Effects of Task Difficulty During Dual Task Circle Tracing in Huntington's Disease

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Abstract

Huntington's disease (HD) is associated with impairments in dual task performance. Despite that, only a few studies have investigated dual tasking in HD. We examined dual task performance in 15 participants in the early stages of HD and 15 healthy controls. Participants performed direct circle tracing (able to view arm) and indirect circle tracing (arm obscured) either on their own (single tasks) or paired with serial subtraction by twos or threes (dual tasks). Overall, our results suggested that HD participants were significantly slower and less accurate than controls. Both groups were slower and less accurate when performing indirect circle tracing compared with direct circle tracing. HD participants experienced greater dual task interference in terms of accuracy when performing direct circle tracing compared with indirect circle tracing. Despite that, controls were more inclined to speed-accuracy trade-offs compared with HD participants. Importantly, unlike controls, HD participants were not disproportionately faster when performing direct circle tracing as a single task compared with the dual task conditions. Our results suggest that simple tasks place greater attentional demands on HD participants compared with controls. These findings support that impaired automaticity may be responsible for some of the attentional deficits manifested in HD.

Introduction

Huntington's disease (HD) is associated with deficits in a range of attentional functions, including divided attention, which is the ability to attend to and respond simultaneously to two or more stimuli or tasks [1]. Divided attention has been typically investigated using dual task paradigm that requires individuals to perform two concurrent tasks [2]. Past studies investigating dual tasking in HD are limited, and the cognitive basis of dual task impairments is still unclear. However, the limited dual task research in HD and anecdotal reports of HD patients and their families, suggest that dual tasking is impaired in HD. Previous explanations have included impairments in resource allocation [3], attentional set-shifting [4], and automaticity [5].

Anatomically, dual task interference in people with HD may be explained by disruptions of basal ganglia functions, specifically the striatum, a major site of neurodegeneration in HD. Standard models of basal ganglia thalamo-cortical circuitry posit that the striatum receives topographically organized input from the cerebral cortex (e.g., dorsolateral prefrontal cortex, motor cortex), and through the globus pallidum/substantia nigra and thalamus it influences cognitive function *and* motor and sensory control [6-8]. It is possible that striatal degeneration may result to compromised dual task performance in HD due to signal cross-talk from divergent brain areas and/or erroneous distribution of signals to control processes [8].

A number of theories, including the Multiple Resources Theory, have attempted to explain dual task interference in healthy individuals. The Multiple Resources Theory states that attention has *separate* resource pools (e.g., a visual resource pool, an auditory resource pool), each of which can be divided among concurrent tasks [9]. Cross-dimensional tasks (e.g., visual-auditory) should lead to better processing than uni-dimensional tasks (e.g., visual-visual). Accordingly, dual task interference is expected when tasks make concurrent demands on the same resources [9, 10]. Our study was designed to test this theory, and to investigate the influence of cognitive demands on motor outputs in HD. To achieve this aim, for this study, we combined a motor task requiring participants to trace a circle on a tablet, in conjunction with a cognitive task requiring backward serial subtractions.

Most previous studies suggest that dual task performance is differentially affected in HD compared with controls. For example, both Sprengelmeyer, Lange and Homberg [11] and Müller et al. [12] used the same visual-auditory dual task and reported significant differences between HD and control groups in reaction times and error rates. Thompson et al. [5] employed a simple, tone-paced finger-tapping task with one hand (single task) compared to both hands concurrently (dual task). HD participants demonstrated greater variability in bimanual tapping than controls, and reported that the dual task was more difficult than the single task. The results suggest that dual task difficulty extends to simple tasks in HD, and thus may be explained by impaired automaticity.

