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Measures of Postural Control and Mobility During Dual-Tasking as Candidate Markers of Instability in Huntington's Disease

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KEYWORDS: multitasking, neurodegenerative disease, postural control, cognitive-motor interference, inertial sensors, Huntington disease

Abstract

Background: Individuals with Huntington’s disease (HD) have impairments in performing dual-tasks, however, there is limited information about the effects of changing postural and cognitive demands as well as which measures are best suited as markers of underlying motor-cognitive interference.

Methods: Forty-three individuals with HD and 15 healthy controls (HC) completed single tasks of walking (Timed Up & Go (TUG), 7m walk), standing (feet together, feet apart and foam surface) and seated cognitive performance (Stroop, Symbol Digit Modalities Test (SDMT), Delis-Kaplan Executive Function System (DKEFS) Sorting test) and dual cognitive-motor tasks while standing (+ Stroop) and walking (+ DKEFS, TUG cognitive). APDM Opal sensors recorded measures of postural sway and time to complete motor tasks.

Results: Individuals with HD had a greater increase in standing postural sway compared to HC from single to dual-tasks and with changes to support surface. Both groups demonstrated a decrease in gait performance during the TUG cognitive, however, this difference was greater in people with HD compared to HC. While those with HD showed a greater dual-task motor cost compared to HC, both groups behaved similarly as condition complexity increased.

Conclusions: Standing postural sway is a more sensitive marker of instability than change in standard gait speed, particularly under dual-task conditions. The more complex TUG cognitive is a sensitive measure of walking dual-task performance. The results of this study provide insights about the nature of motor-cognitive impairments in HD and provide support for a distinction between static and dynamic postural control mechanisms during performance of dual-tasks.

INTRODUCTION

The effect of performing two tasks simultaneously, compared with performance of each task alone, is known as a dual-task effect (DTE). DTE reveals a cost or benefit to task performance and is an indication of interference or facilitation, respectively, of the limited capacity for attention and information processing of a performer. Cognitive-motor interference in neurodegenerative disease populations is well-described,[1] including in those with Parkinson's disease (PD),[2,3] Alzheimer's disease,[4] and multiple sclerosis.[5] In Huntington's disease (HD), studies have shown impairments while performing complex cognitive dual-tasks,[6–9] motor-cognitive dual-tasks,[10,11] and motor-motor dual-tasks. [9] Recent work revealed a link between gait speed during motor-cognitive dual-task and the United Huntington's Disease Rating Scale Total Motor Score (UHDRS-TMS) and performance on cognitive testing.[10] Fritz et al[10] demonstrated that a relatively simple dual-task – walking while saying the alphabet – was related to TMS but a more complex dual-task – walking while reciting alternate letters – was correlated with a range of cognitive measures as well as Total Functional Capacity (TFC), a measure of overall function that is a reliable indicator of disease progression in HD.[12]

Purcell et al. [11] has also shown that cognitive interference increases with task complexity during walking. Individuals with HD demonstrated greater cognitive interference while turning then walking in a straight path.[13] As the complexity of a task increases, requiring greater cognitive engagement as motor performance is no longer automatic,[6,14] individuals with HD may be forced to prioritize performance. Task prioritization refers to the attention allocated to an activity based on the value placed on that action in relation to other activities occurring simultaneously. One of the best-known examples of task prioritization is the speed-accuracy trade-off described for at least a century in scientific journals. (see e.g. Garret[15]) This well-known phenomenon, whereby accuracy decreases with increasing speed of performance, and vice versa, is associated with information processing ability.[16] While initially studied during simple reaction time conditions, the concept has recently been extended to examine the information processing demands in dual task performance. In healthy participants, Tomporowski et al.[17] reported a speed-accuracy tradeoff during dual task conditions such that cognitive errors increased with increasing speed of treadmill walking, demonstrating decreased cognitive flexibility under increasing motor demands coming from a secondary condition. Fitt's initial proposal was that movement difficulty related to movement speed.[18] In dual-task conditions, the difficulty may result from the complexity of either task, or from the addition of a second task requiring increased information processing. Even accounting for overall slower speeds, studies have shown that individuals with HD are more susceptible to speed-accuracy trade-offs than their healthy peers, indicating that when allocating resources under multiple task conditions, HD results in impaired information processing and task performance.[19] In gross motor control tasks, like standing and walking, healthy individuals will frequently prioritize postural stability - to prevent falling - over another cognitive or motor task performed simultaneously.[20] However, people with neurodegenerative diseases have demonstrated a 'posture-second' strategy, inappropriately risking balance in favor of attending to a secondary cognitive or motor task.[21] Neuroanatomical evidence suggests that, in HD, this may be due to damage to the caudate nucleus, which appears to be specifically linked to attentional priority during voluntary movement.[22]

Postural control tasks have also been shown to be impaired in people with HD during dual-tasking. Using a verbal fluency secondary task, Purcell et al[11] demonstrated individuals with HD have greater sway, jerk and sway variability under dual-task conditions than age-matched peers. Similarly, Purcell et al[13] showed that turning during walking resulted in decreased walking speed and increased stepping compared to non-HD control participants. Understanding the effect of different postural challenges and how these relate to clinical measures can provide important insights about the nature of motor impairments in HD and help identify clinically relevant outcome measures. In the present study, we evaluated dual-task impairments across postural stability and gait tasks of increasing complexity in individuals with early-mid stage HD compared to healthy controls. Based on our prior work exploring dual-task deficits in HD[10] and work demonstrating that persons with HD have greater deficits in static control tasks (standing) than dynamic control tasks (walking),[23] we hypothesized that dual-task postural sway would be a more sensitive marker of instability in people with HD than dual-task gait.

