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Sequential aiming movements and the one-target advantage in individuals with Down syndrome

Gavin P. Lawrence [a,*], Niamh E. Reilly [a], Thomas M. Mottram [a], Michael A. Khan [b], Digby Elliott [c]

[a] School of Sport, Health, and Exercise Sciences, Perceptual Motor Group, Bangor University, LL572PX, United Kingdom
[b] Department of Kinesiology, Faculty of Human Kinetics, University of Windsor, ON N9B 3P4, Canada
[c] School of Sport and Exercise Sciences, Liverpool John Moores University, L3 3AF, United Kingdom

A R T I C L E I N F O

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A B S T R A C T

Research has revealed that individuals with Down syndrome (DS) have elevated reaction times, longer movement times, and greater movement errors during single-target single-limb actions compared to their typically developing (TD) peers. These perceptual-motor impairments have been attributed to both central processes and the physical phenotype associated with DS. The purpose of the present study was to directly investigate these possible central and peripheral deficits by examining how individuals with DS plan and execute more complex movements.

Three groups (DS, TD, and individuals with an undifferentiated intellectual disability; UID) of 8 participants completed a single target movement, a two-target movement performed by a single arm, and a two-target movement where the first movement was performed with one arm and the second movement performed with the other arm. For all groups and all conditions, movement times revealed a one-target advantage (OTA). Specifically, times to the first target were longer in the two-target responses compared to the single-target response. In general, the OTA finding reveals that persons with DS utilise planning strategies similar to their TD peers when performing sequential actions involving two targets and two arms. Furthermore, because the OTA was observed in both the single- and two-arm two-target responses the interference in movement one associated with having to make a subsequent movement is not due to peripheral processes associated with single limb constraints. Rather, individuals with DS treat movements within a sequence as functionally dependent. Thus, the central processes associated with timing the implementation of the second element of the movement appear to be responsible for the interference that leads to the OTA.

1. Introduction

Down syndrome (DS) is a genetic condition involving chromosomal abnormality; specifically an additional 21st chromosome (full or partial) occurs in every cell of the body. This genotype results in individuals with DS demonstrating different physiological, anatomical, and neurological features to those of the typically developing (TD) population. Researchers have highlighted differences between the DS and TD populations in the form of longer movement onset and

* Corresponding author at: School of Sport, Health, and Exercise Sciences, Institute for the Psychology of Elite Performance, Bangor University, George Building, Holyhead Road, Bangor, Gwynedd LL57 2PX, United Kingdom. Tel.: +44 01248 388283; fax: +44 01248 371053.
E-mail address: g.p.lawrence@bangor.ac.uk (G.P. Lawrence).

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reaction times (Arisi et al., 2012; Davis, Sparrow, & Ward, 1991; Henderson, Illingworth, & Allen, 1991; Masumoto, Abe, & Inui, 2012), longer movement times, and greater movement errors for DS compared to TD (Elliott, Welsh, Lyons, Hansen, & Wu, 2006; Hodges, Cunningham, Lyons, Kerr, & Elliott, 1995). These perceptual-motor impairments have been attributed to both central processes (i.e., Frith & Frith, 1974) and peripheral anatomical characteristics (Henderson et al., 1991; Morris, Vaughan, & Vaccaro, 1982).

In simple goal-directed movement, the perceived slowness of individuals with DS when performing simple aiming or tapping tasks has been attributed to an inability to develop central control of upper limb movements (Frith & Frith, 1974). This issue with motor programming is thought to cause over dependence on response-produced visual and kinesthetic feedback for the online regulation of movement (Simon, Elliott, & Anson, 2003). Anson (1992) suggested that the slower reaction and movement times observed in individuals with DS indicate the involvement of deficits in both peripheral and central mechanisms. Central processing deficits in DS relate to complications that occur in the time before the required stimulus of the movement. These central processing issues occur when the participant initiates the cognitive process of movement preparation. Whereas, peripheral processing deficits in DS are said to occur during the events of muscle activation up until the time at which onset of movement occurs (Simon et al., 2003). It has been proposed that central deficits in the motor control of individuals with DS occur due to neurophysiology deficits that affect the retrieval or initiation of motor programmes and lengthen both reaction time and movement time (Carvalho & Vasconcelos, 2011; Kerr & Blais, 1987). On the other hand, peripheral anatomical deficits relate to issues with inertia of limb mechanics and muscle organisation. These limb inertia and muscle organisation issues may be due to the prevalence of hypotonia in individuals with DS (Anson, 1989; Anwar & Hermelin, 1979; Henderson, Morris, & Frith, 1981) and/or atypical patterns of muscle activation (Anson & Mawston, 2000).

