looked at the monitor and adjusted the output of muscle strength, and if the intensity was too high or too low, the instructor explained the appropriate intensity. The monitor feedback provided the participant with immediate exercise intensity, and most subjects did not require explanation by the instructor. Therefore, it was considered that the exercise intensity complied during either RT or RT + NMES sessions.

There were significant increases in perceived exertion in the RT and RT + NMES sessions and a slight increase in pain perception in the RT + NMES session. The previous study has shown that fatigue increased according to the increase of resistance exercise duration.[38] The result of this study supported the previous study. On the other hand, pain perception increased slightly only at RT +NMES sessions, but not significantly. Therefore, it was considered that the addition of NMES did not cause a meaningful increase in pain.

There were no differences in autonomic activity and cardiovascular responses in between the RT and RT + NMES sessions when exercise intensity was the same. The exercise intensity in both sessions was low (40% of the maximum voluntary contraction), and almost all participants felt light fatigue, as rated less than "somewhat hard" using the Borg scale, and very slight pain using the numerical rating scale. In these results, it was considered that perceived exertion and pain did not increase by combining NMES and RT. The blood pressure and heart rate increase during isometric exercise were nearly proportional to the exercise intensity.[39,40] As mentioned above, no difference in autonomic activity and/or cardiovascular responses occurred between the RT and RT + NMES sessions because the mental influence of NMES was small and the exercise intensity was equivalent.

In this study, the LF/HF, systolic blood pressure, and heart rate were slightly but significantly increased during each session. Excessive sympathetic activity has been reported to cause arrhythmias, excessive increase of blood pressure, and even sudden death.[17] Accordingly, it is important to suppress excessive sympathetic activity during exercise, especially for patients with several diseases to exercise safely. It is well known that activation of sympathetic activity occurs during exercise and that autonomic activity alters the heart rate and haemodynamic.[41] Moreover, the blood pressure and heart rate increase during isometric exercise because of the vasoconstriction and increased cardiac output.[39,40] Therefore, autonomic activity and cardiac responses obtained from this study are physiologically explainable. In addition, the 10–15 mmHg increase in the systolic blood pressure during exercise was statistically significant but may be unimportant from a clinical standpoint.

There are some limitations to this study. First, the participants of this study were healthy male college students. It is considered that the biological response to exercise changes depending on disease or physical condition. Therefore, further research is needed to prove the safety of RT + NMES for patients with different diseases by observing the biological reactions. Secondly, autonomic activity was evaluated only by the heart rate variability in this study, which is an indirect indicator of autonomic activity. This heart rate variability may limit the reliability and validity of the research results. Therefore, the use of other indicators of autonomic activity such as plasma epinephrine and norepinephrine concentrations and the arterial baroreflex sensitivity[42] are worth exploring as evaluation markers in future research in order to improve the reliability and validity of autonomic activity results. Although this study had some limitations, the results are thought to be useful as basic data for the application of low-intensity RT +NMES to older patients in the future.

In conclusion, our results demonstrated that low-intensity RT + NMES was safe and did not induce excessive cardiovascular and autonomic responses in healthy adults.

Conflict of Interest

The authors have no conflict of interest relevant to this paper.

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Author Contributions

Conception and design of the study was made by T. Kutsuna, H. Sugawara, H. Kurita, and T. Takahashi; acquisition of data were made by T. Kutsuna, H. Sugawara, and S. Kusaka; analysis and/or interpretation of data were made by T. Kutsuna, H. Sugawara, H. Kurita, and T. Takahashi; drafting the manuscript was made by T. Kutsuna; revising the manuscript critically for important intellectual content was made by H. Sugawara and H. Kurita. All authors were involved in the approval of the manuscript to be published.

Randomization and statistical analysis was made by T. Kutsuna; measuring the outcome measures were made by T. Kutsuna and S. Kusaka;

instruction of RT was made by T. Kutsuna and H. Sugawara; location of the electrodes of NMES was made by H. Sugawara. The authors' specialties were physiotherapy for respiratory, circulatory, and metabolic disorders (T. Kutsuna, H. Kurita, S. Kusaka, and T. Takahashi) and electrophysical agents (H. Sugawara), and they had enough experience in the specialized areas.

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Immediate effect of foam roller on pain and ankle range of motion in patients with plantar fasciitis: A randomized controlled trial

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Background: Stretching has been proven to be effective on pain and range of motion (ROM) in patients with plantar fasciitis. Despite recent gain in popularity and the proposed theories of effectiveness of foam roller, there is a lack of literature on the effect of foam rolling on plantar fasciitis.
Objective: The objective of this study was to compare the effects of foam rolling and stretching on pain and ankle ROM in patients with plantar fasciitis.
Methods: A total of 50 participants were included and randomly allocated to the stretching and foam roller groups. Visual analog scale (VAS), pressure pain thresholds (PPTs) for gastrocnemius, soleus and plantar fascia and weight-bearing lunge test (WBLT) measurements were recorded at baseline and immediately after treatment.
Results: Within-group analysis has shown there is a statistically significant difference ($p < 0.001$) in all the outcome measures in both foam roller and self-stretching groups. The between-groups analysis showed no statistical significance difference in VAS, plantar fascia PPT and WBLT parameters (with p-values of 0.171, 0.372 and 0.861, respectively); however, significant differences were found in gastrocnemius PPT ($p = 0.029$) and soleus PPT ($p = 0.013$).
Conclusion: It was seen that both stretching and foam rolling techniques helped in reducing pain and increasing the ROM. However, the effectiveness of foam roller was superior to stretching in terms of increase in PPTs at gastrocnemius and soleus.

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Clinical Trial Registration No: CTRI/2018/01/011398. **Name of registry:** The Clinical Trials Registry — India (CTRI); https://ctri.nic.in.

Keywords: Ankle; foam rolling; plantar fasciitis; trigger points; stretching.

Introduction

Plantar fasciitis has been reported as the most common cause of heel pain, which affects around 10% of the non-athletic and athletic populations.[1–3] Although plantar fasciitis implies inflammatory condition of plantar fascia, evidences suggest it to be associated with degenerative changes and could be classified as a "fasciosis" or "fasciopathy".[4]

The classical signs of plantar fasciitis are severe pain after a period of rest, decrease in pain with activity, restriction in ankle range of motion (ROM) and tenderness over medial aspect of calcaneus.[1,2]

Gastrocnemius and soleus muscles are connected to the plantar fascia by connective tissues.[1] According to Bolívar *et al.*, there is an association between posterior leg muscle tightness and development of plantar fasciitis,[5] which explains why pain in plantar fascia could be caused due to reduced extensibility and trigger points present in the posterior leg muscles.[6]

Physiotherapy management for plantar fasciitis includes electrotherapy,[7,8] exercise therapy,[9,10] myofascial release,[6,11,12] taping,[13] night splints,[14] orthotic devices,[2,15] etc. Stretching of gastrocnemius, soleus and plantar fascia remains an important part of conservative treatment for plantar fasciitis. It helps to increase extensibility of soft tissue thus increasing the flexibility of the muscle.[16]

Recently, foam rolling has been adopted as a tool for self-myofascial release (SMR) which is presumed to work on the same mechanism of treatment as traditional "myofascial release". However, it requires application of pressure by the individual using self-body weight.[17] The movement between the foam roller and tissue structure causes sweeping pressure as well as direct pressure on the soft tissues. This increases lubricity of the fascial layer[18] and causes increase in tissue extensibility by breaking adhesions.[19]

Despite recent gain in popularity and the proposed theories of effectiveness of foam roller, there is a lack of literature on the effect of foam rolling on plantar fasciitis. Previous studies have proven that foam rolling helps to increase extensibility of tissue structures. Therefore, we hypothesized that it could be effective in relieving pain caused by plantar fasciitis by increasing extensibility of the calf muscles and plantar fascia. Hence, this study was undertaken to assess the effects of foam rolling and self-stretching as well as to explore comparative effects of these treatments on pain and ROM in patients having plantar fasciitis.

Methods

The study was approved by the Institutional Ethics Committee, Kasturba Medical College, Mangalore, Manipal Academy of Higher Education. This study was a randomized parallel-controlled trial conducted in tertiary hospitals from February 2018 to February 2019. Based on a previous study, the sample size was calculated to be 25 in each group using 95% confidence interval and 80% power.[6]

Patients with heel pain referred by an orthopedic surgeon for physiotherapy were approached and screened for inclusion and exclusion criteria. Inclusion criteria required the patients to be aged between 18 years and 60 years with heel pain having such clinical features as heel pain in the morning with first step, insidious sharp pain under the heel, tenderness on medial calcaneus and symptoms decreasing with slight activity (like walking) and worsening toward the end of the day. Participants were excluded if they were having any other musculoskeletal conditions which would hamper their performance, having a history of inflammatory joint disorder, impaired blood circulation and altered sensation in lower extremity. The purpose of the study was explained, written and informed consent was taken from willing participants. The method of sampling used was stratified random sampling for group allotment using the chit method.

Outcome measures studied were the pain and ROM of ankle joint. Pain was assessed using visual

analog scale (VAS) and pain pressure threshold (PPT). VAS was a 10-cm-long horizontal line with no pain and worst possible pain at the extremes of the line. PPT was assessed with a mechanical pressure algometer (force gauge, model M3-50; Mark-10 Corporation, USA). PPT was assessed at three predetermined locations on the affected leg: gastrocnemius (middle point over the muscle belly), soleus (center point of the muscle belly 10 cm above the Achilles tendon) and over the posteromedial aspect of the calcaneus for both the groups. Three trials were performed with 30-s rest in between two successive trials. Mean values of the three trials were taken as pain threshold measurements.[6] The reliability of algometer has been reported to be high (ICC = 0.91; 95% CI: 0.82–0.97).[20]

ROM assessment for dorsiflexion was done by weight-bearing lunge test (WBLT). It has been shown that this type of test has high inter-rater and intra-rater reliabilities [intra-rater ICC = 0.97–0.98; inter-rater ICC = 0.97 (angle) and 0.99 (distance)].[21] A measurement tape was placed on the floor perpendicular to the wall to measure the linear distance between the big toe and the wall. Participants were made to stand on the tape with their big toe and heel on the tape. The patient was allowed to lean on the wall for better balance. Participants were instructed to lunge their knee toward the wall in order to make contact with it without lifting the heel. The foot was progressively moved away or toward the wall until the maximum ROM of the ankle was attainted without lifting the heel.[18] Measurements were taken by another physiotherapist before and immediately after the intervention. Assessor was blinded for group allocation and treatment intervention.

Intervention protocols

Foam roller group

Calf muscles: This involved long sitting, with the affected leg extended on the foam roller and foot relaxed. The non-affected leg was flexed at knee so that the foot was rested on the floor. The participants were instructed to use their arms and non-affected foot to propel their body back and forth from the popliteal fossa to Achilles tendon in continuous motion (Fig. 1(a)).[18]

Plantar fascia: This involved standing, with the non-affected foot on the floor and affected foot on the foam roller (Fig. 1(b)), the participants were instructed to move their foot back and forth from heel to toes in continuous motion while exerting pressure on the foam roller. They were asked to stop at the point where they felt maximum pain.[18] Foam rolling was performed by the participants for 45 s followed by a 15-s rest with five repetitions.

Self-stretching group

Calf muscles: This involved standing, with the affected foot away from the wall, the participants were asked to lean forward until they felt a stretch in their calf. To focus on the stretching of soleus muscle, the affected knee was bent, whereas to focus on the gastrocnemius muscle, the affected knee was kept in full extension without lifting the heel.[6]

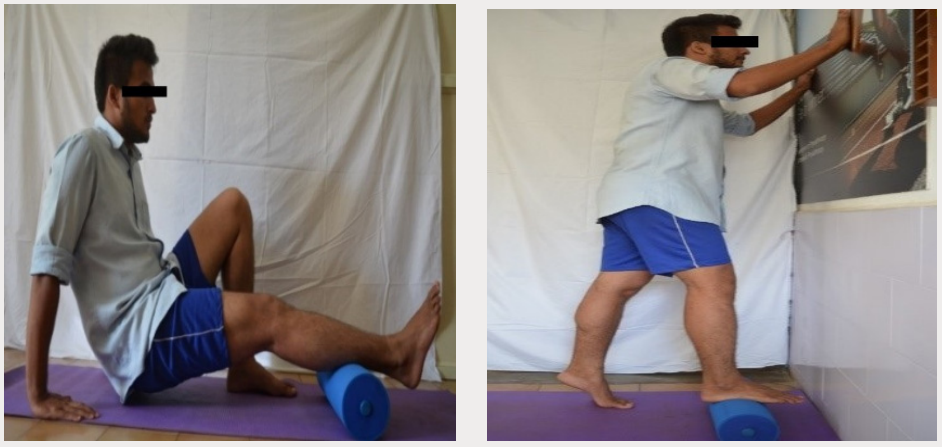
Plantar fascia: This involved sitting, with the participants crossing the affected foot over the contralateral thigh. They were asked to place fingers of one hand over the base of the toes and those of other hand on the heel and pull the toes back toward the shin, until they felt a stretch at plantar fascia. Participants were instructed to start gently initially and were made to work more aggressively as tolerable later.[6] Each stretch was performed for 45 s with five repetitions.[16]

Statistical Analysis

Data was analyzed using IBM SPSS Statistics version 25.0 for Windows (IBM Corp., Armonk, NY). Level of significance was set at $p \leq 0.05$. Test used for the between-groups analysis for age was the Fisher exact test. To analyze gender and affected side, the Chi-square test was used. Independent sample t-test was used to evaluate the mean difference between the two groups for all the outcome measures at baseline. For all the outcome measures, the within-group analysis was done using Student's paired t-test and the between-groups analysis by the Mann–Whitney U-test.

Results

The CONSORT diagram (Fig. 2) shows the progress of participants at each stage of the study. Gender distributions of both the groups were statistically insignificant ($p = 1$). A total of 18 (72%) male and seven (28%) female participants were



(a) (b)

Fig. 1. Foam rolling technique for (a) calf muscles and (b) plantar fascia.

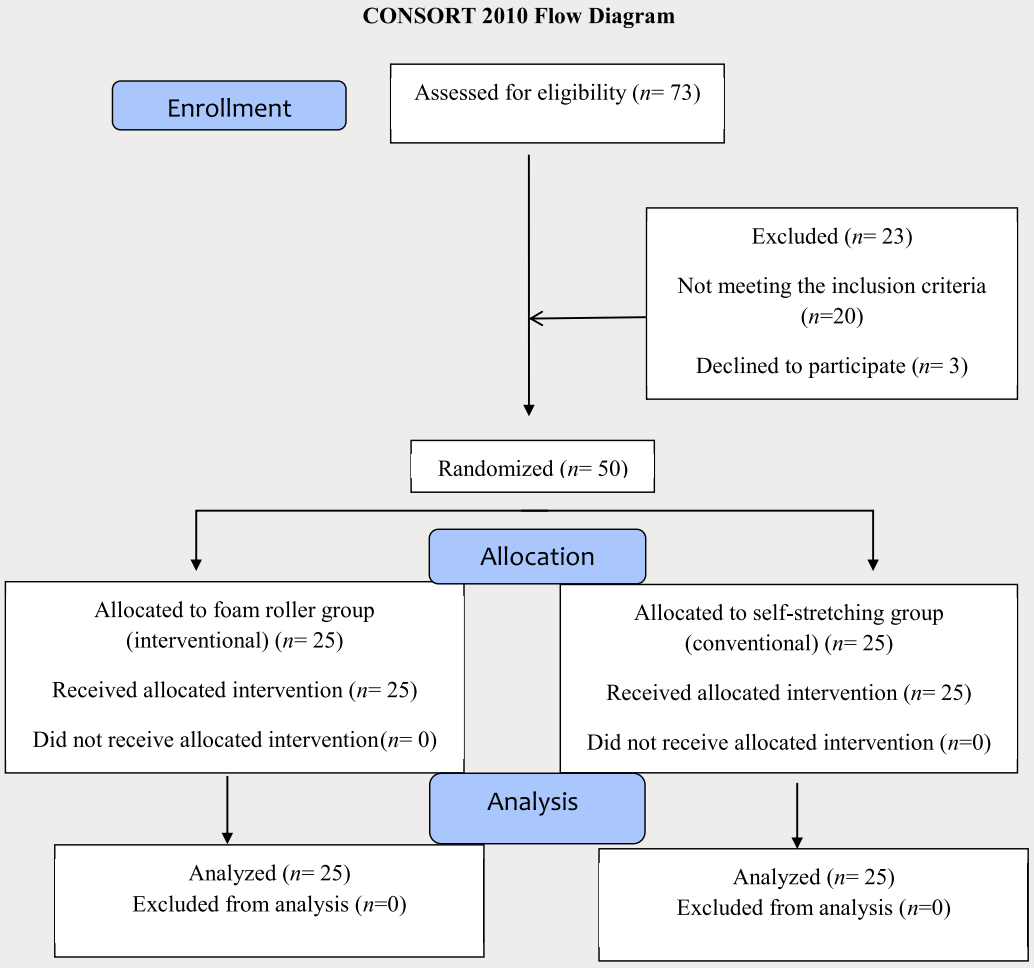


Fig. 2. The CONSORT flow diagram.

