Received: 18 November 2019 | Revised: 14 February 2020 | Accepted: 24 February 2020

DOI: 10.1111/hae.13955

ORIGINAL ARTICLE

Haemophilia WILEY

Effects of performing dual tasks on postural sway and postural control complexity in people with haemophilic arthropathy

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Abstract

Introduction: People with haemophilic arthropathy (PWHA) have impairments in postural control. However, little is known about the effects of demanding conditions, including the unipedal stance and dual tasks, on postural control in PWHA.

Aim: Determine the effects of performing dual tasks while in the one-leg stance on postural sway and postural control complexity in PWHA vs. healthy active (HAG) and non-active (HNAG) groups of individuals.

Methods: Fifteen PWHA and 34 healthy subjects (18 active and 16 non-active) were recruited. Vertical (V), mediolateral (ML) and anteroposterior (AP) centre of mass signals were acquired using a 3-axis accelerometer placed at the L3/L4 vertebrae of subjects as they performed the one-leg stance under single and dual-task conditions. Sway balance and the complexity of postural control were studied via root mean square (RMS) acceleration and sample entropy, respectively. Increased complexity of postural sway was attributed to increased automatism of postural control.

Results: RMS values for PWHA were higher than HAG under both conditions for the V and ML axes, and higher than HNAG under the dual-task condition for the ML axis. Sample entropy was lower in PWHA than healthy individuals under the dual-task condition for V and ML axes, and the single-task condition for the ML axis ($P < .05$).

Conclusion: PWHA had poorer postural sway and decreased postural control complexity when performing a one-leg stance than healthy people, especially when the dual-task condition was applied. These results may help to design new approaches to assess and improve postural control in PWHA.

KEYWORDS

accelerometry, centre of mass, haemophilia, motor control, postural control, sample entropy

1 | INTRODUCTION

In people with haemophilic arthropathy (PWHA), joint destruction is accompanied by changes in the musculoskeletal system such as loss of muscle force, decreased range of motion and proprioception (ie sense of joint position).[1,2] These changes negatively impact postural control in children and adults with PWHA,[3,4] resulting in an increased risk of functional deterioration and suffering new or recurrent injuries.

To adjust the position of the centre of mass during standing tasks, the central nervous system integrates information provided by the somatosensory (ie skin, ligament, capsule and muscle-tendon unit), visual and vestibular systems with minimum conscious effort.[5-7] Postural adjustment during daily life activities is almost automatic, requiring minimal cortical activity.[7,8] This level of postural control can be studied via a complexity (ie regularity) analysis of postural sway through calculation of sample entropy,[9-11] where a greater complexity of postural sway is attributed to reduced levels of attention[10] and reduced physical capacity levels.[12] A recent study analysing sample entropy generated in patients in a bipodal stance reported that PWHA have decreased levels of lower postural control and complexity of postural sway than healthy controls.[11] These results indicated that PWHA have a lesser degree of automatism of postural control. However, the complexity of postural sway as more demanding motor and cognitive tasks, such as one-leg stances and dual tasks, has not been investigated in PWHA.

A one-leg stance position is usually used to assess postural control and improve balance performance since it requires a high degree of motor control, using different motor synergy configurations of the lower limb and trunk muscles.[13-17] The effect of a secondary task (eg cognitive dual task) on postural control depends on cortical sources to maintain static balance.[7] Moreover, a cognitive task may be used during a bipodal stance to increase the complexity of postural sway [10] and increase sway balance in healthy young and elderly individuals.[18-20] Furthermore, reports have shown that dual tasks decrease postural performance in older stroke survivors and patients experiencing low back pain, osteoarthritis of the knee and ankle sprain.[21-25] However, information regarding the effect of dual tasks on sway balance and postural control complexity in PWHA is scarce.[11] Investigating the effects of dual postural tasks in this population may facilitate the implementation of improved approaches to assess postural control and promote the creation of individualized balance training protocols. In addition, incorporating cheap and easy-to-use postural assessment tools has the potential to be very useful in clinical practice. For instance, the use of laboratory-grade force plates for assessing postural control has traditionally been considered the gold standard; however, in recent years, accelerometers have increasingly been used as a result of their low cost, reliability and small size.[26]

This study aimed to determine the effect of performing a dual task while in a one-leg stance on postural sway and the complexity of postural control in PWHA compared to healthy active (HAG) and non-active (HNAG) groups. Our hypothesis was that, due the decreased proprioception and constraints of the sensorimotor system in PWHA,[1,3,11,27] these patients would display less automaticity and a greater degree cognitive demand would be required to maintain a static postural position while performing dual tasks, resulting in increased postural sway and decreased complexity of postural control.

