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Adults with Down syndrome demonstrate peripheral not central deficits when integrating movements during multiple target sequences.

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Abstract

The perceptual-motor impairments of individuals with Down syndrome (DS) are attributed to central (e.g., neurophysiology deficits that affect the retrieval or initiation of motor programs) and peripheral (e.g., anatomical deficits relating to issues with inertia of limb mechanics and muscle organisation) processes. However, recent research suggests that central deficits do not affect the integration between movements. We investigate the impact of central *and* peripheral DS deficits on movement integration by examining the planning and execution of multiple-target multiple-arm movements. Individuals with DS, typically developing (TD), and individuals with an undifferentiated intellectual disability (UID) completed 5 aiming tasks: A one target; a one arm two-target extension; a two arm two-target extension (movement one was performed with one arm and movement two performed with the other); a one arm two-target reversal; and a two arm two-target reversal. MTs to the first target were longer in the two-target tasks compared to the one-target task. For the one arm two-target reversal task, this effect emerged only in individuals with DS. These results indicate that individuals with DS utilise central processing for movement integration similarly to their TD and UID counterparts but cannot exploit peripheral level integration to enhance integration in one arm reversal tasks.

Key words: One Target advantage; Movement integration hypothesis; Sequential aiming; Limb Mechanics

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The genetic condition whereby an additional 21st chromosome (full or partial) occurs in every cell of the body is referred to as Down syndrome (DS). This genotype results in individuals demonstrating different physiological, anatomical, and neurological features to those of the typically developing (TD) population. Individuals with DS typically display delays in achievement of postural milestones e.g., sitting, standing (Cowie, 1970), walking (Ulrich & Ulrich, 1993), and adjusting grip aperture to objects when reaching (Thombs & Sugden, 1991) compared to their TD counterparts. The lag in achievement of these postures has been attributed to hypotonia and joint hypermobility (Dyer, Gunn, Rauh, & Berry, 1990; Henderson, 1985). However, it is unlikely that hypotonia alone explains these postural development delays or the persistence of co-ordination difficulties across the life span because there is evidence for reduction in hypotonia with increasing age (Morris, Vaughan, & Vaccaro, 1982; Owens, Dawson, & Losin, 1971). Furthermore, researchers have revealed that individuals with DS also produce longer reaction times (RT) (Arisi, Forti, Amadeo, et al., 2012; Davis, Sparrow, & Ward, 1991; Henderson, Illingworth, & Allen, 1991; Lawrence, Reilly, Mottram, Khan, & Elliott, 2013; Masumoto, Abe, & Inui, 2012), longer movement times (MT), and greater movement errors (Elliott, Welsh, Lyons, Hansen, & Wu, 2006; Hodges, Cunningham, Lyons, Kerr, & Elliott, 1995; Lawrence et al., 2013) compared to TD populations. These perceptual-motor impairments have been attributed to *both* central processes (i.e., an inability to develop accurate motor programs for upper limb movements; Frith & Frith, 1974) and peripheral anatomical characteristics (i.e., issues with inertia of limb mechanics and muscle organisation; Henderson et al., 1991; Morris et al., 1982).

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Indeed, researchers (Anson & Davis, 1998; Anson & O'Conor, 1989; Mawston & Anson, 1994) have reported that individuals with DS adopt peripheral movement strategies that result in a distal to proximal EMG pattern of activation and co-contraction EMG patterns i.e., simultaneous EMG activity in antagonist and antagonist muscle pairs crossing all the joints of the moving limb (Aruin & Almedia, 1996; Aruin, Almedia, & Latash, 1996). These patterns of activation are directly opposite to the proximal to distal (see Karst & Hasan, 1991) and tri-phasic (see Gottlieb, 1998) muscle pair EMG patterns of activity observed in the TD population and may well represent a peripheral processing deficit unique to individuals with DS. Whilst not empirically tested, much of these DS specific peripheral muscle activation patterns may be attributed to the motor system adapting to hypotonia via activating and co-contracting muscle groups to stabilise non-functional movement variability (see Latash & Anson, 2006).

The importance of simultaneously investigating central and peripheral integration strategies in individuals with DS stems from 1) the differential explanations attributed to the perceived slowness of this population when performing single limb one target aiming tasks; and 2) the different central and peripheral integration strategies reported within the sequential aiming literature of the TD population. In relation to point 1, on one hand, the deficit has been attributed to an inability to develop and produce accurate movement parameters of upper limb movements (Frith & Frith, 1974). This central programming deficit is thought to lead to an increased reliance on afferent feedback for the online regulation of movement (Hodges et al., 1995; Simon, Elliott, & Anson, 2003). However, Anson (1992) suggested that the slower RT and increased MTs observed in individuals with DS reflect deficits in both peripheral and central mechanisms. That is, anatomical deficits

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relating to issues with inertia of limb mechanics and distal to proximal muscle pattern organisation (Anson & Mawston, 2000; Anwar & Hermelin, 1979; Henderson, Morris, & Frith, 1981) together with central deficits associated with neurophysiology that affect the retrieval or initiation of motor programs (Carvalho & Vasconcelos, 2011; Kerr & Blais, 1987), account for RT and MT observations in individuals with DS. In relation to point two above, the literature on the integration strategies adopted by TD individuals when controlling sequential aiming movements has revealed separate central and peripheral integration (Adam et al., 2000, Khan et al., 2006; 2010) strategies. These strategies are revealed depending of the directional constraints between the first and second sequential aiming movements (see Adam et al., 2000). Whilst these are discussed in detailed over the next three paragraphs of the introduction, briefly, the findings reveal that sequential movements that require an extension in direction are governed by central control strategies i.e, the implementation (from a central buffer) of the pre-programmed movement commands of the second movement during execution of the first. Whereas, when movements involve a reversal in direction their integration is governed by the peripheral muscle characteristics between the first and second movement i.e., the muscle(s) used to create the breaking force of the first movement can be exploited to act as the initiating force of the second movement and thus create a peripheral integration strategy that is unique to reversal actions. Utilising the research paradigms within this movement integration body of literature allows investigation into the central and peripheral movement deficits of individuals with DS via behavioural reaching and pointing data.

Researchers have shown that both central and peripheral processes contribute to the planning and control of sequential aiming movements. Typically, RT and MT to the first target are longer in two- compared to one-target responses (Adam et al.,

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2000; Chamberlin & Magill, 1989; Fischman & Reeve, 1992). This one target advantage in reaction and movement time implies that individual segments in a targeted sequence are not prepared and executed independently (Khan, Helsen, & Franks, 2010). This interdependency between movement segments in a two target aiming sequence has been explained via the movement integration hypothesis (Adam, Nieuwenstien, Huys, et al., 2000). Specifically, the hypothesis poses that response segments are programmed and stored in a buffer prior to movement initiation. The implementation of the second segment is performed concurrently with the execution of the first in order to facilitate a smooth and efficient transition between the segments. This online implementation results in increased cognitive control during the production of the first segment, which leads to dual-task interference. Although the transition between segments is facilitated via the implementation of the second segment online, the resultant increased cognitive processing load during response execution leads to a lengthening of movement time to the first target.