METHODS

Site and participant selection

This study was conducted across three HD specialist clinics in Europe and the United States: George Huntington Institute (GHI), Munster, Germany (2017-079-f-S); Teachers College, Columbia University, New York, USA (Approval # 18-071) and Wayne State University, Detroit, USA (approval #1701000248).

All participants were 18 years of age or older and able to walk 10m independently with or without assistance devices. Participants without HD (i.e., Healthy Controls (HC)) were excluded if there was a history of other neurological conditions, an acute orthopedic injury, or an inability to consent and/or follow all directions for this study. Inclusion criteria for participants with HD included a genetically confirmed diagnosis and a Total Functional Capacity (TFC) score ≥7. A diagnosis of juvenile onset HD, history of co-morbid neurological conditions such as stroke or multiple sclerosis, acute orthopedic conditions, or the inability or unwillingness of participant or legal guardian to give written informed consent were exclusionary for those with HD.

Assessments

Individuals completed all testing in a single day in a standardized order. Participants completed a battery of demographic and clinical assessments. Demographic information for all participants included age, sex, height and weight. For HD participants, we obtained Unified Huntington's Disease Rating Scale (UHDRS)[24] including Total Functional Capacity (TFC), Total Motor Score (TMS), Functional Assessment, and Independence Scale. This information was obtained either from clinical assessments taken within 3 months, or was administered as part of the assessment battery by certified raters at each site.

We conducted a standard cognitive assessment battery from the Enroll Registry study[25] on all participants, including verbal category fluency, symbol digit modality test and Stroop word reading, color reading and interference. Participants also performed the Delis Kaplan Executive Functioning System (DKEFS).[26] For the DKEFS, participants were asked to name items from two categories, fruit and furniture, alternating (or shifting) their responses between the two categories. Participants were also timed while reciting the alphabet in sitting and alternate letters of the alphabet (starting with A) in sitting. The Stroop interference, DKEFS and alphabet scores performed in sitting were recorded as baseline single task measures for comparison during dual-task conditions. All assessments were conducted in English (Columbia and Wayne State) or German (GHI) with standard translated versions. The DKEFS, Stroop and alphabet tasks were specifically chosen for their complexity, as they require task-switching (DKEFS) or response inhibition (Stroop and naming alternate letters of alphabet).

Participants completed standing and walking assessments while wearing APDM Opal (Portland, OR) body worn inertial sensors on both wrists, mid-chest, lumbar spine, and both feet. All tasks were filmed using a Go Pro (San Mateo, CA) camera. Procedures and equipment were standardized across sites. For the dual-task conditions, participants were not given prioritization instructions.

Standing Balance with and without a cognitive demand. Standing balance was assessed under three conditions: feet shoulder-width apart on a firm surface (FA), feet together (FT) on a firm surface, and feet apart on a foam surface (Foam) (2' x 2' of medium density 2" foam). Participants were given the following instructions: "When you hear the tone, stand quietly with your feet apart and arms crossed on your chest. Look straight ahead and remain still without talking or moving until you hear the second tone." For the cognitive demand, each of the standing balance tasks were paired with a simultaneous Stroop interference cognitive task projected onto the wall in front of the participant. We modified the standard Stroop interference by replacing the red, green and blue colors with a new color to create three different Stroop combinations to minimize learning effects. Measures of postural sway from the sensors (root mean square (RMS) of postural sway (m/s^2)[11,27] and the number of correct Stroop responses were recorded.

Timed Up & Go (TUG) Test with and without a cognitive demand. The TUG[28] is a standard assessment of mobility and involves participants rising from a chair, walking three meters, turning, walking back and sitting down. Participants were given the following instructions: "When you hear the tone, stand up from the chair, walk at a comfortable pace to the line at the end of the walkway, turn around, walk back, and sit down. Try not to use your hands to assist yourself during standing or sitting." The cognitive demand required participants to perform the task while doing a serial three subtraction task from a random number in the 90s.[29] Time to complete the TUG (s) and the number of correct numbers for the serial subtraction task were recorded.

Walking with and without a cognitive demand. Participants walked 7m to a marking on the floor, turned around and returned (Walk condition). Participants were given the following instructions: "When you hear the tone, begin walking at a comfortable pace and turn around and come back to starting position." For the cognitive demand, participants performed the task while reciting the alphabet aloud (Walk-simple), while reciting alternate letters of the alphabet (starting with the letter B) aloud (Walk-complex) and while performing the Delis-Kaplan Executive Function System (DKEFS) Category Switching Test (Walking-DKEFS). We recorded the walking speed for all walking tasks (m/s), the number of correct letters for the Walk-simple and Walk-complex, and the number of correct responses for the D-KEFS.

Data Analyses

All APDM sensor data were processed using Mobility Lab software (Version 2). We calculated correct response rates (CRR) for the cognitive conditions in both single and dual-tasks following the methods of Hall et al.[30] CRR is the response rate per second x the percent correct. A lower CRR indicates worse performance under dual-task conditions. We calculated dual-task effects for both cognitive and motor conditions of dual-task following the methods of Plummer and Eskes[31].