2 | METHODS

2.1 | Participants

Thirty-four healthy individuals and 15 PWHA volunteered to participate in the study. Subjects of both groups were Male, aged 18–35 and had a body mass index lower than 35 kg/m^2. Specific inclusion criteria for the PWHA group were a diagnosis of haemophilia A or B, haemophilic arthropathy with a minimum of two points (knee plus ankle in the evaluated limb) as assessed by the Haemophilia Joint Health Score 2.1 (HJHS),[28] prophylaxis treatment with deficient factor (ie VIII or IX). PWHA were excluded if they experienced chronic cardiac, neurological and/or respiratory pathologies, dizziness, muscle or joint bleeding of the lower limbs that had occurred in the last two months, history of hip, knee or ankle arthroplasty or equinus foot in the evaluated limb or were unable to walk independently. Exclusion criteria for healthy subjects included a history of chronic cardiac, neurological and/or respiratory pathologies and acute or chronic musculoskeletal disorders. All procedures were approved by the local ethical committee and performed in accordance with the Declaration of Helsinki. All patients were informed about the study and gave written informed consent.

2.2 | Procedures

All subjects participated in one experimental session between 08:00 am and 12:00 AM. All measurements were made by the same physiotherapist in the same room of the same hospital facility. The subject and the evaluator were alone in the room. Height, age and physical activity were registered. Physical activity levels were assessed using the International Physical Activity Questionnaire.[29] According to the results of the questionnaire, healthy subjects were divided into an active group (HAG; n = 18) and non-active group (HNAG; n = 16). In addition, joint health status was assessed in haemophilic participants using HJHS 2.1.[28]

2.3 | One-leg stance test

The most affected leg assessed by HJHS was used for the one-leg stance test in PWHA, while the dominant leg of each healthy individual was used. The dominant leg was determined by asking subjects which leg they preferred using to kick a ball.[30,31]

For the one-leg stance test, subjects stood one metre from the wall, with their vision focused on a 3 × 3 cm mark that was placed on the wall at eye-level. Then, participants were instructed to stand on one leg with a straight knee by lifting their opposite foot for 30 seconds with their arms crossed at the chest and eyes open.[32] The measurement stopped if the participant moved their standing foot, the other foot touched the floor, the subject uncrossed their arms or 30 seconds was reached. To prevent falls, an investigator stood close to each subject while they were performing the test.

2.4 | Cognitive task

Two different conditions were assessed when each participant performed the one-leg stance. First, a single task was evaluated in which a cognitive task was not performed. Second, a dual-task scenario was evaluated. Each condition was repeated three times in a randomized order, with 2 minutes of seated rest between each to avoid muscular fatigue.

To evaluate the capacity of each subject to perform dual tasks, subjects performed the one-leg stance while simultaneously subtracting 7 from a random number between 200 and 400. Subjects gave answers to subtraction problems were using a low, but audible voice at their own pace. All subtraction responses were noted by the same evaluator. The performance of the cognitive task was evaluated based on the following: (a) number of operations performed and (b) number of mathematical errors.

2.5 | Data acquisition

The X16-mini 3-axis accelerometer (Gulf Coast Data Concepts, LLC) with a ± 16 g range, and 2048 count/g sensitivity was used. The device was placed at L3/L4 vertebrae of each participant using a Velcro™ belt (3M).[11] Vertical (V), mediolateral (ML) and anteroposterior (AP) signals were acquired with a sampling rate of 800 Hz.