Consistent with previous research on upper limb sequential aiming movements in the TD population (Adam et al., 2000; Adam, Helsen, Elliott, & Buekers, 2001; Adam, Paas, Eyssem, Slingerland, Bekkering, & Drost, 1995; Helsen, Adam, Elliott, & Buekers , 2001; Khan, Mottram, Adam, & Buckolz, 2010; Mottram, Khan, Lawrence, Adam, & Buckloz, 2014), Lawrence et al. (2013) have revealed that individuals with DS treat movements within a sequence as functionally dependent actions. The research revealed a one target movement time advantage for both the TD population and individuals with DS. That is, MT to the first target in a sequence was faster when the movement was required to stop at the first target compared to when the limb was required to continue to a second target. In line with Adam, et al's., (2000) movement integration hypothesis, Lawrence et al. (2013) suggested that participants programmed the entire movement response in advance of movement initiation. The parameters of the first segment were then utilised to initiate the response, whilst the movement parameters of the second segment were held in a 'central buffer' and implemented during the production of the first segment at a time deemed most appropriate to ensure optimal transition between the first and second segments. The act of implementing the second segment during execution of the first led to interference and resulted in the slowing of the first movement. Thus, in line with the movement integration hypothesis (Adam et al., 2000), Lawrence et al. (2013) proposed that the one target MT advantage and the control strategies used by individuals with DS to integrate the two segments occurred at the central level. The research concluded that any central deficits associated with DS do not prevent the adoption of movement integration strategies that reside at the central level and involve anticipatory behaviour i.e., implementing the second movement in a sequence at an appropriate time during the execution of the first. However, Lawrence et al. (2013) only included extension movements within their experimental design despite previous research having suggested that when movements within a segment are in opposite directions of one another, it is the peripheral processes associated with muscle mechanics that are responsible for movement integration (Adam et al., 2000). Consequently, in order to more fully investigate the possible central and peripheral deficits of individuals with DS, the current investigation examined movement integration strategies in both extension and reversal sequential aiming movements.

While the integration between movement segments is suggested to occur at the central level when the second target is in the same direction as the first (Adam et al., 2000; Lawrence et al., 2013), peripheral mechanisms play a more dominant role when the second target requires a reversal in direction to the first target. For reversal movements, research has demonstrated either the removal of the one target movement time advantage (Adam et al., 2000; Ketelaars, Garry and Franks, 1997; Khan et al, 2010) or significant reductions in MTs to the first target compared to those in one target conditions (i.e., a two-target advantage, Khan, Lawrence, Franks, & Buckolz, 2006). Because the one target movement time advantage is eliminated under reversal conditions, researchers (i.e., Adam et al., 2000; Khan et al., 2006; 2010) have proposed that the antagonist muscle groups used to decelerate the first segment of the movement are also the agonistic muscle groups used to accelerate the second segment. Thus, the bi-phasic muscle characteristics of the two target reversal movement can be interpreted to suggest that the integration between segments occurs at the peripheral (i.e., muscular organisation of the limb being adjusted and readied for a second movement) rather than central (i.e., the online retrieval and implementation of a motor program from a motor buffer) level. In order to further the understanding of the control of multiple movement actions in the DS population together with the possible central and peripheral movement deficits associated with this genotype, the current investigation utilised the two target aiming paradigm that has been used in the TD population. This allowed the current research to simultaneously, and more rigorously, investigate the previously reported central and peripheral movement integration control strategies in DS (see Lawrence et al., 2013).

Specifically, we compared one target movements with two target extension sequences when the two target responses were performed with one hand and when they were performed with two hands (i.e., when there was a switch between the hands used to execute the first and second movement segments). However, we also included responses where the second movement in the sequence required a reversal in direction to that of the first. Similar to Lawrence et al. (2013), we hypothesised that MTs to the first target would be slower in the one hand and two hand extension movements because the central processes proposed within the movement integration hypothesis would govern the transition between movement segments in both the TD and the populations with learning disabilities. This finding would add support for Lawrence et al's (2013) proposal that any central deficits associated with DS do not prevent movement integration strategies that reside at the central level. With regard to conditions where the directional requirement of the second movement was a reversal, it was hypothesised that the removal of the one target advantage, or emergence of a two-target advantage, would be observed in the one hand, but not the two hand reversal task. The rationale being that there is a change in effectors (i.e., hands) in the two hand condition and thus the removal of the bi-phasic pattern of muscle activation proposed to be responsible for the two target advantage in one hand reversal conditions (Adam et al., 2000; Khan et al., 2006; 2010). Furthermore, if the DS specific distal to proximal and or co-contraction of antagonist and antagonist muscle pairs patterns of EMG activation (e.g., peripheral deficits) affect movement integration, then one would expect the two target advantage phenomenon to be reduced or removed in the DS compared to the TD population. That is, individuals with DS would not utilise the bi-phasic pattern of muscle activation observed in the TD population, simply because their EMG patterns of organisation follow a proximal to distal, rather than distal to proximal, pathway (see Anson and colleagues, 1989, 1999) and/or follow a single co-contraction pattern (Aruin & Almedia, 1996; Aruin, et al., 1996). Thus, the peripheral movement strategies that reside at the mechanical level and allow for optimal integration and transition between reversal movements within TD population would not occur in individuals with DS. This is because of the proposed anatomical deficits relating to issues with inertia of limb mechanics and muscle organisation (Anson & Davis, 1998; Anson & O'Conor, 1989; Anson & Mawston, 2000; Anwar & Hermelin, 1979; Aruin & Almedia, 1996; Aruin, et al., 1996; Henderson et al., 1981, 1991; Mawston & Anson, 1994).

The primary aim of the current investigation was to examine the central and peripheral deficits of individuals with DS using a novel behavioral paradigm. A secondary aim was to explore the possible practice effects on the integration of movement segments in persons with DS. Previous non disability specific research has revealed that the one target movement time advantage is resistant to practice (Lavrysen, Helsen, Tremblay, et al., 2003). However, research within the DS population has indicated that motor skills can be modified over a period of days or weeks through task-specific practice sessions and that individuals with DS have the potential to reach the same levels of motor skill proficiency as their TD peers with adequate practice (Latash, 2007; Smith, Kubo, Black, Holt & Ulrich, 2007). As such, we investigated the possible changes to the initial movement strategies adopted by individuals with DS by adopting a total of 400 trials equally spaced over a four day practice period.