In HD, some evidence indicates that adding a second task leads to improved performance, such as increased automaticity of motor tasks in some dual task combinations [13]; however, past research also provides ample evidence of impairments in some dual task combinations compared with healthy controls [14]. Adding to the complexity, HD patient samples in published studies have been quite heterogeneous in their clinical and disease characteristics. For example in Müller et al. [12] disease duration ranged from 3-13 years, and in Delval et al. [14] ranged from 2-12 years, making it difficult to discriminate the cognitive effects in early HD, which are relatively more selective, and those in more progressed stages, which tend to become more severe and wide-ranging. To overcome this issue, we studied a more homogenous sample with respect to disease stage, and included HD individuals within 5 years of diagnosis.

Our dual task paradigm employed visuomotor (circle tracing) and cognitive (serial subtraction) tasks. We manipulated the difficulty level of both tasks to examine the influence of cognitive demands on different difficulty levels of motor behavior. We selected circle tracing since previous studies have shown HD participants to be impaired in both number of rotations and accuracy on this task [15]. These findings were further substantiated in both presymptomatic and symptomatic stages of HD [16]. Lemay et al. (2005) and Say et al. (2011) investigated visuomotor integration under direct and indirect circle tracing. Participants traced an annulus using a tablet and a stylus. In the direct condition, participants could view their arm and tracing path. In the indirect condition, however, their arm was covered, and the annulus and their tracing path were displayed on a separate monitor. HD and controls both performed worse in the indirect condition, and the effect of added difficulty in the indirect condition was relatively more detrimental to HD participants' performances than controls [15, 16].

Our study extends the work of Lemay et al. (2005) and Say et al. (2011) by examining direct and indirect circle tracing under dual task conditions. We selected serial subtraction because it has been found to be an effective distractor task in dual tasking studies [17], it is an attention demanding task [18], and difficulty level can be easily manipulated. We have reported this task combination in a published study of dual tasking in healthy younger and older adults [19]. Vaportzis et al. [19]) concluded that speed and accuracy may be affected differently by dual tasking, and older adults seemed to rely more heavily on proprioceptive feedback to guide movement of their upper limb compared to younger adults.

In consideration of past research and theories, we predicted that HD participants would be slower and less accurate compared with controls. Moreover, we expected that with greater levels of task difficulty, both groups would be slower and less accurate due to the effects of difficulty on limited capacity for resource allocation [20]. Consistent with the Multiple

Resources Theory, we expected interference between the circle tracing and serial subtraction would be minimal, as these tasks are likely to be processed by separate modalities-responses (i.e., visual-manual and auditory-vocal).

Methods

Participants

Fifteen individuals with HD and 15 healthy controls participated. Controls were group-matched to HD participants by sex, age and education. HD participants were diagnosed by an experienced neurologist (AC) on the basis of genetic confirmation of HD and unequivocal presence of motor symptoms. Motor symptom severity was rated using the motor scale of the Unified Huntington's Disease Rating Scale [UHDRS; 21]. The highest possible score is 124 (higher scores = worse motor symptoms). Functional capacity was also rated using the Total Functional Capacity Scale of the UHDRS. The highest possible score is 13 (higher scores = better functioning). Participants' demographics are presented in Table 1.

Sample characterization measures included the Montreal Cognitive Assessment [MoCA; 22], the Wechsler Test of Adult Reading [WTAR; 23], and the Inventory of Depressive Symptomatology-Self-report [IDS-SR; 24]. The MoCA is a 30-point cognitive screening test designed to detect cognitive impairment, with scores of 26 and below considered to be indicative of cognitive impairment. Items from the MoCA emphasize executive functioning and attention. The WTAR is used to estimate verbal IQ, and is composed of 50 words that have irregular letter to sound translations. The IDS-SR is a 30-item questionnaire that assesses the severity of depression within the past 7 days for all symptom domains of major depression according to the Diagnostic and Statistical Manual-IV [25]. A score of 0 indicates no depressive symptoms, whereas a score of 84 indicates very severe depressive symptoms. Education level was assessed based on the International Standard Classification of Education

(ISCED) system, according to which 0 indicates pre-primary education and 6 second stage tertiary education [26].