2.6 | Data analysis

Acceleration signals were processed using a custom-made algorithm implemented using MATLAB software (The MathWorks, Inc, version R2018b). The whole test signal was filtered using a fourth-order Butterworth lowpass filter with a 12 Hz cut-off frequency.[33,34] Then, the root mean square (RMS) and the sample entropy of centre of mass accelerations of each axis were calculated. The input parameters used to obtain sample entropy included the length of the sequence equal to 3 and the pattern similarity tolerance equal to 0.04.[11]

2.7 | Statistical analysis

All analyses were carried out using the IMB SPSS Statistics software (IBM Corp, version 24). Normality of the data was assessed using the Shapiro-Wilk test. Descriptive data were expressed as mean (standard deviation) or median [25th, 75th percentile]. Subjects' characteristics and advanced variables were compared using a one-factor analysis of variance (ANOVA). Kruskal-Wallis was used to compare number of errors that occurred while performing the dual task. To determine significant differences between RMS and sample entropy variables determined for the different conditions (single and dual task) tested and between groups (HAG, HNAG and PWHA), a mixed 2-factor ANOVAs with repeated-measures in the condition factor were used. Age and height were added as covariates in the ANOVAs. When models indicated significant differences in the main effects, a Bonferroni correction was applied to avoid type I error from multiple comparisons. Effect size was interpreted as small (d = 0.2; $\eta_p^2 = 0.01$), medium (d = 0.5; $\eta_p^2 = 0.06$) and large (d > 0.8; $\eta_p^2 > 0.14$). Statistical significance was set at $P < .05$.

2.8 | Sample size

An a priori power analysis was conducted using G*power (Heinrich-Heine-Universität Düsseldorf, Germany, version 3.1.9.2) software to calculate the required sample size. With the present study design, $\alpha = 0.05$ and power = 0.8, a minimum of 42 subjects (14 per group) were required to achieve at least a medium effect size (f = 0.25; d = 0.5).

3 | RESULTS

Except for the number of errors, all the variables met the normality criteria. The PWHA group was significantly older than the HAG and HNAG groups and was shorter than the HNAG group (Table 1). The mean (std; [minimum-maximum]) total HJHS score for PWHA was 31.40 (13.31; [6-55]) points, with a mean of 6.87 (4.09; [0-12]) determined for the knee and 6.13 (3.42; [2-12]) for the ankle. Only two PWHA presented an HJHS of 0 points in the knee, while all patients showed ankle arthropathy (HJHS > 0). In PHWA, 12/15 evaluated

TABLE 1 Demographic characteristics of the study participants

	HAG (n = 18)	PWHA (n = 15)	HNAG (n = 16)	Differences between groups
Age (years)	22.83 (2.50)	27.67 (6.95)	20.56 (2.28)	$F = 10.87$; $\mathbf{P<.001}$ ($\mathbf{P<.008}$; CI = [1.08:8.59])[a] ($\mathbf{P < .001}$; CI = [3.24:10.97])[b]
Height (m)	1.72 (0.06)	1.69 (0.03)	1.75 (0.07)	$F = 4.24$; $\mathbf{P < .020}$ ($\mathbf{P = .017}$; CI = [−0.11:-0.01])[b]
Weight (kg)	71.26 (6.87)	71.15 (12.26)	74.16 (9.88)	$F = 0.49$; $P = .61$

Note: Data are expressed as mean (standard deviation).

Significant differences are highlighted in bold.

Abbreviations: CI, 95% confidence interval; HAG, healthy active group; HNAG, healthy non-active group; PWHA, people with haemophilic arthropathy.

[a]Pairwise analysis results between PWHA and HAG.

[b]Pairwise analysis results between PWHA and HNAG.