Statistical analyses were completed with SPSS Version 26 (IBM, Armonk NY). *Standing Balance with and without a cognitive demand.* We used a 2 group (HD vs. HC) x 2 condition (standing, standing-Stroop) x 3 surfaces (FA, FT, Foam) repeated measures analysis of variance

(ANOVA) to examine differences in motor (postural sway) and a 2 group (HD vs. HC) x 2 condition (sitting-stroop, standing-stroop) ANOVA for each surface condition to assess cognitive (CRR) task performance. *TUG with and without a cognitive demand.* We used a 2 group (HD vs. HC) x 2 condition (TUG, TUG Cog) repeated measures ANOVA to examine differences in motor (walking duration) task performance. *Walking with and without a cognitive demand.* We used a 2 group (HD vs. HC) x 3 condition (Walk, Walk-simple, Walk-complex) repeated measures ANOVA to examine differences in motor (gait speed) and cognitive (CRR) task performance. We used a 2 group (HD vs. HC) x 2 condition (Walk, Walk-DKEFS) repeated measures ANOVA to examine differences in motor (gait speed) and cognitive (CRR) task performance. *Dual-Task Effects.* We used a 2 group (HD vs. HC) x 3 surfaces (FA, FT, Foam) repeated measures ANOVA to examine differences in motor (DTE) and cognitive (DTE) task performance with increasing task complexity. We used a 2 group (HD vs. HC) x 2 condition (Walk-simple, Walk-complex) repeated measures ANOVA to examine differences in motor (DTE) and cognitive (DTE) task performance with increasing task complexity. Corrections for multiple comparisons were made using Bonferroni correction. When indicated, t-tests were used for post-hoc comparisons, with significance levels set at $p<0.05$.

RESULTS

Demographic information is shown in Table 1. Individuals with HD were not significantly different from HC in sex or age.

Standing Postural control with and without a cognitive demand

Postural control was evaluated using RMS sway values across conditions (standing, standing-Stroop) and surfaces (FA, FT, Foam) for HD and HC (2x2x3). There was a significant main effect of group (HD vs. HC) (F=20.95, p<0.001), condition (F=11.86, p=0.001) and surface (F=4.034, p=0.02). There was a significant group by condition effect (F=5.910, p=0.018). Post hoc comparisons revealed that for each surface, individuals with HD had a significantly greater increase in sway from single to dual-tasks compared to HC (see Table 2). There was also a significant condition by surface effect (F=5.096, p=0.008). Post hoc comparisons revealed that this effect was due to differences between the Foam surface and both FA (p=0.005) and FT (p=0.012) (Figure 1).

INSERT FIGURE 1 HERE

Cognitive performance was evaluated using correct response rate (CRR) across conditions (sitting-Stroop, standing-Stroop) for each surface (FA, FT, Foam) for HD and HC (i.e, three separate 2 Group (HD vs HC) x 2 Condition (seated-Stroop, standing-Stroop) analyses, one for each surface). For each condition, there was a significant main effect for group, with HD participants having a lower correct response rate than HC (p<0.001). There was no effect of condition and no interaction effects (p>0.05), suggesting change in surface did not differentially affect cognitive performance in HD vs. HC (Figure 2).

INSERT FIGURE 2 HERE

<u>TUG with and without a cognitive demand</u>

TUG was evaluated using time (s) across conditions (TUG vs. TUG cognitive). There was a significant effect of condition (F=20.52, p<0.001) and group (F=13.56, p=0.001) (Mean (SD) score (s) for HD participants for TUG was 11.05(3.77); TUG cognitive was 15.16 (5.87);HC TUG: 8.05(2.24); TUG cognitive: 9.26 (3.07)). There was an interaction effect (p=0.016) such that while both groups got slower during the TUG cognitive, the difference from single to dual-task in individuals with HD was significantly greater compared to HC (Figure 3).

INSERT FIGURE 3 HERE

Walking with and without a cognitive demand

To evaluate walking with and without a cognitive demand, we examined gait speed across conditions (single task (single), simple dual-task (simple), complex dual-task (complex)) for HD and HC (2x3). The mean (SD) score (m/s) for HD participants across the conditions were single 1.10 (0.22); simple 0.98(0.27); and complex 0.87(0.25); and for HC were single 1.32(0.26); simple 1.26(0.31); and complex 1.17(0.26). There was a significant main effect of group (HD vs. HC) (F=13.778 p<0.001) and condition (ST vs. DT vs complex) (p=55.147,<.001) however there was no interaction effect (p>0.05). Post hoc comparisons revealed that for each successively complex condition, all participants demonstrated slower gait (p<0.01).

Next, walking was evaluated using gait speed across conditions (walking vs. walking with DKFES). There was a significant effect of condition (F=98.76, p<0.001) and group (F=6.95, p=0.011), however there was no significant interaction effect (p>0.05). Individuals with HD were slower overall but both groups were significantly lower when performing the

DKEFS when walking. The mean (SD) score (s) for HD participants across the conditions for HD were: walking 1.10(0.22); walking with DKFES (0.84(0.25); and HC walking (1.32(0.26) and walking with DKEFS (1.03(0.37).

We compared cognitive performance using CRR for single (cognitive task in sitting) vs. dual (cognitive task while walking) task conditions for HD and HC. There were no significant effects of group or condition for the simple or complex dual-task conditions. During performance of DKEFS there was no group effects (p>0.05) but there was a significant effect of condition (F=43.023, p<0.001), with all participants having fewer correct responses when walking compared to sitting.