All participants gave written informed consent, were fluent in English and self-reported that they were free of upper limb impairments (e.g., wrist injuries), and had normal or corrected-to-normal vision and hearing. Controls also self-reported that they were free of other neurological disease and psychological disorders. Ethics approval was granted by the Monash University Human Research Ethics Committee, and therefore, this study has been performed in accordance with the Declaration of Helsinki.

TABLE 1 ABOUT HERE

Dual task description and study procedure

To investigate dual task performance, participants traced a circle on a computer tablet using a stylus while performing a serial subtraction task. The circle tracing *and* serial subtraction tasks both had easy *and* hard difficulty level conditions. Participants first performed circle tracing without serial subtraction, and serial subtraction without circle tracing (single task condition). Specifically, after a practice trial in the easy circle tracing condition, participants performed easy circle tracing, then hard circle tracing, followed by easy serial subtraction, and finally hard serial subtraction. There were three 20 s trials for each circle tracing condition, and two 20 s trials for each serial subtraction condition.

Following performance of these single tasks, participants performed three trials of all possible combinations of difficulty levels of the circle tracing and serial subtraction tasks: (1) easy circle tracing with easy serial subtraction, (2) easy circle tracing with hard serial subtraction, (3) hard circle tracing with easy serial subtraction, and (4) hard circle tracing with hard serial subtraction. Dual task trials lasted 20 s each. Across participants, we used the same order of the eight task conditions for several reasons. We administered single tasks before the dual tasks to facilitate mastery of the single tasks before the added challenge of a second concurrent task. Similarly, we preceded hard tasks by easy tasks to allow familiarization with the easy task before adding to the difficulty level. The circle tracing with serial subtraction dual task set reported here was one of four dual task sets that was performed as part of a larger study. The order of the four dual task sets was counterbalanced across participants.

The circle tracing task was run on a Lenovo ThinkPad® X61 (Morrisville, NC, USA) tablet with a 1.6 GHz processor with a resolution of 1400x1050, and refresh rate of 50Hz. The tablet was positioned in front of the participant at comfortable reach. For the hard condition of the circle tracing task, a separate desktop monitor was placed about 70cm in front of the participant. A 90mm diameter circle with 5mm thick white annulus on a gray background was presented on the tablet for the easy condition, and on the desktop monitor for the hard condition. Participants had to trace the circle, with their preferred hand, using a stylus that left a blue line indicating the trajectory of circle tracing path. Participants were instructed to start at the vertical apex of the circle, and to trace the circle clockwise, as quickly and as accurately as they could. Participants were instructed that only the tip of the stylus, and no part of their hand, was allowed to touch the tablet. In the *easy condition*, participants could observe their arm in motion, and could monitor the circle tracing path on the tablet. In the *hard condition*, participants' views of the tablet and their tracing arm were obscured by a box covering the tablet and a cloak covering the box and their arm. Therefore, in the easy condition participants could *directly* observe their performance on the tablet, whereas in the hard condition they could only observe their progress *indirectly* on the separate desktop monitor. Dependent variables were speed (total number of rotations in 20 s), and error rates (number of errors per rotation). Errors were defined as the stylus moving beyond either the inner or outer edge of the white annulus for > 100 ms.

For the serial subtraction task, participants counted backward by twos (easy) or by threes (hard) for 20 s. Starting numbers ranged between 100 and 86 with half of the trials commencing on an even number. The dependent variable was error rates (percentage of incorrect responses). We also calculated rate of responses for serial subtraction by dividing the time to complete the task (20 s) by the number of responses per participant. We advised participants to perform all tasks as quickly and as accurately as possible.