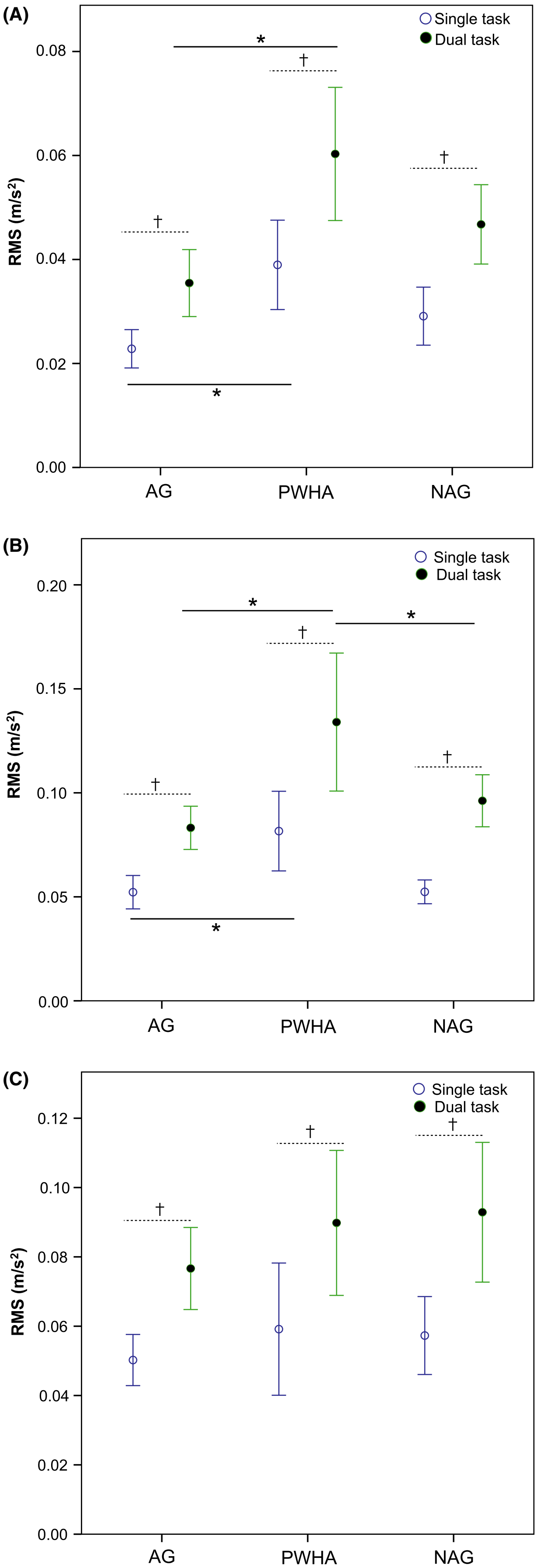

FIGURE 1 A comparison of RMS acceleration values between groups and conditions assessed. Comparisons in the (A) vertical axis, (B) mediolateral axis and (C) anteroposterior axis were assessed. Values shown are means and 95% confidence intervals. HAG: healthy active group; HNAG: healthy non-active group; PWHA: people with haemophilic arthropathy. **P* < .05 between groups; †*P* < .05 between conditions

legs were dominant. Five PWHA were classified as being physically active.

The mixed-model ANOVA revealed a significant interaction between the condition * group factor for RMS and sample entropy of V [RMS: F = 5.68; P = .006; η_p^2 = 0.20, entropy: F = 4.16; P = .022; η_p^2 = 0.16] and ML [RMS: F = 7.53; P = .002; η_p^2 = 0.25, entropy: F = 5.68; P < .006; η_p^2 = 0.20] axes, but not in the AP axis [RMS: F = 0.71; P = .50; η_p^2 = 0.03, entropy: F = 1.03; P = .37; η_p^2 = 0.04]. Covariate age had a significant effect on RMS values at V (P = .030) and ML (P < .001) axes, as well on the entropy of the ML axis (P < .001). Differences in height did produce significant effects in any of the cases examined.

Results of multiple comparisons between the RMS of accelerations are shown in Figure 1. According to within-group analyses, all groups had significantly higher RMS values when dual tasks, rather than single tasks, were performed (P < .001) for each of the three axes. Regarding the between-group analysis, PWHA had higher RMS values than AG in both conditions (single: P = .022; confidence interval (CI) = [−0.022: −0.001]; d = 1.30 and dual: P = .002; CI = [−0.040: −0.007]; d = 1.30) in the V axis (Figure 1A). In the ML axis (Figure 1B), both conditions tested revealed higher RMS values for the PWHA group than HAG (single: P = .021; CI = [−0.045: −0.003]; d = 1.20 and dual: P < .001; CI = [−0.097: −0.026]; d = 1.16) and higher RMS values than HNAG when the subjects were asked to perform dual tasks (P = .006; CI = [−0.093: −0.013]; d = 0.68). In the AP axis (Figure 1C), no significant differences between groups were observed.

Regarding the complexity of postural control (Table 2), all groups presented a significantly higher entropy values when dual tasks, rather than single tasks, were performed (P < .001) in each of the three axes.