Table 1. Outcome measures at baseline.

Variable	Stretching ($n = 25$) (Mean ± SD)	Foam roller ($n = 25$) (Mean ± SD)	p-Value
VAS (cm)	5.35 ± 1.93	5.50 ± 1.55	0.754
Gastrocnemius PPT (lb)	8.09 ± 2.64	6.99 ± 2.93	0.171
Soleus PPT (lb)	7.62 ± 3.32	7.06 ± 2.80	0.521
Plantar fasciitis (lb)	7.58 ± 3.10	6.82 ± 1.98	0.307
WBLT (cm)	9.72 ± 2.76	11.28 ± 2.49	0.041*

Notes: *Significant. VAS: visual analog scale and WBLT: weight-bearing lunge test.

allocated in each group. The mean age of participants in the stretching group (38.28 ± 13.67 years) and in the foam roller group (33.08 ± 10.83 years) was found to be statistically insignificant ($p = 0.143$). Affected side of the leg in both groups was statistically insignificant ($p = 0.777$). Participants with right leg affected in the stretching group were 13 (52%) and in the foam roller group were 12 (48%). Participants with left leg affected in the stretching group were 12 (48%) and in the foam roller group were 13 (52%).

Groups were homogenous and not statistically significant in all the parameters except WBLT where the p-value for between-groups was statistically significant (Table 1).

After the analysis, it was found that within-group analysis showed a statistically significant difference ($p < 0.001$) in all the outcome measures like VAS, gastrocnemius PPT, soleus PPT, plantar fascia PPT and WBLT in both the foam roller group and self-stretching group (Tables 2 and 3). The p-values in these tables were adjusted by

Table 2. Comparison of outcome measures within the stretching group (pre- and post-treatments).

	Stretching ($n = 25$)				
	Mean and SD				
Parameter	Pre-treatment	Post-treatment	Mean difference	Change (%)	p-Value
VAS (cm)	5.348 ± 1.93	2.748 ± 1.68	2.60	48.62	0*
Gastrocnemius PPT (lb)	8.08 ± 2.64	10.7 ± 3.29	2.61	32.28	0*
Soleus PPT (lb)	7.61 ± 3.32	9.937 ± 3.40	2.32	30.45	0*
Plantar fascia PPT (lb)	7.58 ± 3.09	10.81 ± 3.18	3.23	42.65	0*
WBLT (cm)	9.72 ± 2.76	11 ± 3.02	1.28	10.64	0*

Notes: VAS: Visual analog scale, PPT: pressure pain threshold and WBLT: weight-bearing lunge test. The p-value has been adjusted by multiplying it by 2. *Highly significant at $p < 0.001$.

Table 3. Comparison of outcome measures within the foam roller group (pre- and post-treatments).

	Foam roller ($n = 25$)				
	Mean and SD				
Parameter	Pre-treatment	Post-treatment	Mean difference	Change (%)	p-Value
VAS (cm)	5.504 ± 1.55	2.496 ± 1.16	3.01	54.65	0*
Gastrocnemius PPT (lb)	6.99 ± 2.93	10.17 ± 3.06	3.18	45.46	0*
Soleus PPT (lb)	7.05 ± 2.79	10.19 ± 3.50	3.14	44.54	0*
Plantar fascia PPT (lb)	6.82 ± 1.97	9.94 ± 3.17	3.12	45.70	0*
WBLT (cm)	11.280 ± 2.49	12.480 ± 2.50	1.20	10.64	0*

Notes: VAS: visual analog scale, PPT: pressure pain threshold and WBLT: weight-bearing lunge test. The p-value has been adjusted by multiplying it by 2. *Highly significant at $p < 0.001$.

Table 4. Comparison of outcomes between the groups.

Parameters	Group	*N*	Mean difference	SD difference	Change (%)	Median	*p*-Value
VAS (cm)	Stretching	25	2.60	1.02	48.62	2.60	0.171
	Foam roller	25	3.01	1.15	54.65	2.90	
Gastrocnemius PPT (lb)	Stretching	25	2.61	2.16	32.28	2.10	0.029*
	Foam roller	25	3.18	1.39	45.46	3.10	
Soleus PPT (lb)	Stretching	25	2.32	1.86	30.45	1.80	0.013*
	Foam roller	25	3.14	1.73	44.54	3.20	
Plantar fascia PPT (lb)	Stretching	25	3.23	2.21	42.65	2.20	0.372
	Foam roller	25	3.18	2.75	45.70	3.60	
WBLT (cm)	Stretching	25	1.28	0.54	13.17	1	0.861
	Foam roller	25	1.20	0.65	10.64	1	

Notes: *Significant.

multiplying them by two.

The between-groups analysis showed no statistical significance difference in VAS, plantar fascia PPT and WBLT (with *p*-values of 0.171, 0.372 and 0.861, respectively), however, significant differences were found in gastrocnemius PPT ($p = 0.029$) and soleus PPT ($p = 0.013$) at end of the treatment (Table 4).

Discussion

This study compares the immediate effects of foam rolling and stretching on patients with plantar fasciitis. This study showed statistically significant difference in reduction of pain intensity on VAS in the stretching group. Reduction in heel pain may be due to increase in muscle flexibility which causes biomechanical stress on fascia. This leads to increase in Golgi Tendon Organ (GTO) firing resulting in the inhibition of alpha motor neuron activity, thereby relaxing the muscle.[22–24] At a microstructural level, failure of bonds between collagens reduces stiffness and pain at the musculotendinous unit altering its resting length.[16,25,26] These findings are in line with studies which reported decrease in pain after stretching.[10,27]

In our study, we found significant improvement in PPT in the stretching group. The immediate improvement could be justified by the instantaneous rise in psychosomatic tolerance to discomfort and increase in the viscoelastic properties of the tissue.[13] These findings are in line with previous studies which concluded that stretching has shown improvement in PPT scores when performed alone or given with other treatment.[6,28]

In this study, stretching showed an increase in the post-WBLT score which displayed statistical significance. This may be attributed to the viscoelastic properties of the musculotendinous unit to relax and lengthen. Muscular creep and reduced pain perception may be attributed to increase in tolerance to tissue stretch which contributes to immediate increase in ROM. These findings are in line with a study which reported increased ROM after stretching.[28]

In our study, foam rolling showed statistically significant difference in pain. These findings may be attributed to biomechanical, physiological and neurological mechanisms. Reduction in pain may be due to increased blood flow which removes waste products and due to activation of cutaneous receptors which blocks the nociceptive stimulus. Decreased cortisol levels and increased dopamine and serotonin levels have been reported to cause pain reduction after the soft tissue release. Foam rolling also causes decrease in tissue adhesion and muscle stiffness thereby causing an increase in soft tissue extensibility and muscle tendon compliance.[29–31] This is consistent with the findings of previous studies which stated that foam rolling was effective in reducing either chronic pain (muscle tender spots) or latent myofascial trigger points.[29,30,32]

Foam rolling also showed statistically significant difference in the improvement of PPT. It may be due to activation of descending antinociceptive systems by stimulating the skin and muscle nociceptors.[33,34] These findings were similar to previous studies which stated that foam rolling was effective in improving the plantar flexor and iliotibial band PPTs in healthy individuals.[33,34]

In our study, foam rolling technique has also shown to be effective in improving ROM and hence displaying an increased WBLT score. Possible mechanism for the increase in WBLT score may be change in thixotropic property of the fascia. Friction between foam roller and tissue causes warming effect on fascia, thereby breaking up some fibrous adhesions which results in restoration of soft tissue extensibility and flexibility.[17] The normal movements may be interrupted due to the uninterrupted fascia being more viscous and solid in form. Back and forth movement of soft tissue on the foam roller causes overloading of cutaneous receptors by the direct and sweeping pressure. Thus, the friction generated between muscle, fascia and foam roller results in a stretch[19,35] which possibly dampens the sensation of stretch end points. These findings were found to be in line with previous studies.[17,34,35]

Thus, both techniques were effective individually in decreasing pain and increasing the ROM. However, when we compared the effectiveness of both techniques, there was no statistically significant difference in improving any of the outcome measures except the PPTs for gastrocnemius and soleus, which showed statistically significant differences. The statistically significant differences in PPTs of gastrocnemius and soleus may be due to maximum pressure applied by the individuals using their limb weight. On the contrary, no difference in the PPT of plantar fascia may be attributed to inadequate pressure application by the participants and size as well as material of the foam roller.

Stretching and foam rolling have their own advantages and disadvantages. Static stretching does not require availability of specific tool for its application. Though static stretching helps in increasing the range of motion, as a standalone component of warm-up exercises it can be detrimental to strength and performance.[36,37] Stretching of muscle before adequate warm-up may predispose muscle to tear and injury. Foam rolling requires availability of instrument and training for its use. Foam roller glides over the tissue and increases its temperature, hence can be used as a part of warm-up before the commencement of traditional rehabilitation. Hence, foam rolling and stretching may be used as an alternative or adjunct to each other in the clinical practice in patients with plantar fasciitis.

The main limitation of this study was the amount of pressure applied during foam rolling. It varied according to the participant's body weight, ability to take weight on their upper limbs, participant's tolerance of discomfort and knowledge about the use of foam roller. The second limitation was that the conventional treatments like strengthening or electrotherapy were not included.

Future Implications

Long-term study can be conducted to examine the effects of stretching and foam roller. Combined effect of foam rolling and stretching can be assessed.

Conclusion

We found that both stretching and foam rolling techniques helped in reducing pain and increasing the ROM. However, the effectiveness of foam rolling was superior to stretching in terms of increase in the PPTs at gastrocnemius and soleus.

Conflict of Interest

The authors have no conflict of interest relevant to this paper.

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Author Contributions

All authors contributed to the study design. Data was collected by Aishwarya R. Ranbhor. Data analysis, interpretation and writing of the manuscript was carried out by Aishwarya R. Ranbhor, Ashish J. Prabhakar and Charu Eapen.

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Prevalence and patterns of musculoskeletal pain among undergraduate students of occupational therapy and physiotherapy in a South African university

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Background: Musculoskeletal pain (MSP) conditions are common in the educational leaning environment and are often associated with poor ergonomic conditions.
Objective: This study investigated the prevalence, pattern and possible risk factors of MSP among undergraduate students of occupational therapy and physiotherapy in a South African university.
Methods: A cross-sectional survey using an internet-based self-designed electronic questionnaire was used to obtain information about participants' socio-demography, ergonomic hazards, MSP, and relevant personal information. Descriptive statistics, chi-square, and logistic regression were used in analyzing the data.
Results: There were 145 participants (females 115 (79.3%); physiotherapy (74) 51.03%), making 36.7% of the present undergraduate student population in the two departments. The most prevalent ergonomic work

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hazards were prolonged sitting (71.7%) and repetitive movements (53.8%). The 12 months prevalence of MSP among the students was 89.7%. The pattern of MSP revealed that pain on the neck region was most prevalent (66.2%) followed by pain in the low back region (64.4%). Duration of daily travels and participation in regular exercise activities were significantly associated with the prevalence of MSP. Logistic model explained 23.6% of the variance in prevalence of MSP and correctly classified 94.1% of cases ($\chi^2 = 13.73$, $p = 0.03$). The right-handed students were 0.13 times more likely to present with MSP than left-handed students. Also, students who exercised regularly were 9.47 times less likely to present with MSP.

Conclusion: MSP is highly prevalent among health science undergraduates and is significantly associated with sedentary postures and inadequacy in structured physical activity participation.

Keywords: Musculoskeletal pain; undergraduate student; occupational therapy; physiotherapy.

Introduction

Musculoskeletal pain (MSP) is a known consequence of repetitive strain, overuse, and work-related musculoskeletal disorders and these injuries include a variety of disorders that cause pain in bones, joints, muscles, or surrounding structures.[1] The pain can be acute or chronic, focal or diffuse. Low back pain is the most common example of MSP.[2] Other examples include tendonitis and tendinosis, neuropathies, myalgia, and stress fractures.[1] Acute MSP is the pain perceived within a region of the body and believed to arise from the muscles, ligaments, bones, or joints in that region, and these types of pain are named according to the region affected for example back pain, neck pain, shoulder pain, elbow pain, buttock pain, hip pain, knee pain, and ankle pain.[3] Excluded from the definition is pain due to severe pathology, such as tumors, fractures, or infections, and systemic and neurological conditions. When MSP lasts longer than three months, generally, it is referred to as chronic pain. Three months is the standard period in which healing takes place. Chronic pain may be considered a disease state and may be associated with a disease or injury.[4] Chronic pain may arise from psychological states, serve no biologic purpose, and have no recognizable endpoint.[4]

MSP conditions are common in the work environment and are often associated with poor ergonomic conditions at work.[2] Poor ergonomic conditions exist when the work environment is incompatible with the workers' bodies and their ability to continue work. Such conditions may cause discomfort, fatigue, pain, and subsequent injuries.[5] Factors that occasion the incompatibility of the workplace and the worker are referred to as ergonomic work hazards.[5] University students may be prone to acute or chronic MSP conditions because of their exposure to ergonomic hazards like prolonged sitting, prolonged grip, usage of aesthetic but less ergonomic footwear, and the increase in physical demands associated with learning professional skills. These are student-related factors that can be exacerbated by biological factors like the presence of endophenotypes, such as pain amplification and psychological distress.[6] The trouble with persistent MSP is significantly crucial in young adults, making their lives more difficult and challenging.[7] Studies in Malaysia,[8] China,[9] Australia,[10] Saudi Arabia,[11] India,[12] Uttar,[13] Pakistan,[14] UAE,[15] Ghana,[16] Ethiopia,[17] and Brazil[18] have documented the pattern of MSP conditions among undergraduate university students.

Some researchers[19–21] investigated musculoskeletal concerns and associated risk factors among South African students with a specific focus on postural and musculoskeletal concerns associated with laptop usage. Amongst practitioners in South Africa, research on work-related MSP was common from the discipline of dentistry.[22–26] It would be essential to know the association amongst risk factors such as ergonomic challenges, family history of MSP, exercise and physical activity on the pattern and prevalence of MSP in a cohort of undergraduate students. Therefore, this study investigated the prevalence, pattern, and possible risk factors of MSP among undergraduate students of Occupational Therapy and Physiotherapy at the University of KwaZulu-Natal, Durban, South Africa.