Design and statistical analyses

Overall means and standard deviations for *speed* and *error rates* for circle tracing and *errors* and *response rate* for serial subtraction were calculated. There were not any data with values more than 3.5 standard deviations from the individual's mean; thus, no data was removed prior to analyses. For circle tracing we computed 2 X 2 X 3 mixed-model ANOVAs with the between factor, Group (HD, controls), and two within factors, Circle Tracing difficulty (easy, hard), and Serial Subtraction difficulty (none, easy, hard) for speed and error rates. We examined main effects, two- and three-way interactions. We report Greenhouse-Geisser corrected degrees of freedom due to violations of the sphericity assumption. A Bonferroni adjustment was applied. For serial subtraction, ANOVA was inappropriate due to very low error rates. Thus, we used non-parametric analyses (i.e., Wilcoxon signed rank test) to compare the easy and hard conditions for HD and controls separately.

We also computed dual task costs in terms of both slowing and increased errors in the presence of dual tasks compared to single tasks. We used 2 X 2 X 2 mixed-model ANOVAs with the between factor, Group (HD, controls), and two within factors, Circle Tracing difficulty (easy, hard), and Serial Subtraction difficulty (easy, hard). For errors in serial subtraction, we added a value of 1 to each data point before calculating dual task costs due to several participants not committing any errors in the single tasks. As per previous studies [27-30], *dual task costs* for speed and error rates were computed using the following formula: dual task cost = (single task speed−dual task speed)/single task speed, to calculate the relative ratio of single task to dual task speed (or error rates), controlling for single task speed (or error rates). In circle tracing, higher dual task costs for speed indicate that participants performed fewer rotations in the dual tasks compared with the single tasks, whereas for error rates, they indicate lower accuracy. In serial subtraction, higher dual task costs for errors indicate that participants' accuracy was lower in the dual tasks compared with the single tasks, whereas for response rate, they indicate fewer responses. Lastly, in order to examine speed-accuracy trade-offs, we calculated Pearson's correlations between speed and error rates for all conditions separately for each group. We compared correlations between HD participants and controls using Fisher's Z-test. For all analyses, alpha was set at .05.

Results

Circle tracing performance

For circle tracing, a three-way ANOVA with speed as the dependent variable revealed a significant three-way interaction involving Group, Circle Tracing and Serial Subtraction conditions, $F(1.74,48.78) = 10.77$, $p < .001$, $\eta^2 = .27$ (see Figure 1). To understand the different effects within the HD and control groups, we used two-way ANOVAs with Circle Tracing and Serial Subtraction as factors. In the HD group, we found a significant main effect of Circle Tracing condition, $F(1,84) = 38.35$, $p < .001$, $\eta^2 = .31$, with faster performance in easy circle tracing compared to hard circle tracing. We found no other main effects or interactions. In the control group, we found a significant two-way interaction between Circle Tracing and Serial Subtraction conditions, $F(2,84) = 6.67$, $p = .002$, $\eta^2 = .13$. Pairwise comparisons revealed that controls performed significantly ($p < .001$) faster in the easy circle tracing task on its own than when performed concurrently with either easy or hard serial subtraction. For dual task costs, the same model revealed a significant main effect of Circle Tracing condition, $F(1,28) = 22.12$, $p < .001$, $\eta^2 = .44$ with greater costs in the easy circle tracing compared with the hard circle tracing tasks. We found no significant effect of Group, $F(1,28) = .85$, $p < .363$, $\eta^2 = .03$, *or* any other main effects or interactions.

FIGURE 1 ABOUT HERE

A three-way ANOVA with error rates as the dependent variable in the circle tracing task revealed a significant two-way interaction between Group and Circle Tracing conditions, $F(1,28) = 4.54$, $p = .042$, $\eta^2 = .14$ (see Figure 2). Pairwise comparisons revealed that HD participants made significantly ($p < .001$) more errors compared with controls in both easy and hard circle tracing tasks, but were significantly ($p < .001$) more error prone when performing hard circle tracing. For dual task costs, the same model for error rates revealed a significant main effect of Group, $F(1,28) = 4.90$, $p = .035$, $\eta^2 = .15$, suggesting that HD participants were more compromised in the dual task conditions in terms of accuracy compared with the control group. We found no other main effects or interactions.