Method

Participants

Participants were 24 adult volunteers; 8 individuals with DS (4 males and 4 females; mean chronological age = 25 yrs, *SD* = 8.55; mean mental age = 8.1 yrs, SD = 3.2), 8 individuals with an undifferentiated intellectual disability (UID) (5 males and 3 females; mean chronological age = 26 yrs, SD = 6.5; mean mental age = 8.4 yrs, SD = 2.9) and 8 TD (4 males and 4 females; mean chronological age = 20 yrs, SD = 1.5). All participants completed the British Vocabulary Peabody scale as a measure of mental age and intellectual functioning (Dunn & Dunn, 1997). Whilst the individuals with an UID were classified as having a high functioning intellectual disability from local service departments and parent(s)/guardian(s), this disability was not syndrome specific. Although the individuals in the two intellectually disabled groups exhibited similar patterns of day to day adaptive functioning, individuals with an UID did not score significantly higher on the Peabody scale than individuals with DS. Note: the inclusion of the UID group was to help increase the internal validity of the research design. That is, to help ensure any changes in the dependent variables could be attributed to specific characteristics of DS rather than the intellectual functioning differences between individuals with DS and the TD population. The individuals with DS, and those with an UID, were recruited from Pengwern Mencap College, Special Olympics Bangor, and Mencap support groups across Wales. The TD participants were recruited from the student population of the University Institution. Of the 16 individuals with an intellectual disability, all lived in either a group home or with a parent/caregiver and were involved in some form of physical activity (e.g. athletics, basketball, football etc.) at least once a week. In addition, 5 individual with DS and 2 individuals with an UID were in full time education, and 3 individuals with DS and 6 individuals with an UID were involved in part time or full time employment. All participants volunteered for the study, were naive to the experimental hypothesis, were right-hand dominant, and reported normal or corrected to normal vision. Accessible easy read information sheets about the experiment were given to all participants and more in-depth information sheets were supplied to the participants support workers and parents/guardians. All participants were assessed for Mental Capacity (under the guidelines for the Mental Capacity Act 2005) prior to consent. Specifically, participants were provided with accessible information about the experiment, both verbally and visually, and then asked a series of questions related to

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this information. Responses were graded for understanding by an individual trained in Mental Capacity assessment through Mencap Cymru and in line with the procedures for consent to psychological research by people with an intellectual disability (see Arscott, Dagnan, & Kroese, 1998). Accessible consent forms were signed by all participants before the start of the experiment[1] and the study was carried out according to the institutions ethical guidelines for research involving human participants.

Apparatus

Similar to Khan et al. (2010) and Lawrence et al. (2013), participants were seated in front of a horizontal table top upon which was situated a wooden frame with six micro switches mounted under square (25mm × 25mm) keys. The keys were positioned in 3 sets of pairs along the participants' midline with the latitudinal distance between each key being 35mm (centre to centre) and the longitudinal distance between each key being 150mm (centre to centre) (see Figure 1A). Participants were positioned so that each key could be easily reached and pressed with their index fingers. The start positions were the most distal keys, the middle keys were designated as target 1, and the most proximal keys designated as target 2.

Task

As shown in Figure 1, participants were required to perform five separate extension and reversal aiming movements; one target (1T), two-target one hand extension (2T1H), two-target one hand reversal (2T1Hr), two-target two hand extension (2T2H), and two-target two hand reversal (2T2Hr). In all tasks, participants started the trial by simultaneously depressing the upper right key (i.e., right start key)

[1] All participants with an intellectual disability were deemed to have the sufficient mental capacity to consent themselves.

with their right index finger and the middle left button (i.e., left target 1) with their left index finger (see Figure 1). In the 1T task, participants were required to move their right hand from its start position to Target 1. In the 2T1H task, participants moved their right hand from its start position to Target 1 and then from Target 1 to Target 2. In the 2T1Hr task, participants moved their right hand from its start position to Target 1 and then back from Target 1 to the start position. In all three of these one hand tasks, the left hand remained stationary on its Target 1 start position. In the two-target two hand tasks, participants moved their right hand from its start position to Target 1 and then moved their left hand from its start position in either an extension direction to Target 2 (2T2H) or a reversal direction to the start position on the left hand side of the board (2T2Hr). In these two hand tasks, participants were informed not to start the second movement until the first had been completed, but to make this changeover as quickly as possible.

Procedure

Each participant completed a total of 400 trials over four days. On each day participants performed 100 trials consisting of 20 blocked trials in each of the five aiming tasks. The order of the aiming tasks was counterbalanced both between each day and between each participant. At the start of every 20 trial block, participants were given verbal instructions about the task and the movement sequence was visually demonstrated three times. Each participant was then given five practice trials at that movement sequence. At the beginning of each trial, the computer emitted two audible tones. The first tone was provided as a warning to alert the participant that the trial was about to begin, whilst the second tone acted as the stimulus. The time between the warning and stimulus tones randomly varied from 1500-2500ms so that participants could not anticipate the presentation time of the stimulus tone. Following

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the stimulus, participants were instructed to start the sequence of key presses as quickly as possible.

Insert Figure 1 about here

Statistical Methods

Dependent measures consisted of reaction time (RT), movement time to the first target (MT1), pause time at target 1 (PT), and movement time from the first target to the second target (MT2). RT was the interval from the presentation of the stimulus to the release of the key at the starting position. MT1 was measured from the release of the key at the starting position to the pressing of the key at target 1. PT was the time interval between the key press at target 1 and the release of this key in order to perform the second movement. Finally, MT2 was the time from the release of the key press at target 1 to the pressing of the key at target 2.

RT and MT1 were submitted to separate mixed model 3 Group (DS, UID, TD) x 5 task (1T, 2T1H, 2T2H, 2T1Hr, 2T2Hr) x 4 block (trials 1-100; 101- 200; 201-300; 301-400) ANOVAs with repeated measures on the last two factors. PT and MT2 were submitted to separate mixed model 3 Group (DS, UID, TD) x 4 task (2T1H, 2T2H, 2T1HR, 2T2Hr) x 4 block (trials, 1-100; 101- 200; 201-300; 301-400) ANOVAs with repeated measures on the last two factors. Any violation of sphericity was corrected using Greenhouse-Geisser adjustments and all significant main effects and interactions were further investigated using Tukeys (HSD) procedures ($p < .05$).

Results

The means and *SD*s for all variables are reported in Table 1. Trials in which RT was less than 100ms or greater than 800ms, the targets were missed, or the second

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response element was initiated prior to the completion the first, were omitted from the analysis. The mean number of trials omitted from the data for the TD, the UID, and the DS group were 6.3 (1.6%), 9.8 (2.5%), and 11.1 (2.8%), respectively (no one individual participant had more than 10 (4%) of their trials omitted).

Reaction Time

As shown in Figure 2, the analysis of RT data revealed only a significant main effect for task ($F_{(2.44,\ 51.20)} = 6.20$, $p < .05$, $\eta^2 = .92$). Post hoc analysis indicated that RTs in the one target task were significantly shorter compared to all the two target tasks.