Methods

This study is reported according to the Survey Reporting Guideline.[27] The study was cross

sectional, and involved a questionnaire completed by students. We chose to use a survey for this study to allow collection of data at a period when physical distancing was mandated as a public health measure. This study was reviewed and gained ethical approval by the humanities and social sciences research ethics committee of the University of KwaZulu-Natal, South Africa, with protocol reference number HSSREC/00001118/2020.

Questionnaire

An internet-based self-designed electronic questionnaire was used to obtain data on gender, age, marital status, year of study, course of study, duration of daily travel, duration of daily study/usage of laptop, duration of house chores performance, handedness, use of backpacks, participation in exercises/sports, family history of MSP, and smoking habits. The second segment of the questionnaire contained questions on the student's perspective of their undergraduate course experience with a specific recall of existing ergonomic hazards such as prolonged sitting, lifting of heavy objects (see details in supplementary file). The third segment of the questionnaire included the first part of the standardized Nordic questionnaire.[28,29] This was used to measure the presence and absence of MSP in various parts of the body.

Sample selection

The sample included undergraduate students in the discipline of Physiotherapy and Occupational therapy from the University of KwaZulu-Natal, South Africa. These students were selected as their training involved specific knowledge about "musculoskeletal conditions" and by implication these students should have better awareness of body postures and good motor control. The sample size was calculated using the one-sample dichotomous outcome formula.[30] The authors used a small effect size of 0.24 based on an anticipated difference in the proportion of students reporting MSP at an alpha of 0.05 and power of 80% in a two-tailed test. It was necessary to involve at least 137 participants in this study. However, all students of physiotherapy and occupational therapy were invited to participate in the survey.

Survey administration

The survey was launched in April 2020 and closed to participants in May 2020. The primary mode of administration was online via SurveyMonkey (www.surveymonkey.com). The online link to the survey was sent via email and WhatsApp messenger to the participants through their departmental online fora. The participants were informed about the intent of the research and made aware of their right to withdraw, and that completion of the questionnaire was taken as consent for the anonymized data provided to be used in the research and dissemination. No financial incentives were provided. It took between 15 and 20 min to complete the survey.

Data analysis

Responses to the online survey became a valid response when a participant completed 70% of the questions in the survey alongside a final submission. The valid responses were transferred to SPSS version 21 for analysis. Frequency distributions and percentages were used in summarizing sociodemographic and individual characteristics of participants. Chi-square and t-test were used in making inferences on the association between the 12-month prevalence of MSP and selected demographic/personal variables. Logistic regression analysis was used in determining the factors associated with the 12-month prevalence of MSP in this population.

Results

One hundred and forty-five undergraduate students of Physiotherapy and Occupational therapy participated in this study out of 394 undergraduate students who are currently enrolled in these disciplines resulting in a 36.7% response rate. Of the total participants, 115 (79.3%) were females, while 74 (51.03%) were students of physiotherapy (Table 1). The mean age of the participants was 19.7 ± 1.56 years with a range of 17–26 years. The most prevalent ergonomic work hazards were prolonged sitting (71.7%) and repetitive movements (53.8%) (Fig. 1) and 12-month prevalence of MSP among the students was 89.7% (Fig. 2). Pattern of MSP revealed that pain in the neck region was most prevalent (66.2%) followed by pain in the low back region (64.4%) among the students (Fig. 2). Extended duration of travel and participation in regular exercise activities were significantly associated with greater pain. Students who travelled for a period of more than one hour daily ($p = 0.02$) and those who do not frequently exercise ($p = 0.03$)

Table 1. Demographic and personal characteristics of participants ($n = 145$).

Variable	Characteristics	Frequency (n)	Percentage (%)
Gender	Male	30	20.7
	Female	115	79.3
Year of study	One	42	28.7
	Two	48	32.9
	Three	36	25.2
	Four	19	13.3
Marital status	Single	144	99.3
	Married	1	0.7
Course of study	Physiotherapy	74	51.0
	Occupational therapy	71	49.0
Handedness	Right	132	91
	Left	13	9
Smoker	Yes	10	6.9
	No	135	93.1
Family History of MSP	Yes	73	50.3
	No	72	49.7
Doing home chores	Yes	137	94.5
	No	8	5.5
Duration of daily personal study	0–3 h	78	53.8
	4–6 h	61	42.1
	Greater than 7 h	6	4.1
Duration of daily laptop usage	0–3 h	67	46.2
	4–6 h	62	42.8
	Greater than 7 h	16	11.0
Duration of daily travels	Less than 1 h	95	65.5
	Greater than 1 h	50	34.5
Usage of backpack	Yes	108	74.6
	No	37	25.4
Participating in regular exercises	Yes	87	60.0
	No	58	40.0
Participating in sports	Yes	44	30.3
	No	101	69.7

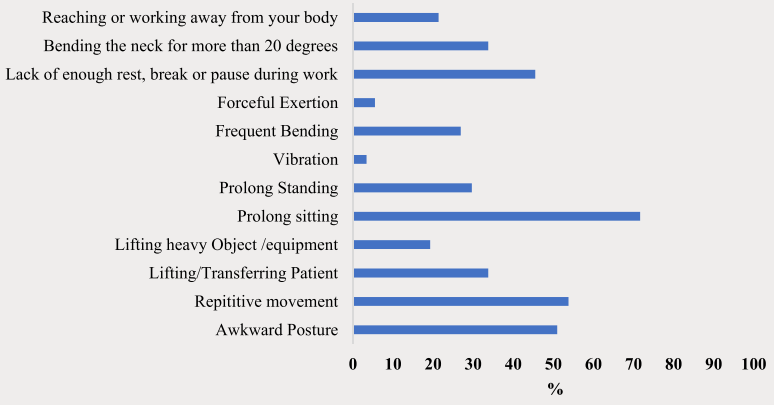

Fig. 1. Prevalence of ergonomic hazards as reported by the students.

were significantly more in reporting the presence of pain. None of the ergonomic work hazards evaluated was significantly associated with the presence of MSP (Table 2).

Logistic regression was performed using a forward stepwise mode to ascertain the impact of variables (demographic, personal factors, and presence of ergonomic work hazard) on the likelihood that

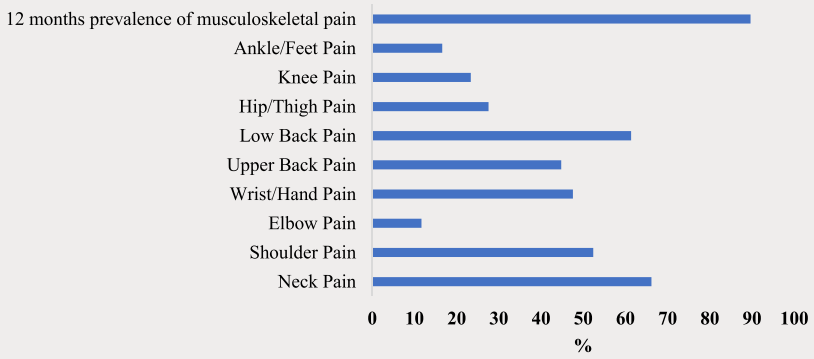

Fig. 2. Pattern of MSP in the past 12 months.

Table 2. Association between perceived ergonomic hazard/demographic/personal variables and the prevalence of MSP.

Variable	Test statistics	*p*-value
Awkward posture	0.04[a]	1.00
Repetitive movement	1.28[a]	0.29
Lifting/Transferring patient	1.42[a]	0.39
Lifting heavy object/equipment	1.72[a]	0.30
Prolong sitting	1.13[a]	0.36
Prolong standing	0.86[a]	0.38
Vibration	0.59[a]	1.00
Frequent bending	0.00[a]	1.00
Forceful exertion	0.04[a]	0.59
Lack of enough rest, break, or pause during work	1.00[a]	0.42
Bending the neck by more than 20°	3.13[a]	0.09
Reaching or working away from your body	0.64[a]	0.53
Gender	0.36[a]	0.51
Course of study	0.63[a]	0.56
Handedness	2.49[a]	0.14
Year of study	4.46[a]	0.22
Age	0.19[b]	0.84
Usage of cigarette	1.24[a]	0.59
Family history of MSP	2.94[a]	0.09
Doing home chores	0.04[a]	0.59
Duration of daily personal study	0.87[a]	0.65
Duration of daily laptop usage	0.77[a]	0.68
Duration of daily travels	5.73[a]	0.02*
Usage of backpack	0.25[a]	0.76
Participating in regular exercises	4.96[a]	0.03*
Participating in sports	2.11[a]	0.23

Table 3. Factors associated with 12-months prevalence of MSP.

Variable	Beta	Standard error	Wald	*P*-value	Exp (*B*)	Lower CI	Upper CI
Constant	−2.11	1.15	3.39	0.066	0.12		
Handedness	−2.07	0.89	5.48	0.019	0.13	0.02	0.71
Participating in regular exercise	2.25	1.12	4.02	0.045	9.47	1.05	86.39
Bending the neck by more than 20°	1.99	1.12	3.17	0.075	0.14	0.015	1.22

Notes: Model Chi-square = 13.73; *p*-value = 0.03; overall percentage predicted = 94.1%; Nagelkerke $R^2 = 0.236$.

respondents will present with MSP (12-months prevalence of MSP). The model was statistically significant with $\chi^2 = 13.73$, $p = 0.03$. The model explained 23.6% (Nagelkerke R^2) of the variance in the prevalence of MSP and correctly classified 94.1% of cases. Right-handed students were 0.13 times more likely to present with MSP than left-handed students. Also, students who exercised regularly were 9.47 times less likely to present with MSP (Table 3).

Discussion

Undergraduate rehabilitation students are exposed to several factors in their daily lives that may predispose them to MSP or trigger the occurrence of MSP. In this study, we investigated the presence of MSP in 145 occupational therapy and physiotherapy students at a university in South Africa.

In an academic environment, health science students (including first and second year rehabilitation students) remain seated for prolonged periods often with furniture that is not ergonomically maximized,[17] they spend time in health institutions for clinical training, and perform professional activities which may be repetitive.[18] With increasing pedagogies that include blended and digital learning, students spend an increased amount of time using their laptops and mobile phones to support their academic activities as well as for their leisure.[19–21] It was therefore not surprising to note that prolonged sitting and repetitive movements emerged as the most prevalent ergonomic work hazards for students in this study and a high prevalence of MSP in the previous 12 months, especially in the neck region followed by pain in the lower back region. More than 60% of our participants are first and second year rehabilitation students who may have probably not learnt the principles of posture and motor control. This may also explain our observation.

Similar findings have emerged in other studies[14,17,18,21,31–33] with university health science students. Xie and colleagues showcased the prevalence of musculoskeletal complaints among mobile device users in a systematic review of eight included studies.[34] A wide range of prevalence rates of musculoskeletal complaints was reported with the highest prevalence commonly found in neck complaints. Rakhadani *et al.*[21] in a study at the University of Venda, South Africa reported a high prevalence of musculoskeletal concerns among the students, which predominantly included the neck, shoulder, and wrist. This was attributed to prolonged computer use, incorrect sitting posture, and uncomfortable chairs. Long study hours and repetitive use of laptops were noted to increase MSP in the study by Hasan and colleagues.[14] Yang *et al.*[31] revealed that severe internet addiction resulted in a higher risk of MSP and Nordin *et al.*[35] concluded that reduced physical fitness and prolonged sitting duration was associated with low back pain amongst health science undergraduates. Internet addiction is associated with adopting static postures for a protracted period usually prolonged sitting and this encourages a sedentary lifestyle resulting in low physical fitness. High prevalence of MSP has been consistently reported to be associated with prolonged static postures and sedentary lifestyle; this fact is corroborated by our present study.

In this study, students who exercised regularly more than nine times are less likely to present with MSP. Generally, engaging in moderate physical activity was associated with reduced risk of neck, shoulder, and low back pain among adolescents.[36] Results of a meta-analysis in a systematic review reflected the protective effect of physical activity and reported a modest inverse association between leisure-time physical activity and onset of MSP.[37] Since our participants were rehabilitation students knowledgeable about the benefit of physical activity, it is not unlikely that they engaged in safe, structured exercise. Engaging in structured physical exercise training has been shown to reduce or cure MSP.[38] Kokic and colleagues' study amongst physiotherapy and social science students revealed that lower levels of moderate intensity and total physical activity were associated with a higher prevalence of MSP in the previous year.[32] However, higher levels of vigorous intensity and total physical activity were also associated with a higher prevalence of MSP, which prevented daily activities. In other studies,[39,40] exercise was not associated with MSP. Again, it needs to be emphasized that only structured physical activities may be beneficial towards the reduction in the prevalence of MSP. It is also possible there is a U-shaped relationship between exercise and MSP — both too much and too little may be harmful.

Given that physical fitness and prolonged sitting is a modifiable risk factor, undergraduates should ensure frequent postural adjustments described as micropauses[2] to minimize occurrences

of MSP. Students should also be encouraged to embrace and sustain structured physical fitness and to integrate physical activity into daily routines whenever possible.

The duration of daily travel was significantly associated with MSP in this study. This is supported by a previous study that included medical students[14] in which students who travelled more than one hour had a significant increase in MSP compared with non-medical students. There appears to be limited evidence that supports a causal relationship between the incidence of MSP and travelling. The statistical evidence for the association between prevalence of MSP and duration of daily travel in our study is biologically plausible as vehicular trips subject the body to static posture and prolong sitting which are confirmed ergonomic risk factors for the presence of MSP.[2]

There was a higher prevalence of MSP in females as compared to males in this study; however, this was not statistically significant. Several other studies reported greater MSP in female health science university students[14,18,32] and attributed this finding to the difference in muscle, bone, mass, height, and joint structure of females as compared to males.[41] The main factors that determine the presence of MSP in our study population were being right handed and not doing regular exercise. Hence, any student from this study population who is right handed and does no regular exercise has a 23.6% likelihood of presenting with MSP. This reveals that some other factors associated with the presence of MSP may have not been identified in our study.

The data from this study may be subject to recall bias as the respondents were expected to recall a discomfort which may not be present at the time of the survey. More importantly, the study was conducted when "social distancing" was adopted and students were mainly at home doing online classes and no practical sessions on campus. This can lead to systematic under-reporting or over-reporting of MSP. In order to have more accurate information on the incidence of MSP in this study population, a prospective cohort study would suffice. Also, the use of physical examination alongside self-reports will ensure the accuracy of prevalence rates obtained from a cross-sectional study like this. The recall error present in this study is clearly a random recall error as none of the participants has any reason to provide inaccurate information deliberately. A random recall error does not create a vital bias that will affect the reliability of the self-reports on MSP in our study population. Hence, the use of self-reports like this is necessary for the estimation of the burden of MSP among this sub-population when direct examinations are not possible.

Conclusion

The knowledge of MSP amongst rehabilitation students within their academic context, especially in occupational therapy and physiotherapy students, is essential in that the presence of pain may negatively influence their learning experiences and interfere with their ability to effectively execute the physical demands of being a student and student-practitioner. Moreover, given that this is the time in which their professional identities are developing, sensitization on how MSP and musculoskeletal disorders may affect their own lives is imperative. Investigating factors influencing student's physical health may also assist in advocating health promotion initiatives at an administrative level and include work ergonomic hazards and programs for preventing MSP in students.

Conflict of Interest

The authors declare no competing interests.

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N/A.