Regarding the between-group analysis, PWHA presented lower entropy values in the V axis than HAG and HNAG in both conditions, with medium to large effect sizes. For the ML axis, the PWHA group presented lower entropy values than HAG and HNAG groups when dual tasks were assessed, which also produced medium to large effect sizes. No significant differences were found in the AP axis.

Results regarding cognitive task performance are shown in Table 3. PWHA were able to complete fewer operations when compared with HAG. In addition, no significant differences among groups were obtained regarding the number of errors made.

4 | DISCUSSION

When subjects were asked to perform a cognitive task while in the one-leg stance, the group comprised of PWHA had a greater degree

TABLE 2 Sample entropy multiple comparisons results

Axis	Condition	HAG (n = 18)	PWHA (n = 15)	HNAG (n = 16)	Between-group analysis (*P* [95% CI]; Effect size) HAG vs PWHA	HAG vs HNAG	PWHA vs HNAG
V	Single	0.10 (0.01)	0.09 (0.02)	0.11 (0.01)	**.020**; [0.001:0.022]; 0.65	1; [−0.010:0.008]	**.027**; [−0.024:-0.001]; 1.28
	Dual	0.16 (0.01)	0.13 (0.02)	0.16 (0.01)	**.001**;[0.008;0.038]; 1.96	1; [−0.010:0.017]	**.016**; [−0.036:-0.003]; 1.92
	Within-group analysis	**<0.001**;[0.047:0.057]; 8.87	**<0.001**; [0.034:0.047]; 3.48	**<0.001**; [0.042:0.053]; 5.47			
ML	Single	0.07 (0.02)	0.06 (0.02)	0.08 (0.02)	1; [−0.011:0.024]	.51; [−0.025:0.007]	.169; [−0.035:0.004]
	Dual	0.11 (0.02)	0.09 (0.03)	0.11 (0.03)	**.043**; [0.001:0.048]; 0.8	.84; [−0.031:0.012]	**.008**; [−0.061:-0.007]; 0.67
	Within-group analysis	**<0.001**; [0.034;0.048]; 2.45	**<0.001**; [0.014:0.032]; 2.05	**<0.001**; [0.034:0.050]; 2.20			
AP	Single	0.05 (0.01)	0.05 (0.01)	0.05 (0.02)	1; [−0.008:0.018]	1; [−0.014:0.010]	.73; [−0.021:0.008]
	Dual	0.08 (0.02)	0.07 (0.01)	0.08 (0.03)	.34; [−0.007:0.033]	1; [−0.021:0.014]	.22; [−0.038;0.006]
	Within-group analysis	**<0.001**; [0.019:0.034]; 4.09	**<0.001**; [0.009:0.028]; 1.91	**<0.001**;[0.019:0.037]; 1.69			

Note: Data are expressed as mean (standard deviation). Significant differences are highlighted in bold.

Abbreviations: CI, 95% confidence interval; HAG, healthy active group; HNAG, healthy non-active group; PWHA, people with haemophilic arthropathy.

of sway balance (ie RMS) and decreased complexity of postural control in the ML and V axes than the HAG and HNAG, which were comprised of healthy individuals. The obtained results support the proposed hypothesis that PWHA have less automaticity and require increased cognitive demand to maintain static postural control when a dual-task condition is examined. To the authors' current knowledge, this is the first study to have tested this hypothesis in PWHA. The present results can be used to design new approaches to assess and improve in exercises designed to enhance postural control in PWHA.

When a single task (maintaining a one-leg stance) was assessed, we observed that PWHA have higher levels of sway balance in the ML and V axes than HAG. Increased sway balance in the ML axis is in agreement with previous studies evaluating bipodal and one-leg stances in PWHA.[3,11] This impairment in the ML axis could be a manifestation of altered multijoint coordination between the trunk and lower limbs, which are needed for optimizing postural control.[35] Thus, this result reinforces the need for improving postural control in the ML axis. Also, the value can be used to predict multiple falls in elderly individuals.[36] Increased sway balance in the V axis, which was observed in PWHA, may explained by impairments of proprioception and knee extensor force in these individuals [1, 2], as well as altered coordination that occurs between knee extensors and flexors.[30,31]

Regarding to complexity of postural control, we observed reduced values in PWHA exclusively in the V axis in comparison to HAG and HNAG. This suggests that PWHA require increased levels of attention to maintain the angular knee configurations, which may be due to impairments in knee muscle control.