Dual-Task Effects

We examined the impact of increasing task complexity on both motor and cognitive dual-task effects for HD and HC. In the standing condition, the increasing task complexity was defined by moving from feet apart to feet together to foam conditions. When examining motor DTE (of RMS Sway), there was a significant effect of surface (F=7.924, p=0.007). Post hoc comparisons revealed this difference was driven by an increase in motor DTE between FA condition and both the FT (p<0.001) and Foam (p=0.002) conditions. There were no significant effects of group (F=1.283; p=0.262) and no significant interaction effect (F=0.015; p=0.903). When examining cognitive DTE (of CRR), there was no significant effect of surface (F=0.101; p=0.752), group (F=0.139; p=0.711), and no interaction effect (F=1.758; p=0.190). Figure 4 shows both motor and cognitive DTE results for the standing conditions.

INSERT FIGURE 4 HERE

In the walking condition, the increasing task complexity was defined by moving from the Walk-simple to Walk-complex. When examining the motor DTE, there was a significant effect of condition (F=25.034; p<0.001), and group (F=5.271; p=0.026), but no significant interaction effect (F=1.341; p=0.252), whereby both groups prioritized motor performance as the task became more complex. When examining the cognitive DTE, there was no significant effect of condition (F=1.513; p=0.224), group (F=0.188; p=0.666), and no interaction effect (F=0.052; p=0.820).

Discussion

Decreased postural stability has significant repercussions, leading to increased falls,[32,33] decreased quality of life,[34] higher overall caregiver burden[35] and healthcare utilization[36] for persons with HD. The present research extends findings from separate studies showing impairments in people with HD while standing[11,37] and walking[38] under single and dual-task conditions. Importantly, the results demonstrate a potential distinction between static and dynamic postural control mechanisms and sensitivity of RMS of total sway during dual-task standing activities.

Standing and walking are inherently different control tasks. In standing, stability comes from maintaining balance between two points creating a fixed base of support. During walking, an alternating single point of support dynamically shifts the center of mass for/aft and side to side. It is perhaps not surprising that most falls occur during walking,[39] or that falls occur more frequently in those with neurological disease than their healthy peers.[40,41] However, while many studies link falls to gait impairments (see for Axer et al[42] for review), there is evidence that poor static postural control under single and dual-task conditions is also an important falls risk factor.[43] Previous work has demonstrated significantly greater deficits in performance of static control tasks compared to dynamic control tasks in HD.[23] In addition, there is evidence in stroke[44] and HD[11] that neural disease results in increased sway and movement variability during standing balance activities and that these behaviors are modified by attentional demands. Our results support these findings, with indications that standing postural sway (RMS) is a more sensitive marker of instability than changes in gait speed, particularly under dual-task conditions.

Our findings demonstrate that individuals with HD consistently demonstrate greater sway in single task and when shifting from single to dual-tasks compared to controls, largely driven by marked increases in sway on foam surfaces. Similarly, participants with HD demonstrated a significantly lower CRR than controls during tasks of standing balance in FA, FT and Foam, though there was no effect of condition (single v. dual) and no interaction effects, suggesting change in surface did not differentially affect cognitive performance in HD vs. HC.

Research in the elderly and those with stroke[45] and HD,[11] demonstrated total sway area, jerk and RMS are increased in standing. Similar to our findings, these studies showed increasing postural sway under more challenging support conditions (FA, FT, Foam) and with the addition of a secondary cognitive task. These consistent findings suggest that there is a greater reliance on attention to balance in HD than in healthy peers and that when challenged to divide attention, individuals with HD are unable to maintain postural control strategies. It is interesting that the same distinction is not found in the walking data, perhaps supporting the notion that walking in a straight line and talking are yoked together neurologically into a single familiar task structure, while standing on a foam surface performing a cognitive task is sufficiently novel and complex to challenge the system.[46] Alternatively, it may be the nature of the postural stability and gait tasks that leads to the distinction between standing and walking; i.e., when required to walk and talk simultaneously, a performer can choose to slow down and focus on the cognitive features of the task without risking a fall. However, there is no clear equivalent for a standing postural task, e.g. participants demonstrating a decrease in sway speed or excursion that allows a shift in focus to the secondary task while ensuring stability. This is likely due to the fact that maintenance of postural sway is a largely unconscious process.

Our results show that both groups (HD and HC) walked more slowly during the TUG cognitive, though the difference from single to dual-task in individuals with HD was significantly greater compared to controls. The TUG is a well-studied measure[28,47,48] that has previously been shown to be related to falls risk in people with HD.[33] The TUG cognitive has not yet been studied in individuals with HD, and our results demonstrate that the TUG cognitive appears to be sensitive to the cognitive interference impairments in HD. In studies in the elderly, participants who completed the TUG cognitive in >15 seconds were classified as fallers with a prediction rate of 87%.[29] The TUG and TUG cognitive may be more useful measures than standard walking assessments in people with HD. In the present study, our walking assessment involved walking 7m, turning 180 degrees and walking 7m back. While individuals with HD walked more slowly, the differences between single and dual-tasks seen in the TUG were not evident in the walking assessment. Thus, the incorporation of a more complex motor task such as the TUG cognitive, which incorporates sit to stand, walking and turning, along with a dual-task may be a sensitive clinical measure of cognitive-motor behavior in HD.