Author Contributions

MOO, PG, and OOO designed the study and were the primary investigators. All authors drafted the initial manuscript, critically reviewed the manuscript for intellectual content, and subsequently revised the manuscript for publication. MOO, PG, and OOO read and approved the final version of the manuscript.

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The Chinese (Mandarin) instructions of the 6-minute walk test: A validation study

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Background/Objective: To date, a validated Chinese (Mandarin) six-minute walk test (6MWT) translated instruction is not available. Translation of the Chinese 6MWT instruction is done in an *ad hoc* manner within the Chinese-speaking populations. This study aimed to develop a set of valid and reliable Chinese (Mandarin) instructions of the 6MWT.
Methods: Translation was performed from the original English instruction via the recommended "Process of translation and adaptation of instruments" by the World Health Organization to generate the Chinese instructions. The Chinese instructions were tested with 52 healthy adult participants for its validity. Each participant underwent three 6MWTs and a cardiopulmonary exercise test. Randomization allowed participants to undergo the walk test in both the original English and the new Chinese instructions. Face and content validity, intra-rater and inter-rater reliability of the Chinese instructions of the 6MWT were established through the translation process. Criterion validity was established by analyzing the results of the 6MWT and cardiopulmonary exercise test.
Results: Intraclass correlation coefficient for inter-rater reliability was excellent (ICC = 0.999, 95% confidence interval = 0.996–1.000). Similarly, the intra-rater reliability across the three raters was high (R1: ICC = 0.996, 95% confidence interval (CI) = 0.812–1.000; R2: ICC = 1.000, 95% CI = 0.994–1.000; R3: ICC = 1.000, 95% CI = 0.998–1.000). The 6-min walk distances collected from the Chinese and English instructed trials correlated positively with the maximal oxygen consumption ($r = 0.315$, $p = 0.023$; $r = 0.309$, $p = 0.026$).

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Conclusion: This is the first study to develop and validate the Chinese (Mandarin) instructions of the 6MWT, and the translation is as reliable and valid as the original English instructions.

Keywords: Six-minute walk test; Chinese translation; exercise test; outcome measures; validation.

Introduction

The six-minute walk test (6MWT) is a submaximal field test which measures the total distance an individual walks in 6 min, recorded as the six-minute walk distance (6MWD).[1] It is widely used to assess an individual's functional exercise capacity, treatment outcome, or as an indicator of morbidity and mortality across cardiopulmonary diseases.[1,2] The test is valid and reliable in both healthy and diseased populations such as chronic obstructive pulmonary disease, pulmonary fibrosis, heart failure, and amputations.[3–8] The 6MWT is simple, easy to conduct, and does not require any sophisticated equipment. Thus, it has an advantage over other comprehensive cardiopulmonary exercise tests (CPETs) in the clinical setting.

The American Thoracic Society (ATS) has established standardized English instructions for the 6MWT.[1] However, this has posed challenges to the non-English speaking populations worldwide in countries such as China, Taiwan, Hong Kong, and Singapore, where many of the people are Chinese speaking and may not comprehend the English instructions. The Chinese language is one of the most spoken languages, with approximately 1 billion speakers globally,[9] thus indicating the need for the Chinese instructions. To our knowledge, the instructions of the 6MWT are commonly translated by clinicians on an *ad hoc* basis. These translations, which are dependent on the linguistic ability of the clinicians, could lead to varied instructions from time to time between researchers and even within oneself, from one day to another.[10]

To date, no standardized and validated Chinese version of the recommended instructions for 6MWT has been published on any mainstream English scientific journal. Thus, we are establishing validated and standardized Chinese instructions with close adherence to the original English version. The establishment of this reliable and valid assessment tool would be of great value to countries with Chinese-speaking populations, in ensuring evidence-based practice in the clinical setting.

Methods

Study design

This was a translation and cross-sectional validation study to assess the feasibility of introducing standardized Chinese instructions for the 6MWT (6MWT-CHN). The study was carried out between August and November 2019 in the exercise laboratory at the Singapore Institute of Technology. Ethical approval (SIT-IRB Project Number: 2019089) was obtained from the Singapore Institute of Technology — Institutional Review Board, and all participants provided informed consent to participate in this study.

Development of the Chinese (Mandarin) instructions

We translated the 6MWT-CHN from the original 6MWT English instructions (6MWT-ENG)[1] while adhering to the process of translation and adaptation of instruments[11] recommended by the World Health Organization (WHO). In brief, two independent bilingual translators performed the forward translations independently. A panel comprising the researchers and the translators compared the two translations and formulated a consensus version. Twelve bilingual participants performed the backward translation of the consensus Chinese version to English. These 12 participants have no prior knowledge of the 6MWT and were not involved in the previous translation work. The backward translated instructions were reviewed for equivalence to the original instructions by another expert panel, which comprised experienced cardiopulmonary physiotherapists. The 6MWT-CHN was finalized after a pilot trial, which involved six healthy adult participants who fulfilled the inclusion and exclusion criteria.

Participants recruitments

The study recruited participants via convenience sampling if they met the inclusion and exclusion

criteria of our study. According to other cross-cultural adaptation studies,[12–19] a minimum sample size of 50 participants would provide adequate study power to observe validity and reliability. Considering the risk of missing datasets and dropouts, we supplemented an additional 20%, bringing the projected number of participants for recruitment to 60. The recruited participants were effectively bilingual and obtained at least a pass in both English and Chinese languages in the Singapore Primary School Leaving Examinations. Additionally, we only included participants between 21 and 60 years old and those without previous experience or knowledge of the 6MWT.

We excluded those with the presence of existing or past medical conditions that were contraindicated for physical activities as indicated by the Physical Activity Readiness Questionnaire for Everyone (PAR-Q+)[20] or contraindicated for the CPET following the American College of Sports Medicine (ACSM) standards.[21] We also excluded participants whose forced expiratory volume in one second (FEV_1) and forced vital capacity (FVC) were less than 80% and the FEV_1/FVC ratio less than 70% in the spirometry lung function test at the start of the study.[22] Subsequently, we randomized the participants into the English-Chinese-English (ECE) or Chinese-English-Chinese (CEC) group through a sealed envelope method (Fig. 1) to mitigate the impact of learning effects on the 6MWT results.

The 6MWT and the Bruce protocol treadmill test

The 6MWT was set up and conducted along a 30-m indoor walkway following ATS guidelines.[1] The participants walked back and forth the walkway for as far as possible within the 6-min duration. At every minute, the assessors gave standardized encouragement and recorded parameters such as Borg scale (0–10) of fatigue and dyspnea, heart

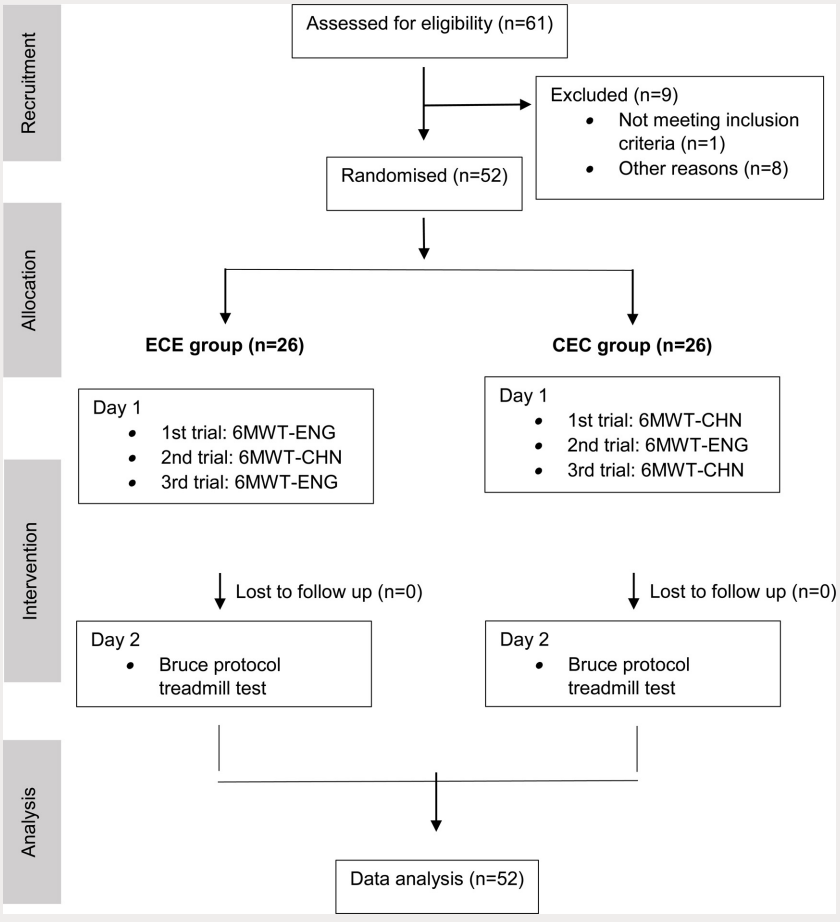

Fig. 1. Flow diagram of the validation study. ECE = English-Chinese-English; CEC = Chinese-English-Chinese; n = number; 6MWT-ENG = English instructions of the 6-min walk test; 6MWT-CHN = Chinese instructions of the 6-min walk test.

rate, and oxygen saturation (SpO_2) readings. The trials took place at 30-min intervals, ensuring that the participants' blood pressure, heart rate, and oxygen saturation returned to baseline before the next trial. At the end of 6 min, the 6MWD was recorded.

Before the validation study, a pilot study established intra-rater and inter-rater reliability among the three assessors. The six bilingual participants underwent five 6MWT trials on the same day using the instructions of the consensus version. Thereafter, participants in the validation study performed three trials of 6MWT on the same day and the CPET on the following day using the Bruce treadmill protocol (Fig. 2). Participants were instructed to exercise to maximal exhaustion while trained personnel monitored blood pressure, heart rate, and Borg scale of perceived exertion and analyzed the real-time electrocardiography.[23] At the end of the test, the relative maximum oxygen uptake (VO_2 max) was recorded for data analysis.

Statistical analysis

Statistical analysis was performed with IBM SPSS® Statistics Version 26.0 (IBM Corporation, Armond, New York, USA). The level of significance was set at $p < 0.05$ for all statistical analyses.

Reliability and validity of 6MWT-CHN

The intra-rater and inter-rater reliabilities of the 6MWT-CHN were analyzed via the intraclass correlation coefficients (ICCs), using average measures of two-way mixed effect and two-way random effect models, respectively, and Bland–Altman plots. A higher ICC value and a mean difference between paired measurements of raters closer to zero represent better reliability. Face and content validity were fulfilled during the translation process and content validity ratio was used as a quantitative measure.[24] Demographical data were tested for normal distribution using the independent *t*-test before analyzing the validation study results. Criterion validity was established by first identifying the best 6MWDs of the 6MWT-CHN and the 6MWT-ENG in each subject and subsequently analyzing the correlation between VO_2 max and the 6MWT-CHN results, as well as between VO_2 max and the 6MWT-ENG results using Pearson's correlation coefficient.

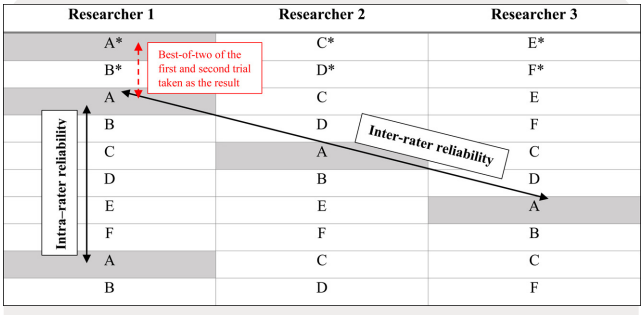

Fig. 2. Pilot study to determine intra-rater and inter-rater reliability. Alphabets A to F represent the six bilingual subjects. Asterisk "*" denotes the first trial for each subject. The best-of-two of the first and second trials was taken as the result for subsequent analysis. Subject A had been highlighted to illustrate how intra-rater and inter-rater reliability were measured.

Results

A total of 52 participants (32 males and 20 females) participated in the study. Table 1 presents the demographic data (age, body-mass index, spirometry results, and Chinese proficiency) of these participants.

Reliability

The 6MWT-CHN demonstrated high intra-rater reliability within each of the three raters (R1: ICC = 0.996, 95% confidence interval [CI] = 0.812–1.000; R2: ICC = 1.000, 95% CI = 0.994–1.000; R3: ICC = 1.000, 95% CI = 0.998–1.000). Similarly, the 6MWT-CHN demonstrated excellent inter-rater reliability (ICC = 0.999, 95% CI = 0.996–1.000) across the three raters involved (Table 2). Figure 3 illustrates the reliability data with Bland–Altman plots over repeated paired analyses between raters. Each of the dots on the Bland–Altman plot represents each of the six participants for the pilot study.

Validity

The face validity of the 6MWT-CHN was established with the rigorous translation process according to the WHO translation guidelines.[11] The subsequent panel review synonymously ascertained that the conceptual meaning of the 6MWT-CHN was accurate to the original with a content validity ratio of 1. Results from the validation study demonstrated that the 6MWDs of the

Table 1. Demographic of participants ($n = 52$).

	ECE ($n = 26$)	CEC ($n = 26$)	p-values
Age (years)	25.6 ± 9.06	26.1 ± 8.68	0.840
Gender			0.577
Male	15	17	
Female	11	9	
Body mass index (kg/m^2)	22.1 ± 3.59	22.8 ± 3.71	0.481
FEV_1/FVC ratio (%)	94.4 ± 7.68	92.3 ± 5.68	0.273
Relative VO_2 max (mL/min/kg)	40.3 ± 8.85	40.6 ± 9.47	0.910
Chinese language qualification			0.576
Junior college	8	7	
Secondary school	18	18	
Primary school	0	1	

Notes: Data are mean ± standard deviation unless otherwise noted. *Definition of abbreviations*: ECE = English-Chinese-English; CEC = Chinese-English-Chinese; n = number of participants; FEV_1 = ratio of forced expiratory volume in one second; FVC = forced vital capacity; VO_2 max = relative maximal oxygen consumption. Significance of p-values < 0.05.

Table 2. Inter-rater and intra-rater reliability of the Chinese version of 6MWT (6MWT-CHN).

6MWT-CHN		ICC	95% CI	p-values
Inter-rater reliability		0.999	0.996–1.000	0.000
Intra-rater reliability	Rater 1	0.996	0.812–1.000	0.000
	Rater 2	1.000	0.994–1.000	0.000
	Rater 3	1.000	0.998–1.000	0.000

Notes: *Definition of abbreviations*: ICC = intra-class coefficient; 95% CI = 95% confidence interval. Significance of p-values < 0.05.