In target directed aiming, Hodges et al. (1995) reported that movement times were approximately twice as long for participants with DS compared to the TD population. Furthermore, the acceleration profiles of the DS participants contained significantly more discontinuities (indicative of online movement adjustment) than those of TD participants. Similarly, Almedia, Corcos, & Hasan (2000) have reported that individuals with DS spend proportionally more time in target regions compared to TD individuals. In both Hodges et al. (1995) and Almedia et al. (2000) movement time differences between DS and TD were attributed to participants with DS making greater use of feedback-based corrections during movement execution. This strategy was reportedly adopted in order to reduce discrepancies between the position of the limb and target that emerged due to central deficiencies in movement planning and feed-forward processes.

The majority of past research on motor performance in children and adults with DS has been conducted using single target-directed movements. The purpose of the present study was to investigate how individuals with DS plan and execute the more complex responses involved in multiple target movements. Researchers have adopted numerous approaches to understanding how multiple segment movements are prepared and executed. Following from an extensive body of research that has investigated the relation between reaction time (RT) and the number of response segments/elements (e.g., Henry & Rogers, 1960; Klapp, Wyatt, & Lingo, 1974; Sternberg, Monsell, Knoll, & Wright, 1978; Vidal, Bonnet, & Macar, 1991), researchers have recently directed their efforts towards examining the time it takes to execute movements (e.g., Adam et al., 2000; Helsen, Adam, Elliott, & Buekers, 2001; Khan, Lawrence, Buckolz, & Franks, 2006). The typical finding has been that movement time to an initial target is slowed when subjects are required to make a subsequent movement (Adam et al., 2000; Chamberlin & Magill, 1989; Helsen et al., 2001; Khan, Mottram, Adam, & Buckolz, 2010; Khan, Sarteep, Mottram, Lawrence, & Adam, 2011). This one-target advantage (OTA) suggests that individual elements in a response are not programmed or executed independently. Furthermore, research has shown the OTA to be a robust phenomenon since it occurs under both left and right hand responses (Helsen et al., 2001; Lavrysen et al., 2003), with and without vision (Lavrysen, Helsen, Elliott, & Adam, 2002), and is resistant to practice (Lavrysen et al., 2003).

Several hypotheses have been proposed to explain the OTA. The movement integration hypothesis (MIH) (Adam et al., 2000) explains the OTA by combining the notion of advance planning and on-line control processes. Specifically, the hypothesis poses that all movement programming is completed before movement initiation and, in order to facilitate a smooth and efficient transition between segments, the implementation of the second segment is performed online, concurrent with the execution of the first movement. The increased cognitive control associated with the implementation of the second segment during the production of the first segment in two target responses leads to interference. This interference results in a lengthening of MT to the first target.

Other researchers have proposed movement constraint based explanations for the OTA (Sidaway, Sekiya, & Fairweather, 1995). Because spatial variability increases as movement progresses (Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979; see Khan et al., 2006a, for a review), the movement constraint hypothesis (MCH) proposes that movements to the first target in two element responses must be performed in a more constrained manner in order to ensure the accuracy requirements of the subsequent movement are met. That is, constraining the accuracy of the first movement has the subsequent effect of providing a less variable starting position for the second movement. This strategy results in a reduced need to adjust the movement parameters of the second element leading to a more integrated and efficient overall response programme.

Although the OTA had been extensively studied for aiming tasks in which movements were performed with a single arm, Khan et al. (2010) recently investigated whether the OTA would emerge when there was a transfer between arms in sequential aiming movements. They compared three movement conditions; a single target movement, a two-target movement performed by a single arm, and a two-target movement where the first movement was performed with one arm and the second movement performed with the other arm. The results of this study revealed the OTA in both the single and