In addition to the importance of the choice of motor task, the choice of cognitive task in a dual-task paradigm is important to consider. We chose three specific tests of cognition thought to be sensitive to domains of cognition impacted in HD that could be performed during a motor task. The Walking While Talking Test (citing the alphabet and then alternating letters of the alphabet), the Stroop Interference test and DKEFS-Switching test all require some level of response inhibition. While there are elements of other domains in each of these tests, the main goal is to suppress a more natural response (e.g. stating the written word in the Stroop test) in order to state the correct response (color of the ink the word is written in). While differences were seen in the Stroop test between HD and controls, there were no difference in the CRR of the DKEFS. To our knowledge, this is the first use of the DKEFS-Switching test in persons with HD. Given known difficulties with task switching,[49,50] we anticipated challenges with this test. However, both HD and control participants showed a similar decrement in performance with the addition of a dual-task, suggesting that the DKEFS-Switching test does not appear to be a sensitive measure to evaluate dual-task cost in HD.

Our results show that there was a significant effect of surface (F=7.924, p=0.007) in the standing conditions. Post hoc comparisons revealed this difference was driven by an increase in motor DTE between FA condition and both the FT (p<0.001) and Foam (p=0.002) conditions. There were no significant effects of group (F=1.283; p=0.262) and no significant interaction effect (F=0.015; p=0.903). These results build on the work of Purcell et al. [11] who showed that less-impaired individuals with HD (TMS 21.86; SDMT 70.89) demonstrate greater sway compared to HC in both single and dual-tasks. Within the HD group, individuals demonstrated greater total sway and sway variability on foam surfaces compared to firm surfaces, though this was only assessed with the feet apart in the single-task condition. Unfortunately, single task cognitive performance was not recorded, so the change in cognition from single to dual-task in this study was not reported.[11] Our results show that there was no significant effect of surface and no interaction effect when examining cognitive DTE (of CRR). Thus, the consequence of dual-task in standing is that sway changes, but cognition does not change; we see this as a shift toward motor priority and/or mutual interference (see Figure 4).

This is the first study to examine the impact of dual-tasks on increasing task complexity (i.e., increasingly difficulty motor conditions). Our results demonstrate that during dual-task walking, there was a significant effect of condition and group but no significant interaction effect, whereby both groups demonstrated decreasing motor DTE as task complexity increased. This builds on the work of Radovanovic et al.[51] and Purcell et al. [13] both of which demonstrated that persons with HD walk significantly slower than HC under single and dual-tasks. Both studies included only a single dual-task condition (i.e., did not explore task complexity), and did not report dual-task costs. Purcell et al. did record cognitive performance in both the single and dual-tasks (in this case, an animal naming fluency task); however, no analyses were performed to determine if there was a significant decline in cognitive performance within group under DT conditions.[13] Our results show that there was no significant effect of condition, group, and no interaction effect when examining the cognitive DTE, suggesting that cognitive performance remains stable for both groups under single and dual-task conditions. Consistent with the results for standing balance, prior work from our [38] shows that individuals with HD demonstrate motor priority or mutual interference under dual-task walking conditions.

The dual-task results from both standing and walking speak to the prioritization of motor function over cognitive performance among persons with HD. This is in contrast to findings in Parkinson’s disease, where a “posture-second” strategy (i.e., cognitive priority) during dual-tasks has been noted.[52] It was suggested that use of a “posture-second” strategy would exacerbate fall risk in dual-tasks situations, [52–54] yet task prioritization during dual-tasks appears to be more challenging. Even young adults do not always prioritize gait during dual-tasks.[55–58] Rather, task prioritization may rely on individual capacity to respond to a postural threat (postural reserve) to avoid falling, self-awareness of environment (hazard estimation) and the nature and complexity of the secondary task.[54] Sensory motor integration including adaptive and anticipatory mechanisms, is critical for response to postural threats; in the setting of a neurodegenerative disease, deterioration in motor and sensory systems and high cortical functions can lead to alterations in balance and postural responses. Changes in cognitive status may impact hazard estimation and further complicate task prioritization. Thus, poor postural reserve and high hazard estimation[54] may explain why persons with HD prioritize the motor task or experience declines in both motor and cognitive performance (mutual interference) during dual-tasks.

Limitations

This study was limited by several factors. First, we did not include individuals with pre-manifest HD, which may have expanded the generalizability of our findings and shed more light on shifts in task prioritization and management of task complexity among persons with HD. Our control group was smaller than our cohort of individuals with HD. While the control group adequately matched the HD group in terms of age and sex, it is possible that with a larger control group, greater differences between groups may have been apparent. This study was delivered across three sites; two English-speaking sites and one German-speaking site. It is possible that differences in language may have impacted the testing protocol, but all documents were translated and translations were verified by a neurologist proficient in English and German. To standardize the testing paradigm across sites, the same order of tests was used at each session. Thus, it is possible that dual-tasks assessed at the end of the testing paradigm may suffer from test-fatigue or multiple test biases. Future studies may consider randomizing the order of the test sequence to address this weakness. We utilized different cognitive tasks for each motor task; while this minimizes practice effects, it also limits direct comparisons across postural and walking tasks. The equivalency in terms of difficulty or complexity across these cognitive tasks has not been established, further limiting direct comparison. Finally, gait speed was derived from a walk with one turn included (on both TUG and 7m walk). Turns may require a greater cognitive demand, resulting in more cognitive responses on straightaways and fewer during turns. Future studies will examine if differences in single and dual-task are greater on walks without turns.