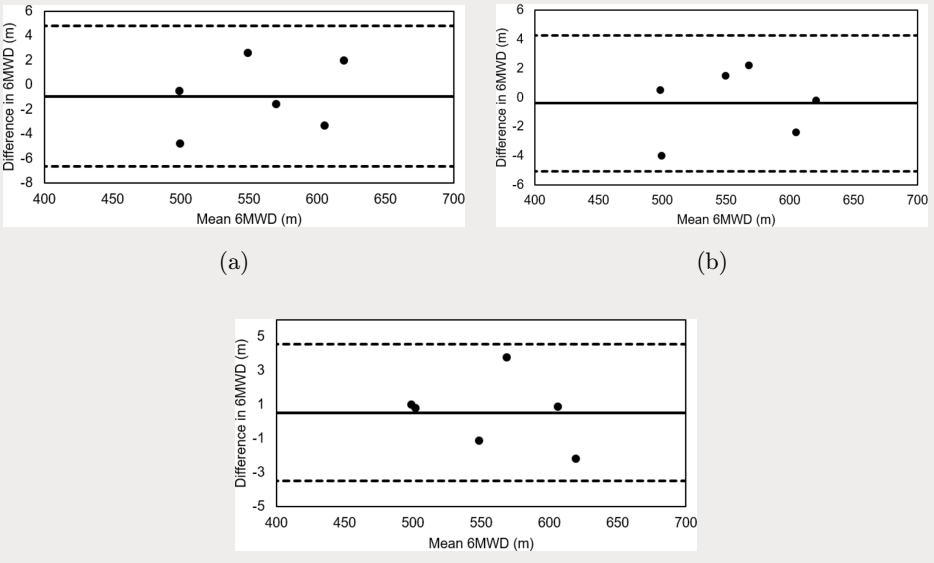

Fig. 3. Bland–Altman plots comparing the agreement of the three raters ([A] Rater 1 and 2, [B] Rater 1 and 3, [C] Rater 2 and 3). The differences in 6-min walk distance between raters are plotted against the mean scores. The straight line represents the mean difference between the two raters; dashed lines represent the 95% limits of agreement. 6MWD = 6-min walk distance; TEM = technical error of measurement; CV% = coefficient of variance.

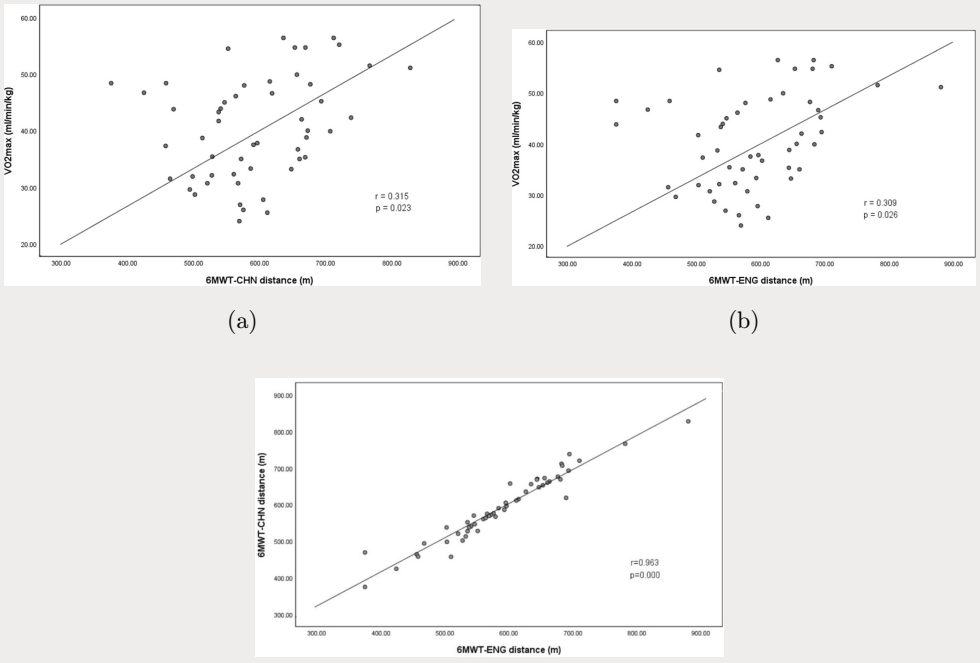

Fig. 4. Scatterplots of relative VO_2 max and 6MWDs of 6MWT-CHN and 6MWT-ENG ([A] VO_2 max and 6MWT-CHN, [B] VO_2 max and 6MWT-ENG, [C] 6MWT-CHN and 6MWT-ENG). VO_2 max = maximal oxygen consumption; 6MWT-CHN = Chinese instructions of 6-min walk test; 6MWT-ENG = English instructions of the 6-min walk test; r = Pearson's correlation coefficient; p = probability value.

6MWT-CHN (593 ± 91.5 m) and 6MWT-ENG (589 ± 94.5 m) had a weak positive correlation with the VO_2 max collected during the Bruce protocol treadmill test ($r = 0.315$, $p = 0.023$; $r = 0.309$, $p = 0.026$). Figure 4 illustrates the scatterplots to show the relationships between the relative VO_2 max (mL/min/kg), 6MWT-CHN distance (m), and 6MWT-ENG distance (m). The relationships of VO_2 max, 6MWT-CHN, and 6MWT-ENG were also highly similar ($r = 0.963$, $p = 0.000$), illustrating no difference between the instructions in the two languages and that 6MWT-CHN has good criterion validity.

Discussion

The 6MWT is a field test that measures submaximal exercise capacity. It is an outcome measure used to assess the effectiveness of interventions and to aid in exercise prescription. Although the CPET is the gold standard for exercise testing, field tests like the 6MWT are conducted more commonly in clinical settings as they are validated, easy to conduct, economic, and less time-consuming. It is also more applicable to patients with cardiopulmonary conditions who are easily fatigued. The ATS established a standardized set of instructions for the 6MWT in the English language in 2002. However, the English standardized instructions pose a challenge for the Chinese-speaking population worldwide. To the knowledge of the researchers, instructions of the 6MWT are usually translated into Chinese in an *ad hoc* manner without any documented standardizations[25–27] in the local clinical setting. The lack of standardization among assessors can alter the psychometric properties of the 6MWT since the test is only valid when conducted with standardized set-up and instructions.[1] Excessive or insufficient motivation can affect the distance an individual completes.[28] Therefore, our study aimed to develop and establish the validity and reliability of the Chinese version of the 6MWT instructions.

This is the first study to develop and validate a Chinese version of the 6MWT instructions against the gold standard measure of exercise capacity, the CPET. The study observed a rigorous process of forward and backward translation and reliability testing under WHO guidelines.[11] The panel of

researchers established the face and content validity of the 6MWT-CHN during the translational phase. Subsequently, the pilot study established intra-rater and inter-rater reliability, and the validation study established correlations of the 6MWT-CHN, 6MWT-ENG, and CPET. The 6MWT-CHN demonstrated acceptable psychometric properties. Our findings suggest that this instrument is a reliable and valid outcome measurement for the Chinese-speaking population. Intra-rater and inter-rater reliabilities of the 6MWT-CHN were excellent in healthy participants with ICC values ≥ 0.90. In addition, absolute reliability was excellent with precision and a small human error for measurements; % coefficient of variation $< 1\%$ and the technical error of measurement below the acceptable 5% mark. This resembles established literature on the 6MWT where the 6MWT has excellent reliability (ICC = 0.72–0.99) in people with pulmonary conditions.[8,29]

The 6MWT-CHN also showed a positive correlation with the CPET; the gold standard for exercise testing.[30] The 6MWT-CHN correlated well with the VO_2 max ($r = 0.315$, $p = 0.023$) and was comparable with the 6MWT-ENG ($r = 0.963$, $p = 0.000$). The high similarity in correlations between the VO_2 max and 6MWDs of 6MWT-ENG and 6MWT-CHN suggested strong agreement between the two 6MWT instruments and indicated the criterion validity of the 6MWT-CHN. The results of this study were comparable with published data on the validity of the 6MWT on healthy adults ($r = 0.54$–0.87),[31–33] healthy children ($r = 0.44$),[6] patients with pulmonary conditions ($r = 0.40$–0.80),[8] patients with heart failure ($r = 0.54$–0.69),[34] patients with diabetes mellitus ($r = 0.54$),[35] and patients with cancer ($r = 0.67$).[36]

Notwithstanding, we acknowledge that this is a limitation of our study. We considered several "gold standards" to test against the 6MWT-CHN/ENG during the inception of this study. However, given the nature of the 6MWT as a self-paced/self-limiting field test, there is no "gold standard" of another self-paced exercise test that is as widely established and used as the 6MWT-ENG. Therefore, we decided to test criterion validity against the CPET. The consistently weak positive correlations of the VO_2 max and 6MWT-CHN ($r = 0.315$, $p = 0.023$), with the VO_2 max and 6MWT-ENG ($r = 0.309$, $p = 0.026$), demonstrate the similar magnitude of positive correlations between the two versions of the 6MWT instructions with VO_2 max. The strong correlation between 6MWT-CHN and 6MWT-ENG proves the equivalency of the two sets of instructions. Hence, we extrapolated the establishment of criterion validity, given the mentioned conditions.

Despite the positive correlation of VO_2 max and 6MWD in our study, we acknowledge that the correlation was poor when compared with the established literature of the 6MWT in both healthy and diseased populations. We recognize that another major limitation of this study was the homogeneity of the participants. Despite a broad age criterion for the validation study, our participants were younger with a mean (SD) age of 25.9 ± 8.79 years. Selection bias may have persisted even with convenience sampling due to the enrollment procedure, which required a level of tech-savviness to navigate and complete the online questionnaire independently. Additionally, the older adults were either reluctant to perform the treadmill test or had existing comorbidities like high blood pressure and diabetes mellitus that did not meet the inclusion criteria of the PAR-Q+. As such, the reach of the study may have been hampered, and thus generalized results. Although the perceived understanding of the translation was well-received with the current participant group, the colloquial adaptation of a language may vary across different generations of individuals. Hence, future studies should recruit participants from varying backgrounds and age groups.

In addition, our pilot study for assessment of reliability had a small sample size of six participants, of whom all were healthy. These two factors could have contributed to the excellent intra-rater and inter-rater reliabilities and may not translate to individuals with existing morbidities. Although the sample size of our study was small compared with other studies, our study managed to generate significant results to affirm the similarity in conceptual terms of our translated instructions compared to the original English instructions. Nonetheless, the results of factor analysis should be interpreted with caution, and larger samples size can be evaluated in future studies.

Conclusion

This study developed and validated a Chinese version of the 6MWT instructions. The established reliability and validity of the 6MWT-CHN version

indicate that the psychometric properties are similar to the original English version. With this 6MWT-CHN version, clinicians can conduct the 6MWT in Chinese (Mandarin) while ensuring standardization. Further testing on the 6MWT-CHN in other patient populations may be warranted.

Acknowledgment

The authors would like to thank the participants who took precious time off to participate in this study to aid in the validation of the Chinese 6MWT instructions.

Conflict of Interest

The authors declare that they have no competing interests.

Author Contributions

V. Z.-Y. T. contributed to the execution of the study, analysis of the data, revision of the manuscript critically for relevant intellectual content and assembly to the manuscript; M. Q. L. and D. L.-W. W. contributed to the execution of the study, analysis of the data, and revision of the manuscript critically for important intellectual content; K. S. H., M. Y. C., C. C. Y., and M. T. Y. contributed to the conception and study design, revision of the manuscript critically for important intellectual content and final approval of the manuscript. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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The utility of upper limb loading device in determining optimal walking ability in ambulatory individuals with spinal cord injury

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Background: Walking devices are frequently prescribed for many individuals, including those with spinal cord injury (SCI), to promote their independence. However, without proper screening and follow-up care, the

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individuals may continue using the same device when their conditions have progressed, that may possibly worsen their walking ability.
Objective: This study developed an upper limb loading device (ULLD), and assessed the possibility of using the tool to determine the optimal walking ability of ambulatory participants with SCI who used a walking device daily ($n = 49$).
Methods: All participants were assessed for their optimal walking ability, i.e., the ability of walking with the least support device or no device as they could do safely and confidently. The participants were also assessed for their amount of weight-bearing on the upper limbs or upper limb loading while walking, amount of weight-bearing on the lower limbs or lower limb loading while stepping of the other leg, and walking performance.
Results: The findings indicated that approximately one third of the participants (31%) could progress their walking ability from their current ability, whereby four participants could even walk without a walking device. The amount of upper limb loading while walking, lower limb loading ability, and walking performance were significantly different among the groups of optimal walking ability ($p < 0.05$). Furthermore, the amount of upper limb loading showed negative correlation to the amount of lower limb loading and walking performance ($\rho = -0.351$ to -0.493, $p < 0.05$).
Conclusion: The findings suggest the potential benefit of using the upper limb loading device and the amount of upper limb loading for walking device prescription, and monitoring the change of walking ability among ambulatory individuals with SCI.

Keywords: Weight-bearing; walker; crutches; walking; rehabilitation; physical therapy.

Introduction

A walking device is commonly prescribed to many individuals, including those with spinal cord injury (SCI), to allow various degrees of upper limb contribution to compensate for the lower limb and mobility deficits, and to promote the independence and effects of task-specific walking practice for these individuals.[1,2] Therefore, individuals who use different types of walking devices should have different weight-bearing or lower limb loading abilities, and different requirements for upper limb contribution while walking.[2–4] Then, when their lower limb loading ability is improved, individuals could reduce the need for upper limb involvement and progress their walking performance.[2,5,6]

The reduction of upper limb contribution when the individuals could walk safely, allows for a less cumbersome, reciprocal, and efficient walking manner,[2–4] as well as minimizes the possible negative impacts due to long-term use of a walking device (e.g., the development of abnormal walking manners with high attention and metabolic demands, as well as the risk of musculoskeletal injuries in the upper extremities and back).[7–12] Contrarily, early reduction of the upper limb contribution when individuals are unable to do so could destroy the self-confidence and safety of individuals that could affect their independence.[13] Therefore, the ability to determine the walking alteration requires periodic follow-up from an experienced health professional over time. Nevertheless, such follow-up by the same assessor may not be possible in every healthcare setting, especially in those cases with limited number of staff, that could affect data comparison among the assessors, as well as time intervals.[4,14–16] These problems may result in many ambulatory individuals with SCI lacking periodic follow-up for walking alteration, causing them to continue using the same walking device even when their walking ability has already progressed or deteriorated.[1,6,13] This issue is important nowadays given that the present rehabilitation lengths have dramatically decreased,[17] and that many ambulatory individuals with SCI need a walking device, particularly a standard walker, at the time of discharge to promote their independence, and minimize the burden of care on family members.[1,3] The researchers hypothesized that the development of an upper limb loading device (ULLD) to assess the amount of weight-bearing on the upper limbs or upper limb loading during walking may indirectly reflect the lower limb loading ability and walking performance of ambulatory individuals with SCI. Thus, this study developed a ULLD from an adjustable walker and used the tool to measure the amount of upper limb loading while the participants were walking. Then the study compared the amount of upper limb loading, lower limb loading ability, and walking performance among the groups of ambulatory individuals with SCI who walked at their optimal ability. Furthermore, the study explored the

correlation between the amount of upper limb loading, lower limb loading ability, and walking performance in ambulatory individuals with SCI. The findings would suggest the use of upper limb loading and a ULLD as an alternative measure to prescribe a walking device and monitor the change of walking ability of individuals who used a walking device in various settings (i.e., hospital, clinic, community, or patient's home).

Materials and Methods

Participants

This study cross-sectionally recruited community-dwelling ambulatory individuals with SCI who walked independently with a walking device from June 2018 to August 2019. The inclusion criteria were as follows: at least 18 years of age, having SCI from traumatic and non-progressive causes, and experiencing a subacute and chronic stage of injury.[1,18] Individuals were excluded if they had any signs and symptoms that might affect the outcomes — for example, deformity in the joints of the extremities, leg length discrepancy, and pain in the musculoskeletal system with a pain score of more than 5 out of 10 on a visual analog scale.[1,6] From the sample size calculation for a correlation study with the alpha level set at 0.05, power of test at 0.8, and level of correlation at 0.55 (from a pilot study, $n = 15$), the findings indicated that the study needed at least 40 participants. Every participant signed informed consent, which was approved by the local Ethics Committee for Human Research (HE601164) prior to participation in the study.

Research procedure

The research protocol was divided into two phases, including upper limb loading device development and data collection. Details of each phase are provided in the following.