Insert Figure 2 about here

Movement Time One

Analysis of MT1 revealed significant main effects for group ($F(2, 21) = 8.26$, $p < .05$, $\eta2 = .44$), task ($F(1.82, 38.26) = 8.60$, $p \leq .001$, $\eta2 = .27$), and block ($F(3, 63) = 6.90$, $p < .001$, $\eta2 = .25$). There were also significant group × task ($F(3.64, 38.26) = 3.31$, $p < .05$, $\eta2 = .24$) and group × block ($F(4.60, 48.27) = 4.89$, $p \leq .001$, $\eta2 = .32$) interactions. Specifically, MT1 was significantly shorter in the TD and UID groups compared to the DS group for all blocks of practice while the TD group had significantly shorter movement times than the UID group for the first block of trials. Of more central interest to the current investigation was the group × task interaction. As can be seen in Figure 3, breakdown of the interaction revealed that whilst all groups demonstrated significantly shorter MT1s in the one compared to two target extension tasks, the magnitude of this difference was significantly greater in the DS compared to TD and UID groups. The magnitude of the difference did not vary

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significantly between the TD and UID groups. Furthermore, for the TD and UID groups, MT1 did not differ between the one target and the two target one hand reversal tasks. However, for the DS group, MT1 was significantly longer in the two target one hand reversal task compared to the one target task. For all groups, MT1 was significantly greater in the two target two hand reversal task compared to the one target task. The magnitude of the difference between the two target two hand reversal and the one target movements was greatest in the DS compared to the TD and UID groups while this difference did not vary statistically between the TD and UID groups. Finally, for the DS group, MT1 was significantly faster in the two target two hand reversal task compared to the two target one hand reversal task. No such difference was observed in the TD or UID groups.

Insert Figure 3 about here

Pause Time

As shown in Figure 4, the analysis of PT data revealed significant main effects for group ($F_{(2, 21)} = 5.83$, $p < 0.05$, $\eta^2 = .38$) and task ($F_{(1.68, 35.27)} = 7.42$, $p < 0.05$, $\eta^2 = .89$). Specifically, PTs in both the two target one hand tasks were significantly longer than those of both the two target two hand tasks. Furthermore, PTs of the DS group were significantly greater than those of the TD group. The UID group did not differ significantly to either the TD or DS group.

Insert Figure 4 about here

Movement Time Two

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Similar to the PT data, the analysis of the MT2 revealed significant main effects for group ($F_{(2, 21)} = 14.61$, $p < 0.05$, $\eta^2 = .58$) and task ($F_{(2.15, 45.25)} = 6.36$, $p < 0.05$, $\eta^2 = .23$). Specifically, MTs for the two target one hand extension task were significantly shorter than those of both the two hand tasks. There was no significant difference in MT2 between the two hand extension and two hand reversal tasks or between the one hand extension and one hand reversal tasks (see Figure 5). Furthermore, MT2s of the DS group were significantly longer than those of the TD group. The UID group did not differ significantly to either the TD or DS group.

Discussion

Summary

The purpose of the current study was to investigate how DS specific perceptual-motor impairments at the central (i.e., Frith & Frith, 1974) and peripheral (Henderson et al., 1991; Morris, Vaughan, & Vaccaro, 1982) levels affect movement integration in multiple target and multiple hand sequential aiming tasks. Movement times to the first target are typically longer in two- compared to one-target responses (see Adam et al., 2000) with the rationale proposed for this one target advantage hinging around central control processes. Specifically, the retrieval and implementation of the previously programmed second movement occurs during the execution of the first, leading to associated interference and a reduction in movement time to the first target e.g., the movement integration hypothesis (Adam et al., 2000). An exception to the one target movement time advantage is seen when the second movement is a reversal of the first. Here, movement times to the first target are either similar, or slower, in the one- compared to two-target responses (Khan et al., 2006, 2010). The proposal for the elimination of the one target movement time advantage in

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reversal movements centres on peripheral processes. That is, the antagonist muscle(s) used to decelerate the first movement can also act as the agonist muscle(s) used to propel the second movement towards its target. This bi-phasic muscle pattern means the integration between segments occurs at the peripheral (rather than central) level because the muscular organisation of the limb is being readied for a second movement. Consistent with Lawrence et al. (2013), the current data revealed that the one target advantage occurred in individuals with DS, typically developing (TD) individuals, and individuals with an unidentified intellectual disability (UID) during both single and dual hand multiple segment extension movements. However, during single hand multiple segment reversal movements the one target advantage was eliminated in TD individuals and individuals with an UID, but not in individuals with DS. These behavioural measure findings demonstrate that peripheral deficits rather than central deficits are the cause of reduced movement integration effects in individuals with DS.

Movement programming

For all populations, RTs were faster in the single compared to the two target conditions. This finding indicates that similar to their TD and UID counterparts, individuals with DS were adopting a strategy of centrally programming both response movements prior to movement initiation and that this strategy was not limited to responses within a limb (see also Khan et al., 2006, 2010; Khan, Mourton, Buckloz, & Franks, 2007; Klapp, 1995, 2003). Interestingly, previous DS research (Anson and Mawston, 2000; Davis et al., 1991; Henderson et al., 1991; Lawrence et al., 2013) has revealed that individuals with DS are significantly slower in initiating target directed movements compared to their TD counterparts. However, whilst the results of the current experiment indicated that individuals with DS produced slower RTs compared to TD individuals and individuals with an UID, this difference was not statistically significant. It is possible that these unexpected findings are a result of the relatively large variability within the DS data or because of the high functioning nature of the individuals with DS within this study's cohort. It is beyond the scope of this study to answer that with certainty.

Movement integration

Central strategies. Similar to the results of Lawrence et al., (2013), movement time to the first target was shorter when a single target response was required compared to when the first movement was followed by a second movement in the same direction. This one target movement time advantage was revealed within all groups for the single hand extension movements and, in line with our hypothesis, indicates that similar movement control strategies were utilised between the TD, UID and DS populations. Furthermore, MTs to the first target were longer in two target extension conditions regardless of whether a two target single hand or two target two hand response was required. Additionally, the magnitude of the one target movement time advantage was similar for both the single arm and two arm conditions. The combination of these findings suggest that the one target movement time advantage occurs as a result of the movement integration hypothesis (Adam et al., 2000) and that the locus of interference responsible for the phenomenon resides at the central level.