FIGURE 2 ABOUT HERE

To investigate whether HD participants were more inclined to trade speed for accuracy or vice versa, we performed a series of correlational analyses between speed and error rates for each of the six circle tracing task (single and dual tasks) conditions separately for HD participants and controls. We found significant ($p < .05$) positive correlations, indicating speed-accuracy trade-offs in controls across all conditions except *hard circle tracing with easy serial subtraction*. In contrast, HD participants showed this trade-off only in the *easy circle tracing single task*. With exceptions (i.e., easy circle tracing *and* hard circle tracing with easy serial subtraction), these correlations were significantly ($p < .05$) different between the two groups as indicated by Fisher Z tests (see Figure 3).

FIGURE 3 ABOUT HERE

Serial subtraction performance

Serial subtraction performance is presented in Table 2. For errors in the serial subtraction task, Wilcoxon signed rank tests showed significant differences only in one dual task condition for the HD participants (i.e., *easy serial subtraction with hard circle tracing* vs *hard serial subtraction with hard circle tracing*); however, controls showed significant differences on a number of conditions. We found no significant main effects or interactions for dual task costs for errors.

For response rate in the serial subtraction task, Wilcoxon signed rank tests showed significant differences on several conditions for both HD participants and controls. Overall, response rate was faster for both groups in the easy serial subtraction conditions. For dual task costs, a three-way ANOVA for response rate revealed a significant two-way interaction between Circle Tracing and Serial Subtraction conditions, $F(1,28) = 17.47$, $p < .001$, $\eta^2 = .38$ (see Figure 4). Pairwise comparisons revealed that all participants experienced greater costs when they performed *easy* serial subtraction concurrently with easy ($p < .001$) and hard ($p = .008$) circle tracing, rather than when performing *hard* serial subtraction with circle tracing (either easy or hard).

TABLE 2 AND FIGURE 4 ABOUT HERE

Discussion

Our most interesting finding was that contrary to controls, HD participants were not disproportionately faster when performing direct circle tracing as a single task compared with the dual task conditions. This finding suggests that simple tasks place greater attentional demands on HD participants compared with controls. Consistent with our predictions, HD participants were significantly slower and less accurate than controls in circle tracing. As expected, both groups were slower and less accurate in the hard circle tracing conditions, with HD participants being disproportionately compromised in terms of accuracy. HD participants had greater dual task costs in terms of accuracy compared with controls when performing easy rather than hard circle tracing. In addition, we found that HD participants were less susceptible to speed-accuracy trade-offs than controls.

Consistent with previous studies using dual task paradigms, but with different tasks [11, 12], HD was associated with slower performance in hard circle tracing compared with easy circle tracing, a finding that may reflect a general decline in psychomotor function and/or speed in HD. In terms of group differences in speed, Figure 1 suggests that controls had disproportionately higher speed in the easy circle tracing condition (single task) compared with the other conditions (i.e., hard single task and all dual tasks). Interestingly, however, and unlike controls, HD participants were not disproportionately faster in the easiest condition of the circle tracing task (i.e., easy circle tracing single task). In contrast, the speed of the controls significantly declined from single to dual tasks, whereas in HD speed was very similar across both the single and dual tasks. These results suggest that in controls, their fast single task accuracy could not be maintained when they had to accommodate a second task, but perhaps because in HD they were already relatively slow in the single task, they more readily accommodated the second task of the dual condition without additional cost. Despite that, both groups showed greater dual task interference in the easy circle tracing task conditions compared with the hard ones; speed declined more steeply from single to dual tasks in the easy circle tracing. Findings also point to impaired automaticity in HD since deficits were also noted in the easy circle tracing single task suggesting that it was attentionally demanding for the HD participants.