Phase I: Upper limb loading device development

The ULLD was developed from an adjustable walker and the digital load cells [model: DBBP-100; maximum capacity: 100 kg/side; mini-patent application number: 2003003449; see Fig. 1(a)] to properly quantify the amount of upper limb loading during walking as controlled by a mobile application. Subsequently, the tool was calibrated using a standard calibration system based on the United Kingdom Accreditation Service (UKAS M3003, edition 3: 2019, with an accuracy of up to 0.2 kg and an uncertainty of measurement of ±0.2 kg). After development, the tool could generate the amount of upper limb loading in real-time while an individual was walking [Fig. 1(b)] and the

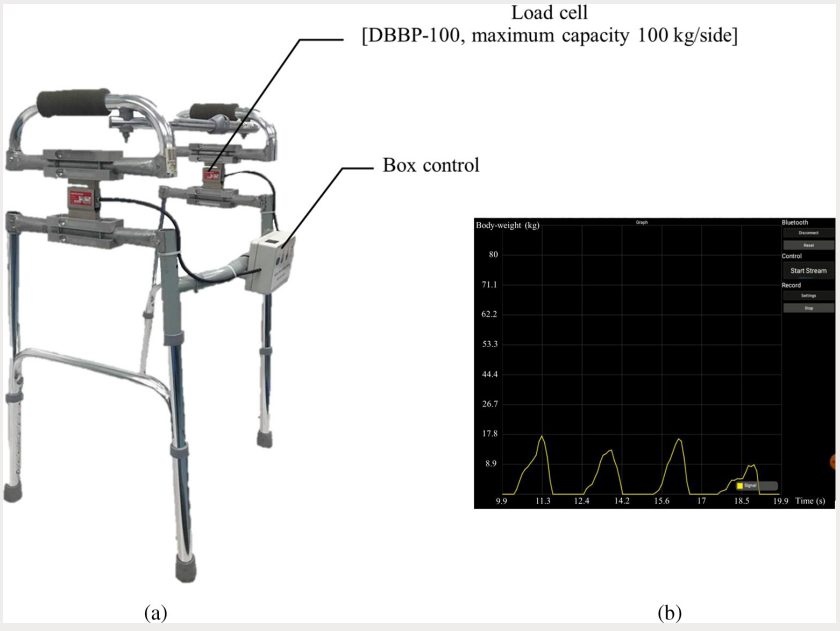

Fig. 1. (a) An upper limb loading device and (b) its real-time display section from mobile application (mini-patent application number: 2003003449).

data was automatically saved in digital memory as an Excel file for further analysis. Then the researchers used the tool to assess the amount of upper limb loading of the participants.

Phase II: Data collection

The eligible participants were interviewed and assessed for their demographics and SCI characteristics, including gender, age, cause of injury, post-injury time, level and severity of SCI, using sensorimotor scores and criteria from the American Spinal Cord Injury Association Impairment Scale (AIS), and the type of walking device used in their daily walking. Subsequently, participants were assessed for the amount of upper limb loading while walking, lower limb loading ability while stepping of the other leg, and walking performance using the 10-m walk test (10MWT) and the 6-min walk test (6MinWT) in a random order. Details of the tests are as follows.

Upper limb loading while walking. The participants walked along a 10-m walkway with a ULLD at their preferred speed. Their amount of upper limb loading throughout the walkway was automatically saved in digital memory, and the average upper limb loading along the walkway was reported in terms of the percentage of body weight.

Lower limb loading ability. Participants were assessed for their weight-bearing ability on the lower limbs or lower limb loading ability during a single limb support period while stepping with the other leg. Participants stood in a step-standing position and placed the leg being tested on a digital load cell (model: L6E3-C, 200 kg-3G; maximum capacity 200 kg with an accuracy of 0.035 kg).[19] They were instructed to shift their body weight onto the leg being tested as much as possible and step forward with the other leg with or without using their arms, according to their ability. Participants performed five trials for each lower extremity in which the first two trials served as practice trials, and the average lower limb loading ability over the other three trials of each lower limb was reported as a percentage of body weight.[20]

Optimal walking ability. Previous studies[2–4] reported the levels of body weight support by different types of walking devices, i.e., up to 75–100% of body weight for a standard walker, up to 50% of body weight for crutches, and only 15–20% of body weight for a single cane. Therefore, participants who had lower limb loading ability better than their usual ability were asked to gradually change a walking device to the ones with the least support or no device as they could walk safely and confidently as determined using the opinion of an experienced physical therapist. The findings were used to indicate an optimal walking ability of the participants.[6]

The 10-m walk test. The 10MWT measures an ambulatory status of the participants in terms of walking speed. Outcomes of the test are associated with overall quality of gait and community participation of the individuals.[21] Participants walked at their optimal ability (with or without a walking device) at a preferred walking speed along a 10-m walkway. The time required for over 4 m in the middle of the walkway was recorded in order to minimize acceleration and deceleration effects. The average finding over the three trials was used for data analysis.[22,23]

The 6-min walk test. The test measures the functional endurance of ambulatory individuals with SCI.[24] Participants walked along a rectangular walkway at their optimal ability (with or without a walking device) for as long as possible in 6 min. During the test, participants were allowed to rest as needed and continue walking as soon as they could, without stopping the timer. Every minute during the test, participants were informed about the time left and offered encouragement. The distance covered after 6 min was recorded.[24,25]

Data analysis

Participants were arranged into the groups of optimal walking ability. With non-normal data distribution, descriptive statistics [median and interquartile range (IQR)] were used to explain the demographics, SCI characteristics, and the findings of the study. The Kruskal–Wallis test or Chi-square test was applied to compare the findings among the groups for continuous and categorical data, respectively. Then the Mann–Whitney U-test was applied to analyze the differences for every pairwise comparison. Furthermore, Spearman's rank correlation coefficient was applied to quantify the relationship between the amount of upper limb loading and other variables relating to walking performance of the participants. A p-value less than 0.05 was considered statistically significant.

Results

Forty-nine ambulatory participants with SCI who daily walked with a walking device completed this

Table 1. Demographics and SCI characteristics of participants.

Variable	All participants ($n = 49$)*	Groups of optimal walking ability				p-Value
		Walker ($n = 12$)	Crutches ($n = 14$)	Cane ($n = 19$)	None ($n = 4$)	
Age (year), median (IQR)	58 (48.50–64.50)	65.50 (51–69.75)	54 (40.75–58.75)	60 (45–63)	58.50 (54–66.75)	0.088[b]
Post-injury time (months), median (IQR)	61 (25–120)	96 (46–150)	78 (24–160.25)	53 (26–108)	18 (11.25–58.50)	0.099[b]
Stage of injury: Chronic,[a] n(%)	45(91.8)	12(100)	12(85.7)	18(94.7)	3(75)	0.322[c]
Gender: Male,[a] n(%)	34(69.4)	9(75)	8(57.1)	16(84.2)	1(25)	0.077[c]
Cause: Traumatic,[a] n(%)	21(42.9)	6(50)	6(42.9)	8(42.1)	1(25)	0.855[c]
Level of injury: Paraplegia,[a] n(%)	30(61.2)	6(50)	10(71.4)	12(63.2)	2(50)	0.684[c]
Severity of injury, n (%):						
AIS C	9(18.4)	2(16.7)	4(28.6)	3(15.8)	—	0.577[c]
AIS D	40(81.6)	10(83.3)	10(71.4)	16(84.2)	4(100)	
FIM-L, n(%):						
FIM-L 5	6(12.2)	2(16.7)	3(21.4)	1(5.3)	—	0.434
FIM-L 6	43(87.8)	10(83.3)	11(78.6)	18(94.7)	4(100)	

Notes: IQR: Interquartile range, AIS: American Spinal Cord Injury Association impairment scale, and FIM-L: Functional Independence Measure Locomotor. *Prior to the assessments, most participants used a standard walker ($n = 23$, 47%), followed by a single cane ($n = 17$, 35%) and the crutches ($n = 9$, 18%); [a]these variables were categorized according to the following criteria: stage of injury: subacute/chronic, gender: male/female, cause of injury: traumatic/non-traumatic SCI, and level of injury: incomplete tetraplegia/incomplete paraplegia. [b]p-Value was from Kruskal–Wallis test. [c]p-Value was from Chi-square test.

study. Most participants were males with a median age of 58 years, at a chronic stage (with a median post-injury time of 61 months), had mild lesion severity (AIS D, 82%), and could walk over a long distance (more than 50 m) with walking device (88%; Table 1).

In their daily walking, most participants ($n = 23$, 47%) used a standard walker, followed by a single cane ($n = 17$, 35%) and the crutches ($n = 9$, 18%). After assessments of their optimal walking ability, it was found that most participants could walk with a single cane ($n = 19$, 39%),

Table 2. Sensorimotor scores of the participants.

Variable	All participants ($n = 49$)	Groups of optimal walking ability				p-Value
		Walker ($n = 12$)	Crutches ($n = 14$)	Cane ($n = 19$)	No ($n = 4$)	
Motor scores						
Upper extremities (50 scores)	50 (44.50–50)	47.50 (38.75–50)	50 (50–50)	50 (45–50)	49 (41.25–50)	0.222
Lower extremities (50 scores)	35 (25.50–42)	35 (25.25–41.75)	30 (24–37.50)	37 (27–43)	41 (34.75–45)	0.150
Sensory scores						
Light-touch	76	74	76	76	71	0.168
Upper extremities (76 scores)	(72–76)	(60.50–76)	(75–76)	(76–76)	(50.25–76)	
Lower extremities (36 scores)	22 (18–30.50)	19 (18–23.50)	22 (19.50–32.25)	26 (18–35)	22 (18–32)	0.243
Pinprick	76	74	76	76	71	0.121
Upper extremities (76 scores)	(72–76)	(60–76)	(72–76)	(76–76)	(50.25–76)	
Lower extremities (36 scores)	24 (18–32)	22 (18–24)	21 (18–31.50)	26 (18–35)	22 (18–32)	0.400

Note: The data were presented using median and IQR, according to the American Spinal Cord Injury Association protocol. The p-value was from Kruskal–Wallis test.

Table 3. The upper limb loading while walking, lower limb loading ability during stepping of the other leg, and walking performance tests of the participants.

Variable	All participants ($n = 49$)	Groups of optimal walking ability: Walker ($n = 12$)	Crutches ($n = 14$)	Cane ($n = 19$)	No ($n = 4$)	p-Value
Loading ability (% of body weight)						
Upper limb loading	22.44 (14.32–30.62)	31.26 (22.85–42.79)	24.63 (15.06–32.35)	18.80^{W} (5.83–28.23)	10.05^{W,Cr} (2.15–14.99)	0.002*
LLLA of the more-affected leg	83.24 (77.76–85.28)	78.72 (70.32–81.07)	85.42 (65.58–90.72)	90.16^{W} (84.65–94.12)	92.33^{W} (87.24–96.77)	0.001*
LLLA of the less-affected leg	84.72 (77.56–91.78)	77.28 (70.55–85.55)	88.07 (71.15–91.24)	89.24^{W} (85.74–91.98)	95.21 (77.98–99.28)	0.029*
Walking performance tests						
The 10-m walk test (m/s)	0.49 (0.29–0.73)	0.29 (0.22–0.42)	0.32 (0.27–0.53)	0.70^{W,Cr} (0.50–0.86)	0.69^{W,Cr} (0.59–0.91)	< 0.001*
The 6-min walk test (m)	118.22 (75.56–142.80)	77.31 (62.98–118.48)	97.05 (69.75–153.25)	130.20^{W} (112–191.80)	182.55^{W,Cr} (153.60–216.68)	0.003*

Notes: LLLA: Lower limb loading ability. The data are median and IQR. The superscripts designate the group(s) with significant differences from the indicated group; here, W denotes walker and Cr denotes the Crutches. The p-value is from Kruskal–Wallis test, and *indicates significant difference. Pairwise differences were compared using the Mann–Whitney U-test.

Table 4. Relationship between the amount of upper limb loading, lower limb loading ability, and walking performance tests.

Variable ($n = 49$)	ρ	p-Value
Lower limb loading ability during stepping of the other leg		
Data of the more-affected side	−0.420	0.003*
Data of the less-affected side	−0.449	0.001*
Walking tests		
The 10-m walk test	−0.351	0.013*
The 6-min walk test	−0.493	< 0.001*

Note: Here, ρ is Spearman's rank correlation coefficient between the amount of upper limb loading during walking and other variables. Also, *indicates significant difference.

followed by the crutches ($n = 14$, 29%) and a standard walker ($n = 12$, 24%); four participants (8%) were able to walk without a walking device (Table 1). The demographics, SCI characteristics, and sensorimotor scores showed no significant differences among the groups of optimal walking ability ($p > 0.05$; Tables 1 and 2). Nevertheless, there were significant differences among the groups for the amount of upper limb loading while walking, lower limb loading ability during stepping of the other leg, and walking performance as determined using 10MWT and 6MinWT, particularly in those who walked with a single cane and no walking device compared to those who needed a standard walker and the crutches ($p < 0.05$; Table 3). Furthermore, the amount of upper limb loading was negatively correlated to lower limb loading ability and the outcomes of 10MWT and 6MinWT ($\rho = -0.351$–-0.493, $p < 0.05$; Table 4).

Discussion

With lower limb and mobility deficits, many ambulatory individuals with SCI need a walking device for their daily walking.[1,6] However, our findings illustrated that approximately one third of participants (31%) could progress their walking ability, whereby some were even able to walk without a walking device (Table 1). The findings also indicated significant differences in upper limb loading, lower limb loading ability, and walking performance among the groups of optimal walking ability, i.e., ability of walking with the least support or no device safely and confidently ($p < 0.05$; Table 3). Moreover, the amount of upper limb loading negatively correlated to the lower limb loading and walking performance of the participants ($\rho = -0.351$–-0.493; Table 4).

The findings were consistent with previous reports that many ambulatory individuals with SCI walked daily using a standard walker.[1,6,20] However, after assessment of the optimal walking ability, the majority of participants required a

single cane (39%), followed by the crutches (29%) and a standard walker (24%); four participants were able to walk without a walking device (8%; Table 1). This evidence was associated with the data reported from a developed country[26] wherein most ambulatory individuals with SCI used cane and crutches, while only a few participants used a standard walker. Although walking with a high-support walking device promotes safety and confidence for the individuals through upper limb involvement, such walking manners require high attention[7] and metabolic demands,[8,9] limit limb movements,[10] introduce abnormal walking manners,[11] and also enhance the risk of musculoskeletal problems in the upper extremities and back.[12] Therefore, a strategy to promote walking ability, i.e., minimizing use of the upper extremities while walking, is needed.

The findings further suggest that participants who could walk optimally with different types of walking device or without a walking device had different lower limb loading abilities and walking performances, and thus they required different amounts of upper limb loading while walking ($p < 0.05$; Table 3). Those who could walk optimally with a single cane and without a walking device needed an amount of upper limb loading less than 19% of their body weight (Table 3), which was clearly less than those needed for the ones who required standard walker and crutches (approximately 31% and 25% of their body weights, respectively; $p < 0.01$; Table 3). These findings are associated with the lower limb loading ability data that individuals who required a single cane and no walking device had a lower limb loading ability of more than 90% of their body weight (Table 3), whereas those who needed standard walker and crutches had the lower limb loading abilities of 78–79% and 85–88% of their body weights, respectively. The findings were associated with previous reports[2,3] that a single cane can support only 15–20% of the individual's body weight. Therefore, it is used in those with relatively good walking ability to enhance the body base of support, self-confidence, and tactile information during walking.[2,3] Our findings further indicated that individuals who could optimally walk with a single cane and no device were able to walk faster than 0.67 m/s, which was suggested as a threshold for the ability of walking without a walking device[27] and functional walking (faster than 0.6 m/s).[1] Having good lower limb loading ability also resulted in these individuals using their energy efficiently[8,9]; thus, they could complete a significantly longer distance walk in 6 min than those who needed walker and crutches ($p < 0.01$; Table 3).