Peripheral strategies. While the one-target advantage has been shown to be robust for movements involving an extension in direction, it typically does not emerge when the second segment involves a reversal in direction. Interestingly, the present study revealed that when the second movement was performed with the same hand and was a reversal of the first (i.e., the 2T1Hr), the one target advantage was eliminated in both the TD and UID individuals but not in individuals with DS. This

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finding supports our peripheral deficit hypothesis because it indicates that movement integration strategies were not the same for the DS and the UID and TD populations when peripheral control processes are involved in movement integration. The elimination of the one target advantage observed in the TD individuals and the individuals with an UID is consistent with previous findings (e.g., Adam et al., 2001; Khan et al., 2006, 2010) and has been explained by the different underlying muscle activation patterns of the single movement and the two movement reversal actions. In a single target movement, the muscle activation follows a tri-phasic pattern. Specifically, the agonist muscle group accelerates the limb towards the target, an antagonist muscle burst decelerates the limb upon nearing the target, and a final second firing of the agonist muscle is used to dampen the mechanical fluctuations at the end of the first movement (Adam et al., 2000; Adam, Savelberg, & Bakker, 2005; Almeida, Freitas, & Marconi, 2006; Britton, Thompson, Day, Rothwell, Findley, & Marsden, 1994; Enoka, 1988; Gottlieb, 1998; Hallett, Shahani, & Young, 1975; Khan et al, 2006; Savelberg, Adam, Verhaegh, & Helsen, 2002; Wierzbicka, Wieger & Shahani, 1986). However, in a two-target reversal movement the elastic properties of the antagonist muscle group used to decelerate the first movement are also utilised to accelerate the limb in the second reversal movement and therefore there is no need to dampen the mechanical fluctuations at the end of the first movement (Adam, Savelberg, & Bakker, 2005). This bi-phasic pattern of muscle activation allows for optimal integration between movements by reducing the muscle activation processes involved, in comparison to single target movements, and results in the elimination of the one target movement time advantage (Adam et al., 2000; Khan et al., 2006; 2010). Because the one target movement time advantage was eliminated in the TD and UID, but not the DS population, in the single hand reversal task, the current data indicate

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that the DS specific deficits proposed to be associated with the mechanics of limb inertia and peripheral muscular organisation (Anson & Mawston, 2000; Anwar & Hermelin, 1979; Henderson et al., 1981, 1991) may have prevented integration at the peripheral level.

These data are consistent with our hypothesis that individuals with DS possess a peripheral integration deficit because the DS group were unable to utilise the peripheral properties of the agonist and antagonist muscles within a limb in order to produce an efficient synergetic coupling between the two movement elements in the same way as the TD and UID participants. This is likely due to hypotonia and the motor systems subsequent adaptation, via activating and co-contracting muscle groups, to stabilise non-functional movement variability (see Latash & Anson, 2006). This functional adaptation would result in the observed differences in the muscle activation patterns between individuals with DS and TD individuals. Indeed, Anson and colleagues (Anson & Davis, 1998; Anson & O'Conor, 1989; Mawston & Anson, 1994) have revealed that individuals with DS initiate actions with a proximal to distal muscle pattern that is directly opposite to their TD counterparts. Whilst Aruin and colleagues (Aruin & Almedia, 1996; Aruin et al., 1996) demonstrated that there is co-activation of agonist and antagonist muscle pairs during the actions of individuals with DS. Both of these observed muscle activation patterns would result in a removal of the bi-phasic synergic activation proposed to be responsible for the removal of the one-target advantage in single limb reversal sequential aiming tasks (Adam et al., 2000; Khan et al., 2006; 2010). That is, individuals with DS would be unable to couple the activation of the muscle pairs such that the antagonist muscle groups that are used to decelerate the first segment of the movement were activated at the appropriate time to be used as the agonistic muscle groups to accelerate the second segment because they are adopting muscle contraction strategies to help achieve tasks under conditions of hypotonia.

Peripheral deficit or inefficient peripheral strategy? In contrast to the one hand reversal condition, when the task removed the possibility of integration at the peripheral level and required only central level integration (i.e., when the task required both a reversal *and* a switch between hands at the first target) the one target advantage emerged in all groups. The combination of the one- and two hand reversal movement data indicate that whilst the DS group were able to adopt and utilise the movement integration strategies that reside at the central level in a similar way to their TD and UID counterparts, they did not exploit the movement integration strategies that reside at the peripheral neuromuscular level proposed to be responsible for reducing or eliminating the one target advantage in multiple segment reversal movements. Thus, the data indicate a DS specific deficit in the exploitation of peripheral muscle characteristics (i.e., exploiting a synergetic coupling between muscles whereby the antagonist activity of the first movement is utilised in order to provide the agonist propulsion force of the second movement) when integrating single hand two element reversal movements.

Results also revealed a significantly longer movement time to the first target in the two target one hand reversal task compared to the two target two hand reversal task in the individuals with DS, but not the TD or UID individuals. This could indicate that the previously suggested peripheral deficits may not be due to an inability of the system to *generate and use* peripheral processes, but rather the use of an inefficient peripheral integration strategy. That is, in the two target one hand reversal task, DS participants were attempting to utilise both central and peripheral integration strategies but central processes dominated because the peripheral neuromuscular organisation was inefficient at producing an intimate and synergetic coupling between the two movements in the same way as the peripheral processes of the TD and UID participants. This dual attempt to use central and inefficient peripheral integration strategies would have increased the processing demands and movement times to the first target in comparison to the two target two hand reversal tasks where peripheral factors are removed.

Practice effects

The movement integration strategies adopted by individuals within each group did not change as a function of day (practice). However, the effect of practice on the movement times to the first target revealed that participants with DS did not show an incremental improvement in performance. This was also the case for both the UID and TD groups. However, it should be noted that MTs of the UID population were comparable to those in the TD population by the end of practice. Following a 4 day practice schedule that included 1,100 trials, Almeida et al (1994) reported dramatic improvements in the kinematics of a simple target aiming movement performed by persons with DS to the extent that performance was comparable to that of TD participants. Although the current experimental design utilised a 4 day practice schedule, the number of trials within this schedule was significantly less than that employed by Almedia and colleagues. Thus, it appears that this was not a sufficient amount of practice to allow performance of the DS population reach a comparable level to that of the TD population. We recommend that future research adopt longer and more extensive practice schedules in order to fully explore this possibility.

Control after integration

For all groups, movement times to the second target were faster in the one hand two target tasks compared to the two hand two target tasks. This may be

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accounted for via an activation and momentum viewpoint; whereby the limb was already active prior to the start of the second movement in the one hand tasks, but was initiated from a static position in the two hand tasks. In addition, performing the second movement with the non-dominant hand (i.e., left hand) in the two target two hand task could produce slower movement times; right hand advantage is well documented in manual aiming studies (Elliott & Chua, 1996).