In our study, assessment of the dual-task condition was better able to discriminate between PWHA and the two healthy groups than the assessment of a single task with regard to ML and V sway balance (Figure 1A,B). These results are relevant since unipedal stances, in the absence of cognitive tasks, are typically focused on maintaining a position with minimal compensation in clinical practice.[32] On the other hand, assessment with a second task obliged subjects to maintain the position while utilizing an increased level of cortical resources, and provided researchers with the opportunity to evaluate the automaticity of postural control. We found that age significantly affected sway balance (V and ML axes) and entropy values. These results can be explained by lower limb joint damage that markedly increases between the ages of 20 and 30 in PWHA.[37]

The dual-task paradigm states that when two tasks are performed simultaneously, the performance of one or both tasks may be affected, depending upon the difficulty of the tasks and the capacity of an individual to maintain both tasks simultaneously.[38] In our results, we observed that the balance of PWHA deteriorates more rapidly in the dual-task condition than it does for HAG and HNAG. Furthermore, the performance of the mathematical task (ie number of mathematical operations) was lower in PWHA than HAG. This impaired cognitive performance observed in PWHA might be a result of increased postural demand as well as a reduced physical activity level. Physical activity level is a relevant factor for postural sway performance and automatism of postural control in healthy people.[12,39] However, future studies will be required to assess

TABLE 3 Number of operations and errors in the dual-task condition

	HAG (n = 18)	PWHA (n = 15)	HNAG (n = 16)	Differences among groups
Advance	10.94 (4.25)	6.42 (3.36)	9.80 (3.58)	F = 4.03; ***P* < .013** (***P* < .013**; CI = [−8.09: −0.75]; d = 1.17)[a]
Error	1.00 [0.33; 1.33]	1.33 [0.33; 2.00]	0.67 [0.33; 1.33]	P = .33

Note: Data are expressed as mean (standard deviation) or median [interquartile range]. Significant differences are highlighted in bold.

Abbreviations: CI, 95% confidence interval; d, Cohen's d; HAG, healthy active group; HNAG, healthy non-active group; PWHA, people with haemophilic arthropathy.

[a]Pairwise analysis results between: PWHA and HAG.

whether physical activity level affects postural control and automatism in PHWA.

Different studies have reported the positive effects of dual-task training on balance and cognitive performance in healthy adolescents and older adults.[15,40] Hence, the use of dual tasking is promising and could be easily incorporated to balance training activities for PWHA. Importantly, its postural control effects can be controlled using simple 3-axis accelerometers, which are accurate, ease to transport and inexpensive. These factors make them good alternatives to traditional force platforms, especially in clinical practice.[26]

This study had some limitations. First, we did not assess lower limb kinematics and muscle activity patterns. These measurements could help researchers elucidate motor strategies used between lower limbs and the trunk. Second, the baseline mathematical levels of subjects were not assessed, and it is not possible to know whether this might have influenced the performance of the cognitive task. Third, due to the limited sample size, PWHA were not separated based on physical activity level and leg dominance. Finally, the one-leg stance test was performed in each condition only with eyes open because most of the PWHA were not able to maintain the position with eyes closed for 30 seconds. Therefore, it was not possible to evaluate the degree where visual information, physical activity level, and leg dominance influenced the postural control and automatism as different tasks were performed.

5 | CONCLUSION

PWHA have poorer postural sway and complexity of postural control when maintaining the one-leg stance than healthy people, especially when a dual task is applied. These results may help to design new approaches to assess and improve postural control in PWHA.

ACKNOWLEDGEMENTS

The authors wish to thank PhD Xavier García-Massó for his thoughtful review of this paper. The Haemophilia and Inherited Bleeding Disorder Treatment Centre of the Roberto del Río Hospital, particularly, Estefania Figueroa and Nicole Pavez for facilitating the recruitment of haemophilia patients.

DISCLOSURES

The authors stated that they had no interests which might be perceived as posing a conflict or bias.