Furthermore, the upper limb contribution while walking was negatively correlated to the lower limb loading ability and walking performance (i.e., a reduction in the amount of upper limb loading associated with the increased lower limb loading ability, walking speed, and distance covered in 6 min; $\rho = -0.351$–-0.493; Table 4). Previous studies also reported that walking with high supportive demand from the upper extremities could confound the lower limb functions, make walking cumbersome, and increase the energy expenditure that could affect walking speed and distance covered.[1,20,22,27] Thus, our findings suggested that walking devices should be prescribed to those who actually need them, along with a periodic follow-up to monitor their walking alteration over time in order to optimize their walking performance and minimize possible negative impacts that could occur due to long-lasting use of a walking device. Hicks *et al.*[28] also reported that an improved walking ability is associated with increased life satisfaction and physical functioning of the individuals. Our findings also suggest the use of a ULLD and the upper limb loading as an alternative measure for determining and the periodic follow-up of optimal walking ability of ambulatory individuals with SCI in various clinical and home-based settings.

Nevertheless, there are some limitations of the study. With the major aim to capture those with the potential of walking progression, the study recruited only those who could walk independently with a walking device. Such criteria resulted in most participants requiring rather low amounts of upper limb loading while walking (Table 3), including those who used a standard walker, and no clear differences between those who used a standard walker and the crutches ($p > 0.05$; Table 3). In addition, the cross-sectional data cannot clearly confirm the proportion of actual progression, benefits, and possible negative impacts after walking progression, as well as the causal relationship between upper limb loading, lower limb loading, and walking performance of the participants. Therefore, a further prospective study with participants having a wider range of walking abilities and data

analysis on a cut-off score for optimal walking ability specifically for individuals with SCI is needed. In addition, information on how ULLD facilitated the therapist to make the decision and the agreement between patients classified solely based on various ULL cut-offs versus the patients classified with therapist decision are also worthy to be investigated.

Conflict of Interest

The authors declare no conflict of interest.

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Author Contributions

Concept and design, interpretation of the data, critical revision of the paper for important intellectual content, final approval of the paper, provision of study materials and patients, and obtaining of funding, administrative, and technical support were made by Sugalya Amatachaya. Makamas Kumprou was involved in the concept and design, collection and assembling of data, analysis and interpretation of the data, drafting of the paper, and final approval of the paper. Pipatana Amatachaya helped in the concept and design, critical revision of the paper for important intellectual content, provision of study materials, obtaining of funding, providing administrative, logistic, and technical support, and the final approval of the paper. Thanat Sooknuan also helped in the concept and design, provision of study materials, providing technical support, and the final approval of the paper. Preeda Arayawichanon took part in the concept and design, provision of study patients, providing administrative support, critical revision of the paper for important intellectual content, and the final approval of the paper. Finally, Thiwabhorn Thaweewannakij contributed to the concept and design, provision of study patients, providing administrative support, critical revision of the paper for important intellectual content, and the final approval of the paper.

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The multi-directional reach test in children with Down syndrome

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Objective: This study investigated the limits of stability (LOS) and the movement patterns during reaching by applying the Multi-Directional Reach Test (MDRT) in children with Down syndrome (DS) aged 7–12 years old.
Methods: Thirty children with DS and 30 age and gender typical development (TD) matched children, aged 7–12 years old were recruited. Each child was asked to reach as far as possible during standing in four directions using a self-selected movement pattern. The movement patterns were classified by two experienced pediatric physical therapists.
Results: The reach distance in children with DS aged 7–9 years old was significantly shorter than TD children aged 7–9 years old for the forward and backward directions. Also, the reach distance in DS children aged 7–9 years old was significantly smaller than that of TD children aged 10–12 years old for all directions. For children with DS aged 10–12 years old, the reach distance was significantly less than that of TD children only in the backward direction. All children with DS in this study adopt a hip and mixed strategy during forward and backward reaching. In contrast, TD children adopt an adult-like movement pattern.
Conclusion: The boundary of stability in an anteroposterior (AP) direction of children with DS aged 7–12 years old was lesser than the matched TD children, especially for the backward direction. These findings may assist therapists in detecting postural control and balance problems in children with DS.

Keywords: Down syndrome; limits of stability; Multi-Directional Reach Test; movement patterns.

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Introduction

Down syndrome (DS) is the chromosome genetic disorder which most commonly causes mental impairment and developmental disability.[1] Children with DS show a deficiency of static and dynamic balance tasks, difficulty acquiring the movement skills and have a slowness of movements described as clumsy.[2,3] A standing reach is one of the essential components in functional balance and is necessary in performing daily activities.[2] Ineffective postural control and poor reaching performance during standing reaching were found in school-age (7–12 years old) children with DS. They demonstrated significantly decreased anteroposterior (AP) center of pressure (COP) displacement and forward momentum during forward reaching.[4] Moreover, the consequences of balance deficits lead to falls which relate to lacking confidence to performing daily activities, and activity restrictions.[5]

At present, several of the available clinical balance measurement tools for children with or without disabilities in any age group have been developed. Balance assessment tools are helpful in identifying whether a balance problem exists and determining the effectiveness of balance interventions.[6] Reach tests include the Functional Reach Test (FRT), the Pediatric Reach Test (PRT) and the Multi-Directional Reach Test (MDRT) which commonly assess risk of falling and the maximum limits of stability (LOS) in elderly and pediatric populations.[7,8] The variability of movements with immature nervous and musculoskeletal systems can increase the probability to fall among children.[9] Falls occur neither exactly forward nor exactly in a lateral direction. A previous study reported that school age children have a high risk of injury when falling backward.[10] Although most daily activities are performed on the anterior side of our body, leaning backwards could occur during daily routine. The task of leaning backwards is more difficult as it requires a lot of effort to control the body without falling.[11] It may prove more sensitive for identifying the balance problems. The MDRT is a single task test which evaluates the voluntary postural responses of upper limb and indirectly assesses the LOS in forward, backward, and lateral directions.[12] The MDRT is more challenging when compared with the FRT and the PRT as it is conducted on the subject in the backwards direction. In addition, the MDRT is easy for children to perform and can be interpreted and therefore yield results quickly.[11] The test demonstrated high reliability and validity with other balance measurement tools. In healthy adult and the elderly, the MDRT has excellent reliability (ICC = 0.93 to 0.95) and fair to moderate concurrent validity (concurrent validity of the MDRT with Timed Up and Go (TUG) $r = 0.26$ to 0.44 and Berg Balance Scale (BBS) $r = 0.36$ to 0.48).[13,14] In school-age typical development (TD) children, the MDRT has high inter-rater reliability (ICC = 0.80–0.86) and intra-rater reliability (ICC = 0.89–0.97) in all directions.[11] Various clinical balance tests such as FRT, four square step test (FSST), TUG are available for children with DS.[15–17] However, no study has examined dynamic standing balance using the MDRT in this population. Possibly, children with DS would demonstrate differences in their LOS in other directions compared with TD children. Hence, the MDRT in children with DS would help to examine the boundary of stability in four directions.

Therefore, the purpose of this study was to evaluate the LOS by applying the MDRT and compare the reach distances between children with DS and TD aged 7–12 years old. Exploration of the MDRT in children with DS indicated the difference of the boundary of stability and the movement patterns used for reaching between children with DS and TD. This study might be useful for detecting balance problems and providing rehabilitation programs to improve postural performance in children with DS.

Materials and Methods

A total of 65 children with DS ($n = 35$) and age and gender matched TD children ($n = 30$), aged 7 to 12 years. The calculation of the sample size was based on the pilot study which evaluated the MDRT in 10 children with DS aged 7–12 years compared with aged and gender matched TD children. The sample size was calculated by G * Power program version 3.1.9.2. A power analysis (power, 95%; $\alpha = 0.05$; effect sizes = 0.48) determined a total of 58 children required for this study. Children with DS were recruited from special education schools in Bangkok and the metropolitan region. Five children with DS aged 7–9 years were not cooperative during testing. Data was obtained from 30 children with DS and 30 age and gender matched TD children. The convenient sampling technique was used to recruit children who were eligible based on the criteria. Children with DS and

TD were divided into 4 groups: DS aged 7–9 years, DS aged 10–12 years, TD aged 7–9 years, TD aged 10–12 years. The division of groups was based on the development of postural control. Differences in the maturation of sensory systems affected the postural control between the two age groups. The 7–9 years group required to properly solve the conflict of sensory information and motor experiences for their complete motor development and postural control. On the other hand, the maturation of the integrated motor and sensory systems and the postural control strategies similar to adults were observed in the 10–12 years group.[18] Children with DS were recruited through interviewing the parents or guardians. The inclusion criteria for children with DS was presence of trisomy-21, aged 7–12 years, able to stand and walk independently, and able to follow instructions. The exclusion criteria included impairment of hearing or uncorrected visual, musculoskeletal problems that might affect standing. The study protocol was approved by the University Ethics Review Committee for Research Involving Human Research Subjects. Informed consent to participate in the research was obtained from parents and children prior to data collection.

Anthropometric data including height and weight were measured and recorded before performing the MDRT. The MDRT tool in this study consisted of a yardstick and a bubble level was used to ensure that the level of the yardstick was horizontal to the floor. A slide pad was used to evaluate reach distance (Fig. 1). The MDRT was administered in a private room without noise and disturbance. The order of reaching directions was randomized by computer program. At the beginning of measuring the MDRT, a child was asked to stand barefoot on a sheet of paper which was fixed on the floor. Stance width was equal to shoulder width. Foot position was traced in order to prevent any starting point change. The testing procedures were explained and demonstrated by the same rater. Each child outstretched an arm to shoulder height, made a fist with the thumb in palm. All children used their dominant arm for forward and backward reaching and used right and left arms for lateral reaching. The child was instructed to "reach to the (direction given) as far as possible, without lifting the feet, stepping forward or losing their balance and to maintain that position for two seconds", and "lean backwards as far as possible" for the backward direction. The reach distances were measured between starting and ending position. The child was guarded during testing. For all directions each child had one practice trial and three trials of the test. Ten-second and one-minute rests were given between trials and directions, respectively. The best performance of the three successful trials was used for analysis. In addition, the children's height was a covariate in analyses.

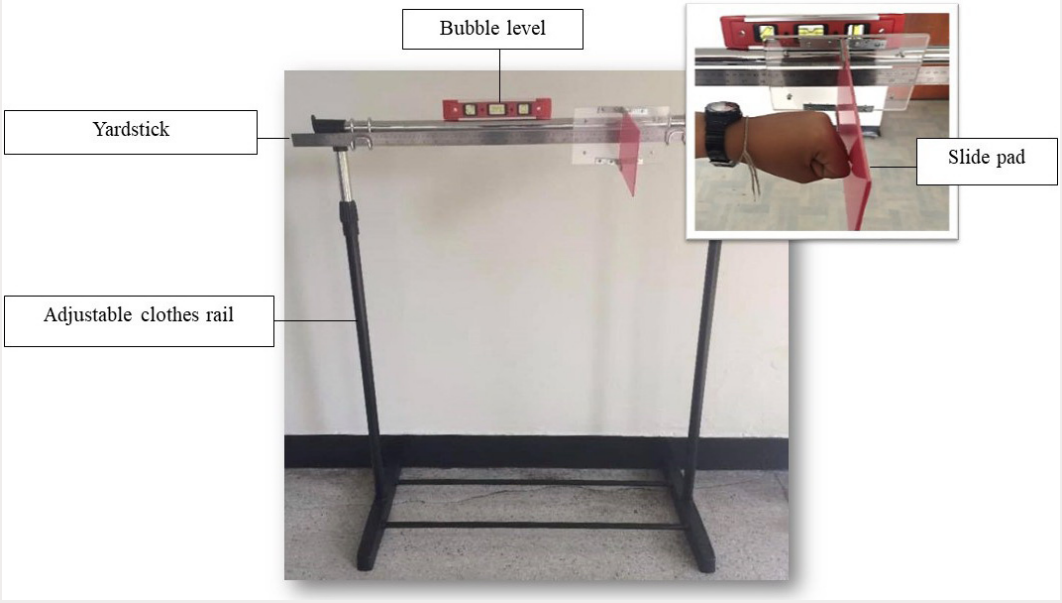
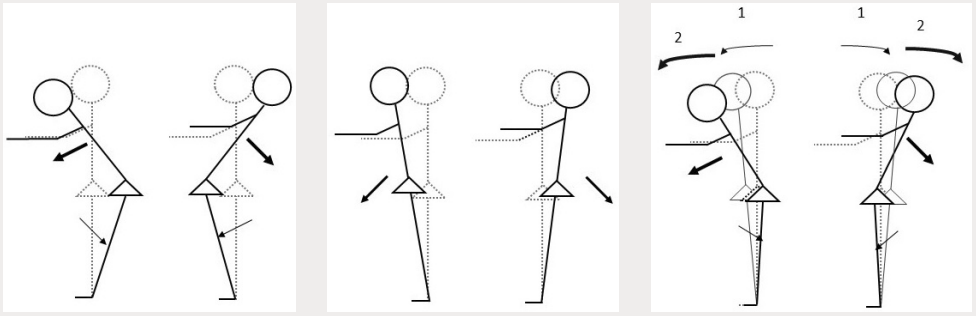


Fig. 1. MDRT tool consisted of a yardstick, a bubble level and a slide pad.



(a) Hip strategy (b) Ankle strategy (c) Mixed strategy

Fig. 2. The movement patterns during forward and backward reaching.

A reliability evaluation was performed in a pilot study with 10 children with DS aged between 7 and 12 years. They were evaluated by two pediatric physical therapists who had more than two years of clinical experience. For the intra-rater reliability of the MDRT, in the first session, the reach distance in each direction for each child was measured three trials by the first rater, and then again 10 min later by the second rater. In the second session, the whole procedure was performed by the same two raters with the children again 8 hours after the first session. The intra-rater reliability was moderate to excellent (the 1st rater, ICC = 0.72–0.90 and the 2nd rater, ICC = 0.70–0.82).

The inter-rater reliability of the MDRT was assessed by two raters. The first rater explained and then evaluated the reach distances in each direction three trials for individual child, who then took a 10 min seated rest. The second rater then carried out an evaluation using the same testing procedure. The inter-rater reliability of the MDRT estimate varied from fair to excellent (ICC = 0.47–0.915) in all directions. Regarding the low estimates, this may be due to the rater's experience. It was probably that the rater who had longer experience in applying the MDRT might have greater self-efficacy in using the test. The self-efficacy of the rater is associated with their confidence, proper task performance, and making the appropriate decisions in any situation.[17] Nevertheless, all children were given the similar testing set-up and testing protocol that included standardized verbal instructions and visual demonstrations.

Later, the movement patterns during reaching considered and classified by the same two raters who conducted the MDRT. All children were allowed to reach in a self-selected movement pattern. The movement patterns during reaching were analyzed using the video recorded by camera. Movement patterns were classified for the best performance trial for each subject. The raters watched the videos separately. Inter-rater agreement between the two raters was high (95% confidence intervals for kappa coefficients ranged from 0.76 to 0.89 and 0.70 to 0.86) for forward and backward directions. Concerning classification, the movement patterns were divided into three strategies based on the study by Liao and Lin[19] as shown in Fig. 2. First, the hip strategy, whereby the body moves as a double-segment inverted pendulum, while the upper part of the trunk moves in the opposite direction from the lower limbs during the reaching. Second, an ankle strategy, the primary movement occurring at the ankle joint and the whole body moving as a single-segment inverted pendulum. Third, the mixed strategy is executed by the ankle joint moving at the beginning and then the trunk forward or backward bending with hip flexion or extension. The mixed strategy is achieved through hip flexing or extending at the hip, without the lower limbs backward or forward.