Conclusion. The current findings revealed that the central strategies proposed to be responsible for the one target advantage emerged in the DS population during multiple segment extension movements. However, the same individuals did not exploit the movement integration strategies that reside at the peripheral neuromuscular level proposed to be responsible for reducing or eliminating the one target advantage in multiple segment reversal movements. Thus, the research proposes that the separate central (Frith & Frith, 1974) and peripheral anatomical characteristics (Henderson et al., 1991; Morris, Vaughan, & Vaccaro, 1982) associated with DS, effect movement integration and associated anticipatory behaviour in contrasting ways. Specially, any central deficits do not prevent the preplanning and online implementation processes proposed within the movement integration hypothesis (Adam et al., 2000). Whereas, peripheral deficits appear to disrupt the exploitation of the elastic muscle properties (e.g., the antagonist muscles being used as the agonist muscles in a single hand reversal movements) typically adopted by individuals without DS when integrating movements within a one hand reversal task. It is proposed that the peripheral integration deficits observed in the current investigation may be as a result of the systems adaptation to the condition of hypotonia i.e., individuals with DS utilise muscle activation patterns designed to stabilise non-functional movement variability associated with hypotonia which reduce

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the integration strategies that result from bi-phasic synergistic muscle activation patterns. We conclude that individuals with DS apply similar movement planning and control strategies as the TD population when controlling actions requiring multiple hand, multiple movement and multiple direction tasks (e.g., computer typing and use, food preparation), but not when tasks involve one hand *and* a reversal in direction between the first and second movement (e.g., reaching toward and grasping an object with the goal of moving it closer to one's body). The differing movement integration strategies between these types of tasks should be considered when designing practice and training interventions for individuals with DS. Specifically, results suggest that for tasks involving two hands and multiple directions, interventions could be similar to those adopted when teaching TD individuals. However, interventions for one hand reversal tasks, such as reaching toward and grasping an object with the goal of moving it closer to one's body, do need to ensure the peripheral deficits associated with DS are considered. This is because the movement integration strategies of individuals with DS are significantly different to the TD population when performing these one hand reversal tasks.

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Table 1. Means and *SDs* for all dependent variables and all groups (DS = Down syndrome; UID = unidentified intellectual disability; TD = typically developing) as a function of practice (block = 1 trials 1-100; block 2 = trials 101-200; block 3 = trials 201-300; block 4 = trials 301-400) and task (1T = one target; 2T1H = two-target single hand; 2T2H = two-target two hand; 2T1Hr = two-target single hand with a reversal; 2T2Hr = two-target two-hand with a reversal).

		Block 1					Block 2					Block 3					Block 4				
		1T	**2T1H**	**2T1Hr**	**2T2H**	**2T2Hr**	**1T**	**2T1H**	**2T1Hr**	**2T2H**	**2T2Hr**	**1T**	**2T1H**	**2T1Hr**	**2T2H**	**2T2Hr**	**1T**	**2T1H**	**2T1Hr**	**2T2H**	**2T2Hr**
DS	**RT**	338.82	367.22	337.10	409.49	399.82	347.87	386.33	354.23	387.71	420.85	361.43	371.09	359.07	393.86	381.91	325.11	367.06	364.95	347.60	353.46
		110.36	*115.77*	*76.73*	*166.66*	*183.20*	*148.10*	*145.34*	*130.45*	*122.99*	*179.94*	*107.59*	*108.95*	*113.07*	*118.57*	*100.09*	*95.93*	*106.68*	*97.07*	*107.94*	*100.20*
	MT1	448.38	497.05	498.76	538.25	519.41	508.23	557.02	559.49	596.01	537.22	479.70	555.55	547.39	591.11	500.97	490.80	549.67	558.18	556.83	522.83
		152.51	*176.20*	*158.87*	*194.72*	*219.83*	*197.53*	*213.58*	*199.60*	*230.72*	*211.85*	*196.08*	*216.57*	*213.10*	*218.11*	*175.50*	*229.63*	*256.93*	*221.82*	*215.73*	*220.59*
	PT	-----	358.48	277.79	190.45	197.30	-----	219.22	275.42	201.31	160.32	-----	183.47	261.47	202.37	120.57	-----	187.15	281.20	161.32	135.41
		-----	*299.91*	*281.44*	*59.36*	*160.43*	-----	*133.12*	*244.73*	*117.10*	*109.10*	-----	*80.53*	*203.00*	*120.68*	*33.33*	-----	*86.06*	*317.50*	*78.87*	*104.18*
	MT2	-----	403.57	436.14	458.85	475.75	-----	454.58	458.25	599.88	551.28	-----	416.26	449.56	530.14	493.48	-----	421.06	435.56	536.86	559.59
		-----	*135.99*	*164.63*	*132.10*	*108.47*	-----	*177.81*	*156.40*	*284.37*	*172.70*	-----	*187.37*	*185.49*	*223.18*	*169.28*	-----	*195.66*	*154.32*	*221.73*	*191.57*
UID	**RT**	280.59	354.37	346.97	355.15	331.23	291.30	346.47	323.57	335.40	326.95	294.28	330.86	314.41	339.67	300.63	288.39	330.25	333.95	330.38	353.66
		49.58	*125.45*	*63.24*	*101.66*	*80.36*	*57.93*	*66.63*	*58.88*	*85.72*	*90.63*	*65.33*	*85.46*	*81.67*	*88.85*	*37.81*	*60.51*	*82.25*	*86.50*	*112.41*	*140.01*
	MT1	276.14	308.27	283.23	335.89	321.91	301.75	328.60	299.92	309.69	292.40	252.97	271.47	253.58	298.24	297.33	255.77	270.67	286.77	304.82	263.22
		123.62	*151.08*	*123.85*	*149.42*	*128.83*	*165.72*	*176.88*	*177.67*	*161.80*	*178.73*	*104.70*	*118.01*	*108.62*	*163.45*	*143.47*	*127.90*	*117.56*	*171.31*	*191.83*	*136.43*
	PT	-----	146.31	133.91	111.16	86.74	-----	135.48	150.36	79.94	97.54	-----	154.41	142.22	84.42	93.94	-----	132.65	140.64	73.39	75.28
		-----	*64.53*	*43.27*	*99.22*	*50.28*	-----	*58.25*	*58.58*	*55.09*	*51.44*	-----	*67.66*	*36.37*	*38.58*	*23.08*	-----	*44.06*	*37.85*	*39.20*	*21.11*
	MT2	-----	246.75	278.72	314.61	306.37	-----	279.60	267.02	297.02	305.52	-----	208.72	248.78	310.63	313.26	-----	216.27	241.72	327.28	322.25
		-----	*126.53*	*139.27*	*147.10*	*136.97*	-----	*187.74*	*141.14*	*158.36*	*210.31*	-----	*79.72*	*118.12*	*177.70*	*161.91*	-----	*61.07*	*84.95*	*213.26*	*165.49*
TD	**RT**	255.92	288.39	276.39	282.62	283.57	296.88	321.85	311.58	292.42	316.07	307.92	306.61	321.45	295.09	311.58	291.91	322.28	322.57	296.96	312.07
		25.16	*34.10*	*53.95*	*57.59*	*35.23*	*50.76*	*67.77*	*77.89*	*65.48*	*63.41*	*61.00*	*65.86*	*60.51*	*64.04*	*57.22*	*48.65*	*65.46*	*56.60*	*53.93*	*75.38*
	MT1	169.32	185.79	175.30	186.55	182.73	296.88	321.85	311.58	292.42	316.07	307.92	306.61	321.45	295.09	311.58	291.91	322.28	322.57	296.96	312.07
		70.22	*71.73*	*68.71*	*67.48*	*82.39*	*50.76*	*67.77*	*77.89*	*65.48*	*63.41*	*61.00*	*65.86*	*60.51*	*64.04*	*57.22*	*48.65*	*65.46*	*56.60*	*53.93*	*75.38*
	PT	-----	103.23	97.08	77.37	66.42	-----	106.40	112.89	68.94	68.70	-----	101.50	106.72	67.93	70.56	-----	102.99	109.10	67.30	59.91
		-----	*30.60*	*34.29*	*29.53*	*32.87*	-----	*45.22*	*44.26*	*29.09*	*23.43*	-----	*26.46*	*34.52*	*22.32*	*36.70*	-----	*31.42*	*38.77*	*21.85*	*28.54*
	MT2	-----	163.46	161.07	173.61	169.67	-----	170.00	169.92	169.82	189.47	-----	169.47	173.99	170.91	169.86	-----	163.43	170.18	176.68	173.94
		-----	*49.49*	*35.53*	*54.69*	*52.48*	-----	*51.78*	*36.84*	*62.99*	*35.22*	-----	*43.14*	*34.46*	*54.43*	*56.56*	-----	*46.76*	*27.59*	*58.22*	*47.71*