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REFERENCES

1. Hilberg T, Herbsleb M, Gabriel H, Jeschke D, Schramm W. Proprioception and isometric muscular strength in haemophilic subjects. *Haemophilia*. 2001;7(6):582-588.
2. Stephensen D, Drechsler WI, Scott OM. Biomechanics of lower limb haemophilic arthropathy. *Blood Rev*. 2012;26(5):213-221.
3. Gallach JE, Querol F, Gonzalez LM, Pardo A, Aznar JA. Posturographic analysis of balance control in patients with haemophilic arthropathy. *Haemophilia*. 2008;14(2):329-335.
4. Perez-Alenda S, Carrasco JJ, Aguilar-Rodriguez M, et al. Balance evaluation in haemophilic preadolescent patients using Nintendo Wii Balance Board(R). *Haemophilia*. 2016;23(1):e18-e24.
5. Massion J. Postural control system. *Curr Opin Neurobiol*. 1994;4(6):877-887.
6. Peterka R. Sensorimotor integration in human postural control. *J Neurophysiol*. 2002;88(3):1097-1118.
7. Shumway-Cook A, Woollacott M. Attentional demands and postural control: the effect of sensory context. *J Gerontol Biol Sci Med Sci*. 2000;55(1):M10.
8. Shumway-Cook A, Woollacott M, Kerns KA, Baldwin M. The effects of two types of cognitive tasks on postural stability in older adults with and without a history of falls. *J Gerontol Ser A Biol Sci Med Sci*. 1997;52(4):M232-M240.
9. Rigoldi C, Cimolin V, Camerota F, et al. Measuring regularity of human postural sway using approximate entropy and sample entropy in patients with Ehlers-Danlos syndrome hypermobility type. *Res Dev Disabil*. 2013;34(2):840-846.
10. Stins JF, Michielsen ME, Roerdink M, Beek PJ. Sway regularity reflects attentional involvement in postural control: effects of expertise, vision and cognition. *Gait Posture*. 2009;30(1):106-109.