In terms of circle tracing accuracy, compared with controls, HD participants made significantly more errors in both easy and hard circle tracing, were disproportionately compromised in the hard circle tracing conditions, and showed greater dual task interference as demonstrated by higher dual task costs on circle tracing error rates. Say et al. (2011) has also reported disproportionately reduced accuracy in hard (indirect) circle tracing in HD compared to easy (direct) circle tracing. Our data extend these findings into a dual task paradigm. Previous studies have suggested that slowed performance in indirect circle tracing may be due to the sensorimotor transformation requirements, which include the integrations of visual and proprioceptive information into a common reference frame [16, 18, 31]. Furthermore, for understanding the relative contributions of the psychomotor versus visuospatial demands in the impairments observed in the HD group, it is important to note that the direct and indirect circle tracing tasks are matched in terms of their motor demands, but differ in terms of their visuospatial demands. Thus, the relative impairment in dual tasking in the indirect condition points to the visuospatial problems as the source of the difference in performance in the dual task context. This is an important distinction because both motor and visuospatial functions are affected by HD, and the design of our task conditions made it possible to tease apart which of these impairments contributes most to the dual tasking deficit.

The finding that HD was not associated with speed-accuracy trade-offs (with a single exception), but that speed-accuracy trade-offs were consistently present in controls, may be considered in the context of accumulator models. Specifically, accumulator models of speed-accuracy trade-offs assume that sensory evidence accumulates over time from baseline until a decision threshold [32]. Accumulation of evidence may proceed more or less slowly *and* more or less accurately, depending on the task and individual differences. Speed-accuracy trade-offs have been found to be implemented by a prefrontal network [32, 33]. Evidence suggests that interactions between prefrontal regions that are essential for cognitive performance are compromised in HD [34-36]. Although our instructions emphasized equally speed and accuracy, controls may have used strategies that emphasized either speed or accuracy, whereas HD participants may have been less able to implement such strategies due to this dysfunctional prefrontal network. Therefore, controls showed speed-accuracy trade-offs, whereas HD participants did not. This point may be able to be tested more directly by studying the effects of systematically varying instructions to emphasize the speed or accuracy of performance.

Contrary to predictions of the Multiple Resources Theory, our finding of interference between the circle tracing and serial subtraction tasks is evidence of resource sharing between two apparently different tasks, suggesting that the visual and auditory modalities *and* the manual and vocal responses are not entirely separate. Our results may be explained by the Unitary Resource Theory. The Unitary Resource Theory holds that attention is a *single, limited capacity resource* that can be allocated to a single task or divided between several tasks, and can be affected by task difficulty, as well as individual's arousal levels and motivation [20]. This theory postulates that dual task performance deteriorates if one task is difficult and requires a large proportion of this limited attentional resource, because there is little left to support the performance of other tasks. When the demand exceeds the amount of attentional capacity, allocation strategies are used to establish where the attention resource should be allocated. Our results showed that participants' speed and accuracy decreased with task difficulty; therefore, they provide support to the unitary resource framework.

In summary, we demonstrated that HD was associated with slower speed and less accuracy compared to controls in the circle tracing tasks, with both groups slower and less accurate in the hard circle tracing compared with the easy circle tracing conditions. Compared with controls, HD participants experienced greater dual task interference in terms of accuracy, and were less susceptible to speed-accuracy trade-offs. HD participants were not disproportionately faster when performing direct circle tracing as a single task compared with the dual task conditions providing support to the automaticity account. Our findings suggest that simple tasks place greater attentional demands on HD participants compared with controls, and support that attentional deficits in HD may due impaired automaticity.

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Table 1

Descriptives and *t*-tests of demographics for HD participants and controls

	HD (n = 14)			Controls (n = 14)			
	M	*SD*	Range	*M*	*SD*	Range	*t*-test
Sex (F:M)	4:10			4:10			
Age	58.40	8.87	41-73	55.53	12.33	41-72	$t(28) = -.73$, $p = .47$
CAG	42.64	1.90	40-47				
Diagnosis (Years)	4.67	1.90	2-5				
UHDRS Motor score	21.21	8.86	7-34				
UHDRS TFC	10.20	3.05	3-13				
WTAR	109.13	6.27	99-118	102.53	29.52	102.53	$t(28) = -.84$, $p = .27$
MoCA	24.60	3.06	20-29	27	2.36	26-30	$t(28) = 2.40$, $p = .02$, $d = .87$
IDS-SR	13.40	9.68	2-33	11.60	6.87	11.60	$t(28) = -.58$, $p = .56$
ISCED	4.07	.799	3-6	4.47	1.12	4.47	$t(28) = 1.12$, $p = .27$