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Figure Captions

Figure 1. A) Target locations and size. 1T = one target; 2T1H = two-target single hand; 2T2H = two-target two hand; 2T1Hr = two-target single hand with a reversal; 2T2Hr = two-target two-hand with a reversal.

Figure 2: Reaction time as a function of task (1T = one-target extension; 2T1H = two-target one hand extension; 2T1Hr = two-target one hand reversal; 2T2H = two-target two hand extension; 2T2Hr = two-target two hand reversal). Error bars represent *SEm.* * indicates a statistically significant difference ($p < .05$) from the 1T task.

Figure 3. Movement time 1 as a function of group (DS = Down syndrome; UID = higher functioning undifferentiated intellectual disability; TD = typically developing) and task (1T = one-target extension; 2T1H = two-target one hand extension; 2T1Hr = two-target one hand reversal; 2T2H = two-target two hand extension; 2T2Hr = two-target two hand reversal). Error bars represent *SEm*. * indicates a statistically significant within group difference ($p < .05$) from the 1T task. ** indicates a statistically significant within group difference ($p < .05$) from the 2T2H task.

Figure 4. Pause time as a function of group (DS = Down syndrome; UID = higher functioning undifferentiated intellectual disability; TD = typically developing) and task (1T = one-target extension; 2T1H = two-target one hand extension; 2T1Hr = two-target one hand reversal; 2T2H = two-target two hand extension; 2T2Hr = two-target two hand reversal). Error bars represent *SEm.* Dashed box indicates a statistically significant within group difference ($p < .05$) from the 2T1H and 2T1Hr task. * indicates a significant difference ($p < .05$) to the TD group within that task.

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Figure 5. Movement time 2 as a function of group (DS = Down syndrome; UID = higher functioning undifferentiated intellectual disability; TD = typically developing) and task (1T = one-target extension; 2T1H = two-target one hand extension; 2T1Hr = two-target one hand reversal; 2T2H = two-target two hand extension; 2T2Hr = two-target two hand reversal). Error bars represent *SEm.* Dashed box indicates a statistically significant within group difference ($p < .05$) from the 2T1H task. * indicates a significant difference ($p < .05$) to the TD group within that task.

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Figure 1.