11. Cruz-Montecinos C, De la Fuente C, Rivera-Lillo G, et al. Sensory strategies of postural sway during quiet stance in patients with haemophilic arthropathy. *Haemophilia*. 2017;23(5):e419-e426.
12. Decker LM, Ramdani S, Tallon G, et al. Physical function decline and degradation of postural sway dynamics in asymptomatic sedentary postmenopausal women. *J Nutr Health Aging*. 2015;19(3):348-355.
13. Bizid R, Margnes E, François Y, et al. Effects of knee and ankle muscle fatigue on postural control in the unipedal stance. *Eur J Appl Physiol*. 2009;106(3):375-380.
14. Garcia-Masso X, Pellicer-Chenoll M, Gonzalez LM, Toca-Herrera JL. The difficulty of the postural control task affects multi-muscle control during quiet standing. *Exp Brain Res*. 2016;234(7):1977-1986.
15. Lesinski M, Hortobágyi T, Muehlbauer T, Gollhofer A, Granacher U. Effects of balance training on balance performance in healthy older adults: a systematic review and meta-analysis. *Sports Med*. 2015;45(12):1721-1738.
16. Noe F, Garcia-Masso X, Paillard T. Inter-joint coordination of posture on a seesaw device. *J Electromyogr Kinesiol*. 2017;34:72-79.
17. Yelnik A, Bonan I. Clinical tools for assessing balance disorders. *Clin Neurophysiol*. 2008;38(6):439-445.
18. Bernard-Demanze L, Dumitrescu M, Jimeno P, Borel L, Lacour M. Age-related changes in posture control are differentially affected by postural and cognitive task complexity. *Curr Aging Sci*. 2009;2(2):135-149.
19. Huxhold O, Li S-C, Schmiedek F, Lindenberger U. Dual-tasking postural control: aging and the effects of cognitive demand in conjunction with focus of attention. *Brain Res Bull*. 2006;69(3):294-305.
20. Prado JM, Stoffregen TA, Duarte M. Postural sway during dual tasks in young and elderly adults. *Gerontology*. 2007;53(5):274-281.
21. Mazaheri M, Salavati M, Negahban H, Sanjari MA, Parnianpour M. Postural sway in low back pain: effects of dual tasks. *Gait Posture*. 2010;31(1):116-121.
22. Bensoussan L, Viton J-M, Schieppati M, et al. Changes in postural control in hemiplegic patients after stroke performing a dual task. *Arch Phys Med Rehabil*. 2007;88(8):1009-1015.
23. Levinger P, Nagano H, Downie C, et al. Biomechanical balance response during induced falls under dual task conditions in people with knee osteoarthritis. *Gait Posture*. 2016;48:106-112.
24. Negahban H, Hadian MR, Salavati M, et al. The effects of dual-tasking on postural control in people with unilateral anterior cruciate ligament injury. *Gait Posture*. 2009;30(4):477-481.
25. Rahnama L, Salavati M, Akhbari B, Mazaheri M. Attentional demands and postural control in athletes with and without functional ankle instability. *J Orthop Sports Phys Ther*. 2010;40(3):180-187.
26. Ghislieri M, Gastaldi L, Pastorelli S, Tadano S, Agostini V. Wearable inertial sensors to assess standing balance: a systematic review. *Sensors*. 2019;19(19):4075. https://doi.org/10.3390/s19194075
27. Garcia-Masso X, Ye-Lin Y, Garcia-Casado J, Querol F, Gonzalez LM. Assessment of haemophilic arthropathy through balance analysis: a promising tool. *Comput Methods Biomech Biomed Engin*. 2019;22(4):418-425.
28. Sun J, Hilliard PE, Feldman BM, et al. Chinese Hemophilia Joint Health Score 2.1 reliability study. *Haemophilia*. 2014;20(3):435-440.
29. Hagströmer M, Oja P, Sjöström M. The international physical activity questionnaire (IPAQ): a study of concurrent and construct validity. *Public Health Nutr*. 2006;9(6):755-762.
30. Cruz-Montecinos C, Perez-Alenda S, Cerda M, Maas H. Neuromuscular control during gait in people with haemophilic arthropathy. *Haemophilia*. 2019;25(2):e69-e77.
31. Cruz-Montecinos C, Pérez-Alenda S, Querol F, Cerda M, Maas H. Changes in muscle activity patterns and joint kinematics during gait in hemophilic arthropathy. *Front Physiol*. 2020;10:1575.
32. Springer BA, Marin R, Cyhan T, Roberts H, Gill NW. Normative values for the unipedal stance test with eyes open and closed. *J Geriatr Phys Ther*. 2007;30(1):8-15.
33. van Dieën JH, van Leeuwen M, Faber GS. Learning to balance on one leg: motor strategy and sensory weighting. *J Neurophysiol*. 2015;114(5):2967-2982.
34. Koltermann J, Gerber M, Beck H, Beck M. Validation of various filters and sampling parameters for a COP analysis. *Technologies*. 2018;6(2):56.
35. Donath L, Kurz E, Roth R, Zahner L, Faude O. Leg and trunk muscle coordination and postural sway during increasingly difficult standing balance tasks in young and older adults. *Maturitas*. 2016;91:60-68.
36. Sparto PJ, Newman A, Simonsick E, et al. Contributions to lateral balance control in ambulatory older adults. *Aging Clin Exp Res*. 2018;30(6):633-641.
37. Chang CY, Li TY, Cheng SN, et al. Prevalence and severity by age and other clinical correlates of haemophilic arthropathy of the elbow, knee and ankle among Taiwanese patients with haemophilia. *Haemophilia*. 2017;23(2):284-291.
38. Broglio SP, Tomporowski PD, Ferrara MS. Balance performance with a cognitive task: a dual-task testing paradigm. *Med Sci Sports Exerc*. 2005;37(4):689-695.
39. Leong H-T, Fu SN, Ng GYF, Tsang WWN. Low-level Taekwondo practitioners have better somatosensory organisation in standing balance than sedentary people. *Eur J Appl Physiol*. 2011;111(8):1787-1793.
40. Bustillo-Casero P, Cebrian-Bou S, Cruz-Montecinos C, Pardo A, Garcia-Masso X. Effects of a dual-task intervention in postural control and cognitive performance in adolescents. *J Mot Behav*. 2019;1–9.

How to cite this article: Cruz-Montecinos C, Carrasco JJ, Guzmán-González B, et al. Effects of performing dual tasks on postural sway and postural control complexity in people with haemophilic arthropathy. *Haemophilia*. 2020;00:1–7. https://doi.org/10.1111/hae.13955