Conclusion

The results of this study provide support for a distinction between static and dynamic postural control mechanisms during performance of dual-tasks. Measures of standing postural sway (RMS) is a more sensitive marker of instability than changes in gait speed, particularly under dual-task conditions. Individuals with HD have greater reliance on attention to balance than HC subjects and that when challenged to divide attention, individuals with HD have a noticeable decrement in postural control. With regards to gait tasks, we found the TUG cognitive, which incorporates complex motor and cognitive tasks, is a sensitive measure of dual-task performance in people with HD. Finally, individuals with HD demonstrated motor priority or mutual interference under dual-task walking conditions. Future research should evaluate the potential of measures of postural control as candidate markers for clinical trials.

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Table 1. Participant Demographics

	HD	**Control**	**p-value**
Age (years)	53.6 (11.6) [29-78]	52.2 (13.2) [32-73]	0.698
Sex (male:female)	25:18	8:7	0.751
TMS	40.6 (16.4) [10-70]	-	-
TFC	10.6 (2.2) [5-14]	-	-
SDMT (# correct)	27.5 (12.0) [4-59]	55.7 (16.3) [27-78]	**<0.001**
Fluency (# correct)	24.9 (11.6) [0-54]	43.1 (14.8) [20-65]	**<0.001**
Stroop (# correct)			
Word Reading	52.6 (20.5) [16-112]	92.2 (19.8) [57-128]	**<0.001**
Color Naming	49.7 (18.5) [17-89]	76.8 (15.7) [49-102]	**<0.001**
Interference	24.5 (11.5) [0-59]	46.4 (15.5) [28-80]	**<0.001**

All values listed as mean(SD)[range]. Bolded values indicate $p<0.05$. Symbol Digit Modalities Test (SDMT); Total Functional Capacity (TFC); Total Motor Score (TMS).

Table 2 – Main Effects and Interactions for Motor and Cognitive Performance during Postural Tasks

Main Effects	Postural Sway RMS (m/s^2)				Correct Response Rate (CRR)				
	Mean (SD)	F	P	η2		Mean(SD)	F	P	η2
Group									
HD	0.42 (0.09)	20.9	**<0.001**	0.27	Sit v. FA HD HC	0.58 (0.13) 1.05 (0.18)	10.53	**<0.001**	0.16
HC	0.13 (0.02)				Sit v. FT HD HC	0.61 (0.09) 1.04 (0.01)	9.43	**<0.001**	0.14
					Sit v. Foam HD HC	0.61 (0.10) 1.03 (0.00)	8.92	**<0.001**	0.14
Surface									
FA	0.26 (0.18)	2.5	0.09	0.04					
FT	0.27 (0.17)								
Foam	0.29 (0.19)								
Condition									
Single	0.23 (0.13)	6.72	**0.01**	0.11	Single	0.86 (0.25)			
Dual	0.32 (0.20)				Dual FA	0.77 (0.40)	0.46	0.50	0.01
					FT	0.80 (0.36)	0.19	0.66	0.00
					Foam	0.78 (0.35)	0.36	0.55	0.01
Group x Surface									
HD									
FA	0.29 (0.19)	1.66	0.20	0.03					
FT	0.34 (0.20)								
Foam	0.37 (0.26)								
HC									
FA	0.10 (0.04)								
FT	0.12 (0.05)								
Foam	0.12 (0.06)								
Group x Condition									
HD Single	0.34 (0.04)	3.66	0.06	0.06	HD Single	0.68 (0.93)			
					HC Single	1.03 (0.34)			
					FA HD Dual	0.49 (0.27)	0.80	0.38	0.14
					HC Dual	1.06 (0.40)			
HD Dual	0.50 (0.03)				FT HD Dual	0.55 (0.26)	0.36	0.55	0.01
					HC Dual	1.05 (0.46)			
HC Single	0.11 (0.01)				Foam HD Dual	0.54 (0.29)	0.30	0.59	0.01
HC Dual	0.14 (0.00)				HC Dual	1.03 (0.44)			

Bolded values represent significant effects.

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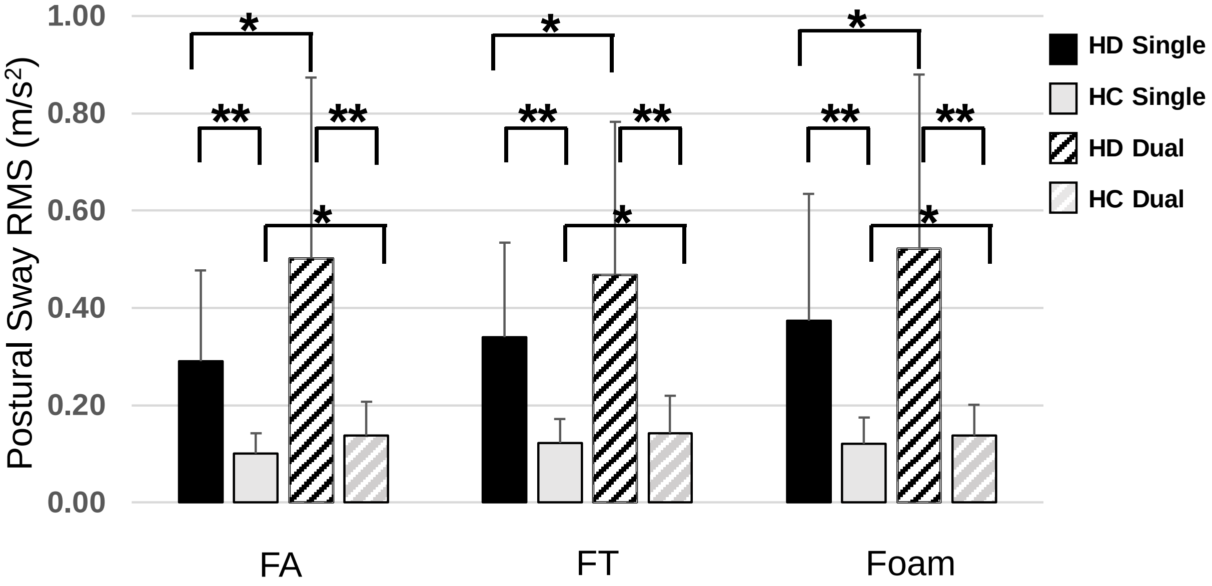