Statistical Analysis

The data analysis was performed using the IBM SPSS Statistics (version 22.0) software. The normality of all variables was checked by Kolmogorov–Smirnov test. Descriptive statistics were applied to the characteristics data and reach distances. The independent sample t-test was used to determine the between-group differences in the participants' characteristics. The effects of group and direction on all the calculated variables were evaluated using 4 (groups: DS aged 7–9 years, DS aged 10–12 years, TD aged 7–9 years, TD aged 10–12 years) × 4 (directions: forward, backward,

leftward, rightward) two-way mixed analysis of variance (ANOVA) for repeated measures. A Tukey post-hoc test was performed to assess differences between groups. The level of statistically significant differences was set at p-value < 0.05.

Results

The characteristics of children with DS and TD children are presented in Table 1. Regarding the weight, there were no significant differences between children with DS and TD children. The heights of the children with DS were shorter than the TD children ($p < 0.001$). The reach distances in each direction for all children with DS and TD is shown in Table 2. There were interactions between group and direction effects for the reaching distance ($F_{9,168} = 2.06$, $p = 0.036$). There was significant difference in forward, backward, leftward and rightward directions between groups ($F_{3,56} = 13.10$, $p = 0.001$). Children with DS aged 7–9 years old had significantly smaller reach distances than TD children aged 7–9 years old in both forward and backward directions ($p < 0.05$). In children with DS and TD children aged 10–12 years old, the reach distances only showed significant differences in the backward direction ($p < 0.05$). In addition, the reach distances for all directions in children with DS aged 7–9 years old demonstrated significantly shorter distances when compared with TD children aged 10–12 years old ($p < 0.05$). The direction effects were found in all groups ($F_{3,168} = 143.89$, $p = 0.0001$). The reach distance in the forward direction was the highest value while the reach distance in the backward direction was the lowest value in all direction for all four groups ($p < 0.001$). Lateral reach distances were symmetrical, and no significant difference was found between leftward and rightward for all groups ($p > 0.05$).

The movement patterns during forward and backward reaching in each group are included in Figs. 3 and 4. Almost all children with DS adopted hip and mixed strategies. In the DS aged 7–9

Table 1. Characteristics of the participants.

	DS 7–9 years ($n = 15$) (mean ± SD)	TD 7–9 years ($n = 15$) (mean ± SD)	p value	DS 10–12 years ($n = 15$) (mean ± SD)	TD 10–12 years ($n = 15$) (mean ± SD)	p value
Age (years)	8.29 ± 0.59	8.32 ± 0.64	0.880	10.76 ± 1.08	10.71 ± 1.02	0.906
Gender (male: female)	4:11	4:11	—	7:8	7:8	—
Weight (kg)	25.87 ± 8.22	28.38 ± 5.43	0.330	34.13 ± 9.86	35.55 ± 5.71	0.636
Height (cm)	121.37 ± 6.72	128.61 ± 4.89	0.002*	129.6 ± 6.76	143.93 ± 8.03	0.001**

Notes: SD: standard deviation; *statistically significant, $p < 0.05$; **statistically significant, $p < 0.001$.

Table 2. Group comparison of the reach distance in all directions.

Group	Forward (cm) (mean ± SD)	Backward (cm) (mean + SD)	Leftward (cm) (mean ± SD)	Rightward (cm) (mean ± SD)	Main effects
DS 7–9 years ($n = 15$)	16.2 ± 2.3	8.1 ± 2.1[a]	12.2 ± 1.6[a,b]	12.4 ± 1.3[a,b]	$F_{9,168} = 2.06$ $p = 0.036$
TD 7–9 years ($n = 15$)	20.7 ± 3.9*	10.9 ± 1.7*[,a]	14.1 ± 2.9[a,b]	14.4 ± 2.6[a,b]	$F_{3,56} = 13.10$ $p = 0.001$
DS 10–12 years ($n = 15$)	18.9 ± 4.8	8.6 ± 2.6[a]	13.3 ± 2.4[a,b]	13.5 ± 3.5[a,b]	$F_{3,168} = 143.89$ $p = 0.0001$
TD 10–12 years ($n = 15$)	21.2 ± 3.9*	11.8 ± 0.9*[,±,a]	15.3 ± 3.1*[,a,b]	15.4 ± 1.5*[,a,b]	

Notes: *Significant difference between group when compare with DS 7–9 years ($p < 0.05$).
± Significant difference between group when compare with DS 10–12 years ($p < 0.05$).
[a]Significant difference within group when compare with forward direction ($p < 0.001$).
[b]Significant difference within group when compare with backward direction ($p < 0.001$).

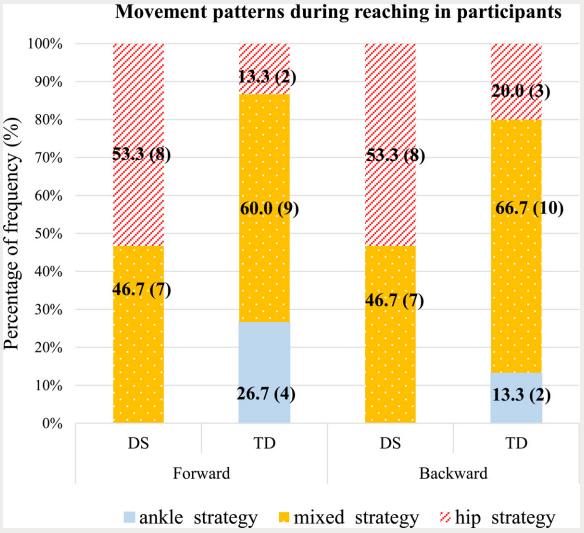


Fig. 3. Frequency distribution of each strategy in children with DS and TD children aged 7–9 years old.

years, the hip strategy was the dominant movement pattern during forward and backward reaching. The mixed strategy was the dominant movement pattern in the DS aged 10–12 years. In contrast, the TD children adopted hip, mixed, and ankle strategies when given the same instructions. In the TD aged 7–9 years, the mixed strategy was the dominant pattern during forward and backward reaching. Conversely, the ankle strategy was the dominant pattern during forward reaching in the TD aged 10–12 years. The mixed strategy was the dominant pattern during backward reaching.

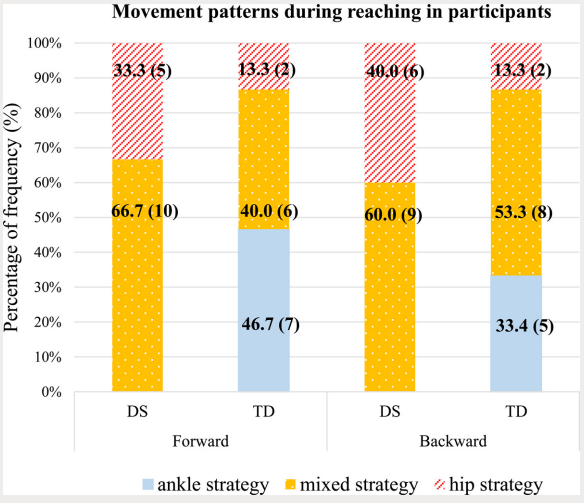


Fig. 4. Frequency distribution of each strategy in children with DS and TD children aged 10–12 years old.

Discussion

This is the first study to evaluate children with DS aged 7–12 years using the MDRT. We investigated dynamic balance ability from the reach distance and movement pattern in children with DS. Children in each group used different movement patterns during forward and backward reaching.

This study found that children with DS in both 7–9 and 10–12 years groups had significantly shorter reach distance in the backward direction, compared to TD children. Backward reaching is the most challenging task, requiring a shift in the body weight toward the rear which is unable to depend on visual information.[8] The ability to lean backward was limited to the biomechanical arrangement of the ankle and foot which allows greater ability for forward movement than backward movement,[8] sensorimotor deficiency and fear of falling.[13,20] It is possible that individuals with DS demonstrated deficits in sensorimotor, including poor sensory organization, delayed activation of postural muscles, inefficient postural control strategies.[21] In addition, children with DS were unfamiliar with backward reaching. Mostly daily activities are commonly performed in front of the body.[11] These might affect their confidence to perform the movement in the backward direction. Therefore, backward reaching is the most restrictive when compared to TD children. Moreover, the lowest reaching distance was observed in the backward direction for both children with DS and TD. This may be due to the great effort to control the body without falling, which is required when leaning backward. Furthermore, the reason for the backward reaching distance being lower than the forward reaching distance could be because the angle obtained from the hip extension is much smaller than the hip flexion angle.[11]

Focusing on the forward direction, there were significant differences between children with DS and TD in aged 7–9 years old, and the children with DS aged 7–9 years old and the TD aged 10–12 years old. This result shows that children with DS aged 7–9 years old had a restrictive boundary of stability in the forward direction. These results correspond with previous studies[4,22] whereby children with DS had significantly smaller AP COP displacement than TD children in the forward reaching phase and during the forward dynamic tasks. The smaller value was probably a result of a trunk stiffening strategy which exhibited trunk

stabilization and less movement to compensate for their impairments. The body's degrees of freedom adjustment are required to maintain postural stability and perform the tasks.[7] During reaching, adopting the stiff trunk decreases the degree of freedom and simplifies inter-segmental coordination in order to complete a task.[4,7]

Children with DS exhibited reliance on hip strategy during both forward and backward reaching. Liao and Lin[19] reported that older adults and patients who had balance deficits adopt a hip strategy during the FRT. This may be due to compensatory postural adjustment in order to return the COG to the center of BOS.[23] Possibly, children with DS also need to keep the COG within the BOS in order to maintain stability. The findings in this study are consistent with the reporting of a previous study, that children with cerebral palsy (CP) moved their COP less in the AP direction compared with TD children while reaching forward. They used this strategy to compensate for their poor ankle control.[24] However, half of children with DS in younger group also exhibited the mixed strategy. According to the previous study, researchers showed that the mixed strategy was the second highest in frequency during the FRT motion in healthy older adults. In this pattern, the forward reaching is executed by bending the trunk forward with hip flexion and without moving the lower limbs in opposite directions, the forward weight shift is controlled by a contraction of ankle plantarflexors.[23] The magnitude of ankle plantarflexor torque was higher than the magnitude of the hip flexor torque in the mixed strategy which was associated with larger COG displacements that indicated better balance control. The mixed strategy contains the hip and ankle strategies which are transient features of an adaptive process in order to produce an optimal postural response.[25] This implies that some children with DS who adopted the mixed strategy might have greater postural control than children with DS who adopted the hip strategy.

Interestingly, the ankle strategy was not observed in all children with DS. The ankle strategy in forward and backward reaching is controlled by the eccentric contraction of the surrounding muscles of the lower limbs especially the ankle plantarflexors in forward reaching, dorsiflexors in backward reaching, followed by activation of the trunk muscles.[23,25] It requires precise somatosensory information.[26] Children with DS presented a significant decrease in plantar flexor moments, the muscle power and higher hypotonia and ligament laxity at the ankle joint.[27,28] These impairments may result in the decrease of the proprioceptive input[29] that partially causes their inability to adopt the ankle strategy. In contrast, the ankle strategy was used by TD children and this increased with age. It indicated that dynamic balance and adult-like movement pattern improved within TD children as they grew older. This finding demonstrates that children in all groups used different strategies to maintain their balance in the AP direction. Children with DS preferred to adopted hip and mixed strategies in order to compensate for the insufficient control of the ankle and in the attempt to keep the COG within the BOS.

Additionally, there was no significant difference in the forward reach distance between children with DS aged 10–12 years and TD peers. This result reveals that children with DS could improve the ability to move the COG's body toward the LOS in the forward direction. A previous study found that children with DS aged 10–11 years spent more time in moderate-to-vigorous physical activity compared with other age groups.[30] They might have more experience performing activities in daily life such as physical education, sport, etc. Another possible explanation could be connected to the different movement patterns used by the DS and TD children. The reach distances obtained from the ankle strategy adopted by TD children were less than the hip strategy in children with DS. According to the previous study, the reach distances in ankle strategy were significantly less than the hip strategy.[19] Thus, there was no significant difference in the reach distance between DS and TD children due to the increasing of TD children aged 10–12 years who adopted the ankle strategy.

The lateral reach distances in the children with DS showing no significant difference from TD children in similar age may be due to familiarity with preserving mediolateral (ML) stability in children with DS. The wider step width is one of the typical features of school-age children with DS during walking.[31] The increase in the step width conduces to ML stability by exhibiting a wider BOS. This characteristic is due to the compensatory strategies of balance preservation.[32] In addition, during the quiet standing and dynamic task movement, individuals with DS demonstrated a significant increase in the ML COP displacement compared to normal subjects.[22,27] Their characteristics

of having a wider BOS and the COP within their BOS seems adequate in providing greater stability in this position. Moreover, the efficacy of ankle joint control is not enough to maintain standing stability, a balance strategy involving the hip occurs instead.[33] Therefore, they familiarized themselves with the using hip in order to control stability. The balance in ML direction is the responsibility of the hip muscles.[34] The greater hip-generated work possibly leads to a more stable posture during lateral reaching. This result revealed that lateral reaching is not challenging enough for children with DS when compared with similar age TD children. However, children with DS aged 7–9 years old demonstrated significantly smaller lateral reach distance than TD children aged 10–12 years old. By 10 years of age, children with TD present a mature postural control that is similar to that of adults.[35] This implies that the balance in children with DS aged 7–9 years is not yet fully completed.

This result indicates that children with DS aged 7–9 years demonstrated both insufficient forward and backward reaching, while insufficient backward reaching was observed in children with DS aged 10–12 years. This may increase the risk of falling forwards and backwards. Therefore, restoring their ability to shift the COG in the stability area for the forward and backward directions should be considered as important part of a dynamic balance rehabilitation program for children with DS aged 7–12 years. Our results suggest that the MDRT may be useful and more sensitive to identifying the standing balance deficit and discrepancy of the LOS especially in the backward direction in children with DS and TD aged 7–12 years old. However, this requires a laboratory measurement tool to discriminate different balance impairment. Moreover, the MDRT may be limited to children who have the ability to understand and follow instructions. A limitation of this study was that information on the participation of children with DS in any rehabilitation program or extracurricular activities was not collected. This information may confound the significant findings between children with DS and TD. Thus, generalizations of this study findings should be made cautiously. Further study needs to collect information on the physical activities of the participants and investigate different populations who have poor balance performance, such as autism, CP, developmental coordination disorder, etc.

Conclusion

The decreasing of the boundary of stability in an AP direction indicated inefficient postural balance in children with DS. Moreover, movement patterns during reaching in children with DS were different from TD that may be associated with the difference of the ability to maintain postural stability. This finding may be helpful for physical therapists to detect balance deficits and promote the balance rehabilitation program for children with DS.

Conflict of Interest

There are no conflicts of interest for any author of this paper.

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Author Contributions

Data collection, data analysis, and manuscript writing were carried out by Promsorn. Data analysis, critical discussion, revising manuscript, and management of the study were carried out by Taweetanalarp.

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Erratum

A systematic review and meta-analysis on effect of spinal mobilization and manipulation on cardiovascular responses

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The systematic review erroneously reported that the study by Roffers *et al.* (Ref. 27) was conducted in the US while in fact it was conducted in El Salvador. Roffers *et al.* also would like to add that their subjects were classified into clinically relevant classes (Normotensive, Prehypertensive, Stage I hypertension, and Stage II hypertension), and that about 72% of their subjects were hypertensive.

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