Note. IDS-SR: Inventory of Depressive Symptomatology-Self-Report; ISCED: International Standard Classification of Education; MoCA: Montreal Cognitive Assessment; UHDRS: Unified Huntington's Disease Rating Scale; TFC: Total Functional Capacity; WTAR: Wechsler Test for Adult Reading.

Table 2

Comparison of serial subtraction conditions for HD and control groups

	Errors				Response Rate			
	HD		Controls		HD		Controls	
	z	*p*	z	*p*	z	*p*	z	*p*
E Subtraction vs H Subtraction	-1.75	.080	-4.62	<.001	-3.40	.001	-3.40	.001
E Subtraction vs E Subtraction with E Tracing	-1.06	.285	-4.48	<.001	-3.40	.001	-3.40	.001
E Subtraction vs E Subtraction with H Tracing	-.184	.854	-4.55	<.001	-.341	.001	-2.95	.003
E Subtraction vs H Subtraction with E Tracing	-1.75	.080	-1.69	.091	-3.41	.001	-3.40	.001
E Subtraction vs H Subtraction with H Tracing	-1.96	.051	-1.15	.249	-3.41	.001	-3.41	.001
H Subtraction vs E Subtraction with E Tracing	-.734	.463	-.169	.866	-.345	.730	-1.65	0.96
H Subtraction vs E Subtraction with H Tracing	-1.48	.138	-1.57	.116	-1.92	.055	-3.23	.001
H Subtraction vs H Subtraction with E Tracing	-1.75	.080	-2.61	.009	-1.84	.062	-2.04	.041
H Subtraction vs H Subtraction with H Tracing	-1.48	.138	-3.17	.001	-1.85	.064	-1.56	.118
E Subtraction with E Tracing vs E Subtraction with H Tracing	-.730	.465	-.552	.581	-1.53	.125	-2.44	.014
E Subtraction with E Tracing vs H Subtraction with E Tracing	-.405	.686	-4.42	<.001	-1.36	.173	-2.79	.005
E Subtraction with E Tracing vs H Subtraction with H Tracing	-.631	.528	-4.48	<.001	-3.18	.001	-2.54	.011

E Subtraction with H Tracing vs H Subtraction with E Tracing	-1.48	.138	-4.25	<.001	-2.54	.011	-3.40	.001
E Subtraction with H Tracing vs H Subtraction with H Tracing	-2.02	.043	-4.22	<.001	-3.40	.001	-3.40	.001
H Subtraction with E Tracing vs H Subtraction with H Tracing	-.169	.866	-.300	.764	-2.27	.023	-.283	.777

Note. E: Easy; H: Hard.

Figure captions

Fig. 1. Circle Tracing difficulty (easy, hard) as a function of Serial Subtraction difficulty (none, easy, hard) in HD participants and controls using speed as the dependent variable. E = Easy; H = Hard. Standard error bars included.

Fig. 2. Circle Tracing difficulty (easy, hard) as a function of Group (HD, controls) using error rates as the dependent variable. E = Easy; H = Hard. Standard error bars included.

Fig. 3. Speed-accuracy trade-offs for HD participants and controls across all circle tracing task conditions. Asterisks next to the r values represent significant correlations: ** $p < .001$, * $p < .05$.

Fig. 4. Dual task costs for serial subtraction. E-E = Easy serial subtraction with easy circle tracing; E-H = Easy serial subtraction with hard circle tracing; H-E = Hard serial subtraction with easy circle tracing; H-H = Hard serial subtraction with hard circle tracing. Standard error bars are included.

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