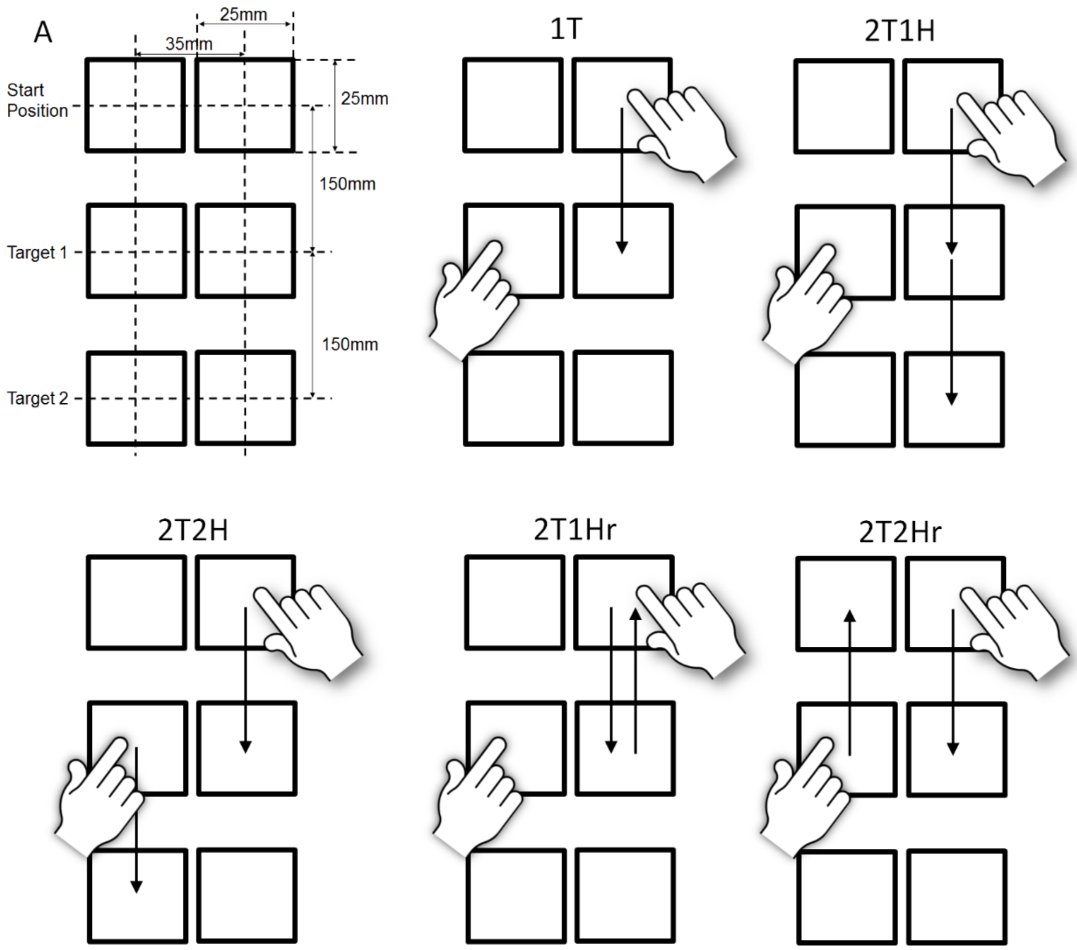

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Figure 2

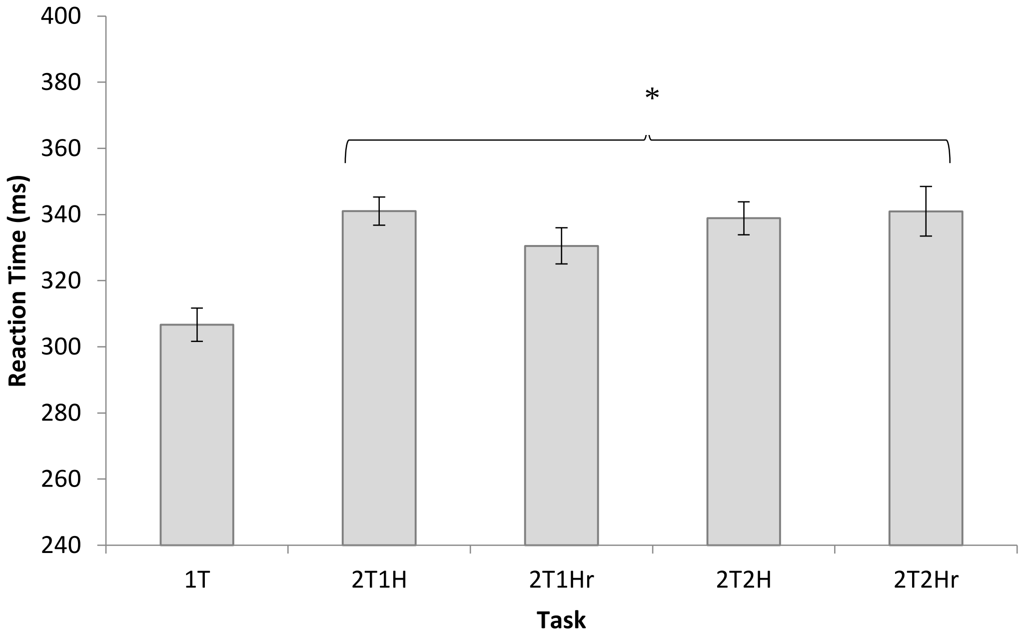

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Figure 3.

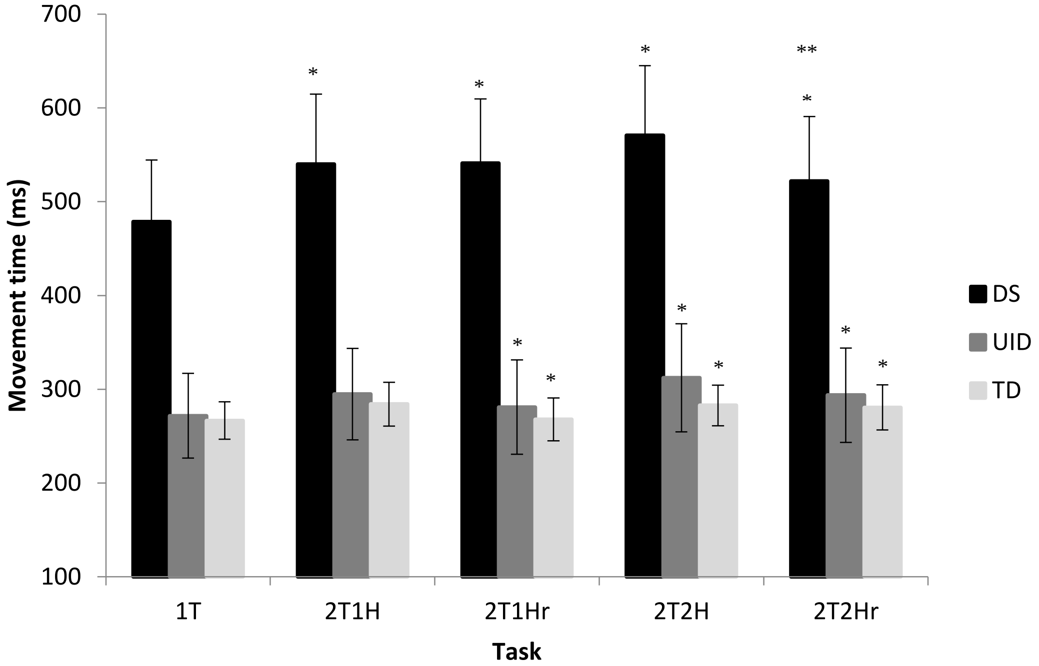

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Figure 4.

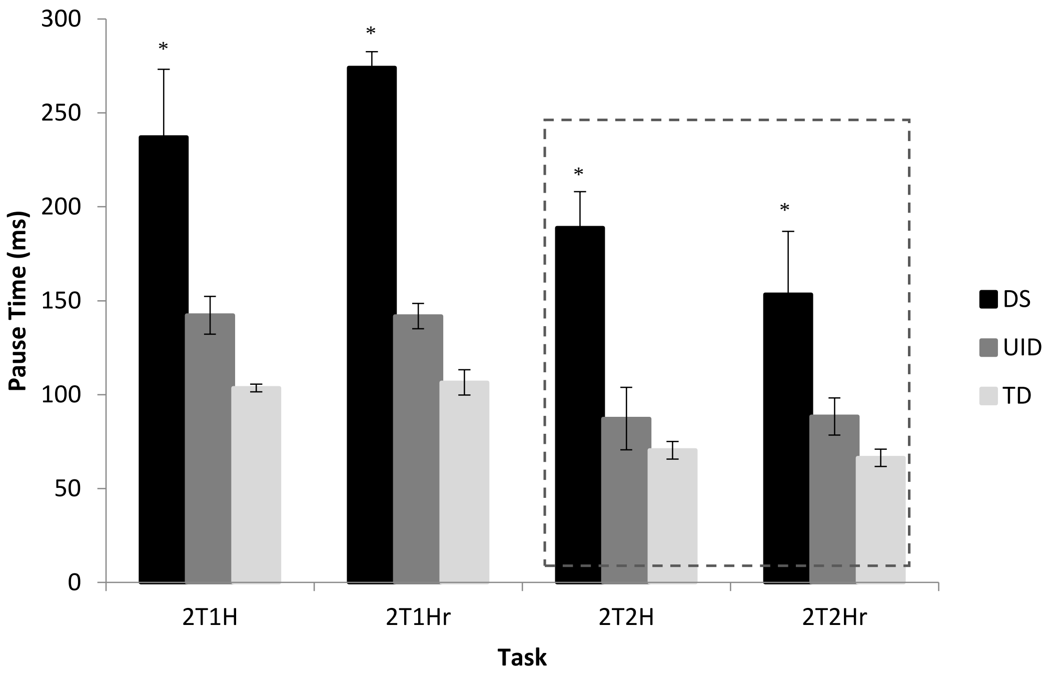

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Figure 5.