Fig 1. Mean(SD) root mean square (RMS) of postural sway for participants with HD and controls during three standing conditions (firm surface with feet apart (FA) and feet together (FT) and foam surface (Foam)) without (single) and with (dual) the Stroop interference task. The participants with HD consistently had more sway than the HC (**p<0.001) and both groups increased sway moving from single to dual task performance (*p<0.01)

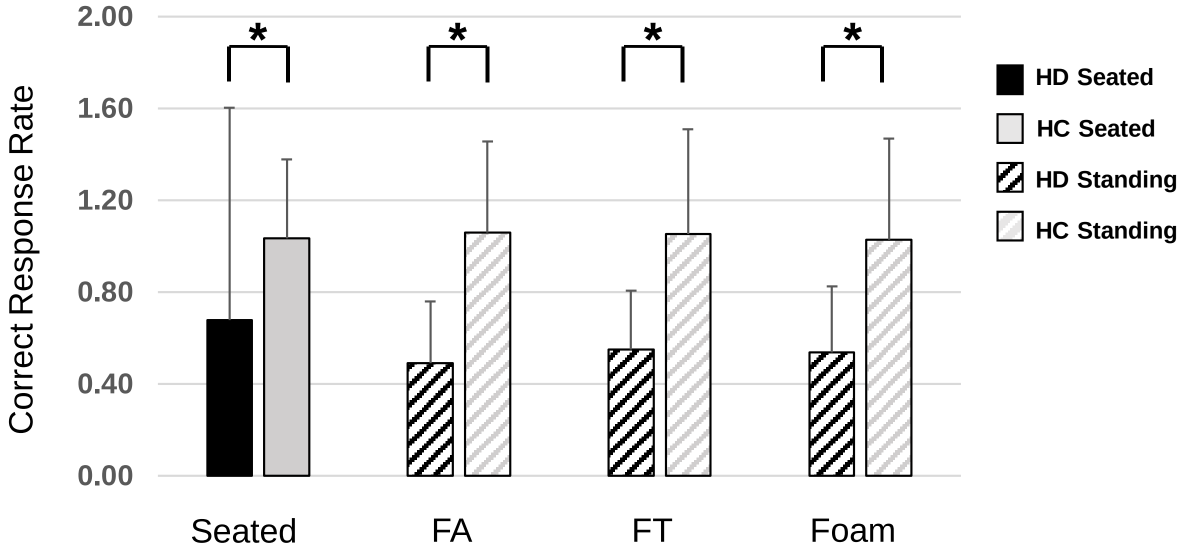

Fig 2. Mean (SD) correct response rate (CRR) on the Stroop interference task for participants with HD and controls seated and during three standing conditions (firm surface with feet apart (FA) and feet together (FT) and foam surface (Foam)). The two groups differ under all conditions (*p<0.005)

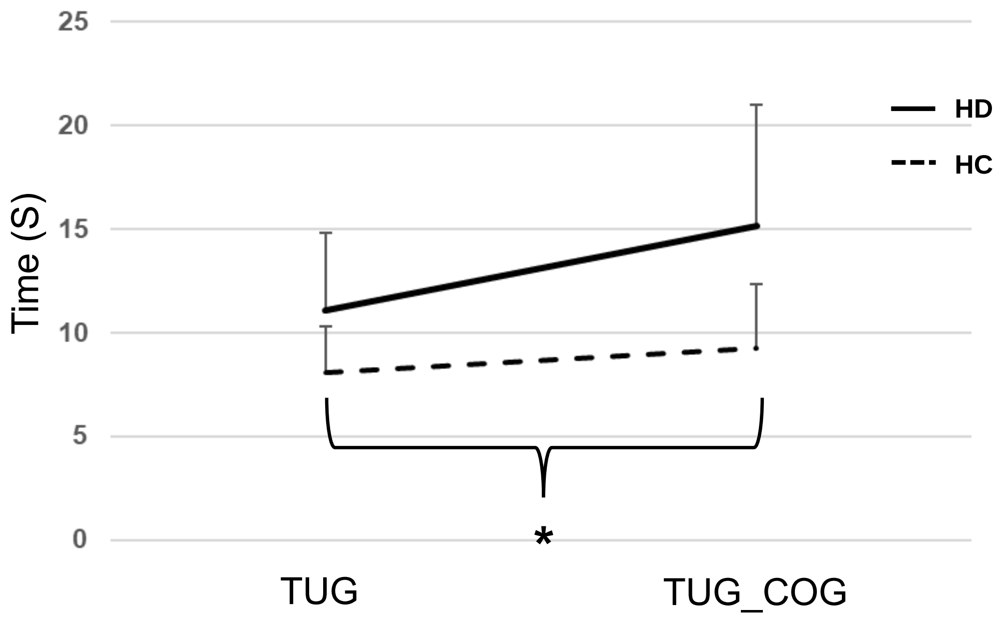

Fig 3. Mean (SD) Timed Up and Go (TUG) alone (A) and with a secondary cognitive task (TUG_Cog) (B) for participants with HD and controls. While both HD and HC groups slowed during the more complex task (p<0,001) the two groups differed (p=0.001) such that HD participants becoming significantly slower with the addition of a cognitive component to the task (*p<0.05).

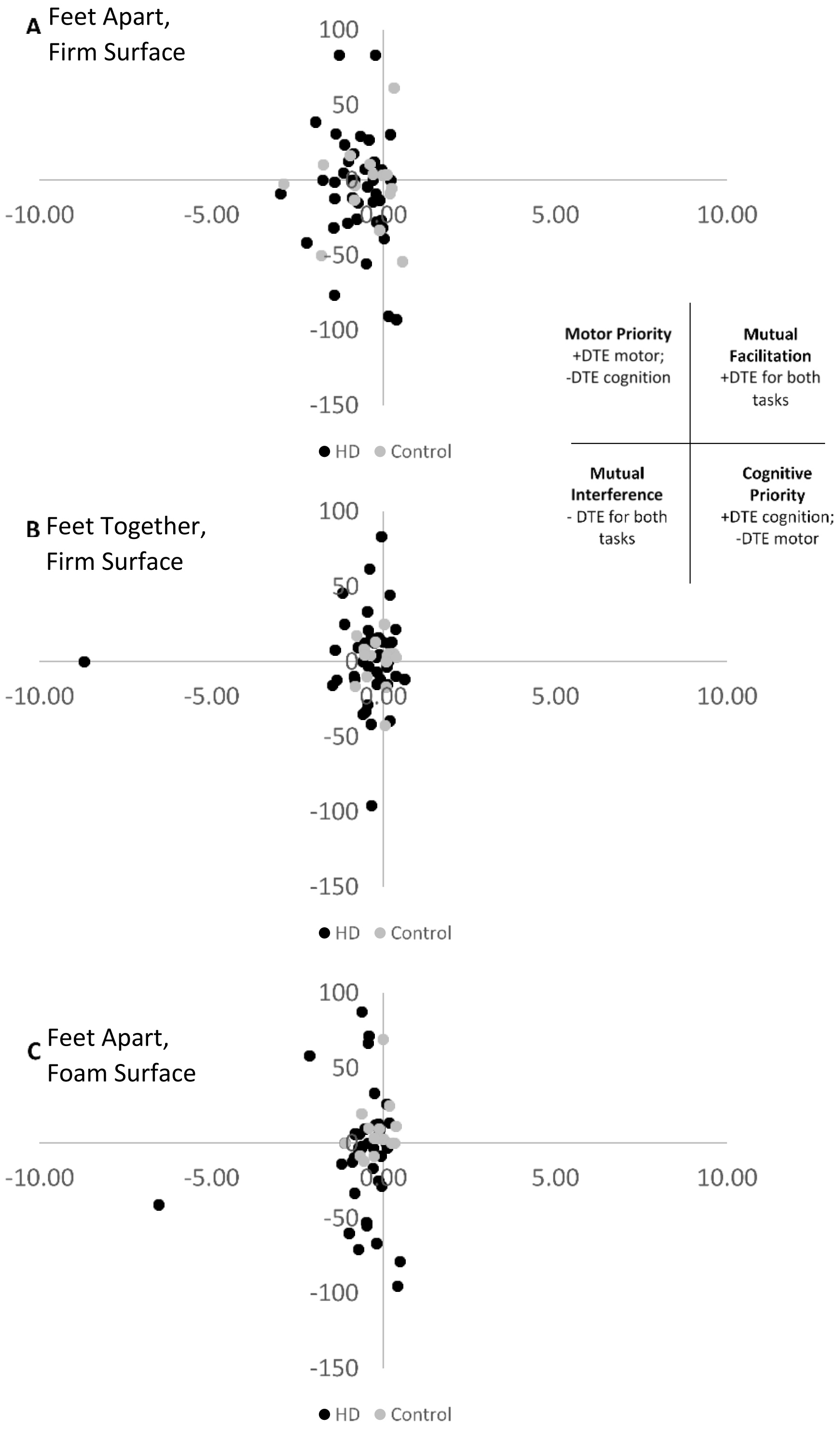
A Feet Apart,
Firm Surface
100
50
0
-50
-100
-150
-10.00
-5.00
0.00
5.00
10.00
● HD ● Control
Motor Priority
+DTE motor;
-DTE cognition
Mutual
Facilitation
+DTE for both
tasks
Mutual
Interference
- DTE for both
tasks
Cognitive
Priority
+DTE cognition;
-DTE motor
B Feet Together,
Firm Surface
100
50
0
-50
-100
-150
-10.00
-5.00
0.00
5.00
10.00
● HD ● Control
C Feet Apart,
Foam Surface
100
50
0
-50
-100
-150
-10.00
-5.00
0.00
5.00
10.00
● HD ● Control

Fig 4. Dual-task effect (DTE) of RMS Sway motor (x-axis) and cognitive (y-axis) across with varying task complexity A) feet apart, firm surface; B) feet together, firm surface; and C) feet apart, foam surface. Across conditions, individuals with HD primarily demonstrate a motor priority or mutual interference.