The integration of sequential aiming movements: Switching hand and direction at the first target

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ARTICLE INFO

ABSTRACT

Movement times to a single target are typically shorter compared to when movement to a second target is required. This one target movement time advantage has been shown to emerge when participants use a single hand throughout the target sequence and when there is a switch between hands at the first target. Our goal was to investigate the lacuna in the movement integration literature surrounding the interactive effects between switching hands and changing movement direction at the first target. Participants performed rapid hand movements in five conditions; movements to a single target; two target movements with a single hand in which the second target required an extension or reversal in direction; and movements to two targets where the hands were switched at the first target and the second target required an extension or reversal in direction. The significance of including these latter two (multiple hand-multiple direction) movements meant that for the first time research could differentiate between peripheral and central processes within movement integration strategies. Reaction times were significantly shorter in the single task compared to the two target tasks. More importantly, movement times to the first target were significantly shorter in the single target task compared to all two target tasks (reflecting the so-called one target advantage), except when the second movement was a reversal movement with the same hand. These findings demonstrate for the first time the contrasting effects of movement integration at central and peripheral levels.

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In two target aiming sequences, researchers have revealed that reaction times and movement times to the first target are typically longer compared to single target responses (Adam et al., 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). Understanding the factors that influence the nature of the interdependency between segments has been of considerable interest to researchers (Adam et al., 2000; Cullen et al., 2001; Helsen, Adam, Elliott, & Buekers, 2001; Khan, Mottram, Adam, & Buckolz, 2010; Khan, Sarteep, Mottram, Lawrence, & Adam, 2011; Lavrysen, Helsen, Elliott, & Adam, 2002; Lavrysen et al., 2003; Lawrence, Reilly, Mottram, Khan, & Elliott, 2013; Mottram, Khan, Lawrence, Adam, & Buckolz, 2014). The aim of the present study was to differentiate between the processes underlying the integration

between movement segments at central cognitive and peripheral neuromuscular levels by examining the interactive effects of switching hands and movement direction at the first target.

The interdependency between movement segments in a two target aiming sequence has generally been explained via two central or cognitively based hypotheses. The movement constraint hypothesis is based on the assumption that the variability of movement endpoints accumulates from one target to the next. Hence, in order to be accurate at a second target, movement to the first target must be constrained so that the accuracy demands at the second target are met (Sidaway, Sekiya, & Fairweather, 1995). The constraining of movement endpoints at the first target is achieved through more precise movement planning and/ or feedback processing during movement execution (Khan et al., 2010).

The movement integration hypothesis (Adam et al., 2000) poses that response segments are programmed and stored in a buffer prior to movement initiation. In order to facilitate a smooth and efficient transition between segments, the implementation of the second segment is performed concurrently with the execution of the first. 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.

The one target movement time advantage has typically been investigated using single limb movements (Adam, Helsen, Elliott, & Buekers, 2001; Lavrysen et al., 2002). More recently, the robustness of the one target movement time advantage was extended to include movements involving two limbs. In a study by Khan et al. (2010), participants performed single target movements, two target extension movements with one hand, and two target extension movements in which hands were switched at the first target (i.e., one hand was used to perform the first segment and the other hand for the second segment). The results revealed a robust and similar one-target movement time advantage for the single and two hand conditions. This finding had two important theoretical implications. Firstly, the presence of the one target movement time advantage for two hand movements would seem to be inconsistent with the central processes proposed within movement constraint hypothesis. This is because the start position of the hand responsible for the second movement was fixed and hence did not depend on the variability of endpoints of the first movement. Hence, accuracy of the second segment should not have depended on the accuracy of the first segment. Secondly, the finding that the magnitude of the one target movement time advantage was similar for both the single and two hand conditions implied a central locus of interference as the underlying cause of the one target movement time advantage (i.e., the online retrieval and implementation of a motor program from a motor buffer). If the one target movement time advantage was due to peripheral factors (i.e., muscular organisation of the limb being adjusted and readied for a second movement), one would not expect the effect to emerge in the two hand condition because the first and second movement segments were performed by separate effector systems.

The one notable exception to the one target movement time advantage is when the second movement segment involves a reversal in direction. For reversal movements, the one target movement time advantage either does not emerge (e.g., when movements involve tapping target areas) (Adam et al., 2000), or a two-target movement time advantage arises where movement times to the first target are shorter for two compared to single segment responses (e.g., when movements involve sliding in a single dimension between target areas) (Khan, Lawrence, Buckolz, & Franks, 2006; Khan, Mourton, Buckolz, & Franks, 2007). Researchers have accounted for the two-target movement time advantage in terms of peripheral processes (i.e., the patterns of muscle activity) underlying rapid aiming movements. Single target movements are typically characterised by a triphasic, agonist–antagonist-agonist, pattern of muscle activity (Adam, Savelberg, & Bakker, 2005; Britton et al., 1994; Gottlieb, 1998; Hallett, Shahani, & Young, 1975; Savelberg, Adam, Verhaegh, & Helsen, 2002). The initial agonist activity accelerates the limb towards the target while the burst of antagonist activity serves to decelerate the limb upon nearing the target. The final burst of agonist activity is responsible for dampening mechanical oscillations at the end of the movement. More specifically, this final agonist muscle activity counteracts any tendency of the limb reversing direction due to the storage of elastic energy from a rapidly lengthening antagonist muscle. In two target reversal movements, there is no need for the second burst of agonist activity since the elastic properties of the muscle can be exploited to save energy in moving the limb in the reverse direction. Moreover, the antagonist muscle forces used to decelerate the first element also act as the agonist for the second component. This dual purpose of antagonist activity allows 'the possibility to establish an intimate, synergetic coupling between the two movement elements' (Adam et al., 2005, pp. 249) leading to optimal integration between elements and the two-target movement time advantage (Adam et al., 2000). Direct support for the contrasting neuromechanical activation patterns proposed between extension and reversal movements has been offered by both Adam et al. (2005) and Savelberg et al. (2002). Specifically, only tri-phasic patterns of muscle activity emerged for

extension movements and comparison of muscle activity levels between the two movement tasks revealed that agonist activity was greater at the end of the first movement in the extension compared to reversal movements, whereas the antagonistic muscle activity was greater in the reversal compared to extension movements.

It is important to distinguish between the mechanisms underlying integration between segments in two target extension and reversal movements (see Khan, Helsen, & Franks, 2010). For both single and two limb extension movements, the Movement Integration Hypothesis accounts for the one target movement time advantage by proposing that executive processes control the implementation of the second segment during execution of the first. This explanation implies that interference arises from cognitive processes operating online, that is, when the pre programmed movement commands of the second segment are retrieved from the central buffer and implemented during the execution of the first movement. While the one target movement time advantage is due to interference at a cognitive level, the two target advantage in reversal movements emerges from the integration of muscular forces associated with the mechanical characteristics of changing direction. Hence, while the integration between segments in two target extension movements is at the cognitive level, segments involving a reversal in direction are integrated at a more peripheral neuromuscular level as a single unit of action (Khan, Tremblay, Cheng, Luis, & Mourton, 2008).

The aim of the present experiment was to examine single and two hand extension and reversal movements in order to directly investigate the contributions of the central processes (proposed within the movement integration hypothesis) and the peripheral neuromechanical processes (proposed to account for the two target advantage) when integrating two target movements. To achieve this, we extended the two hand sequential aiming paradigm employed by Khan et al. (2010) to include movements with a reversal in direction. Hence, participants performed movements to a single target, two target movements with a single hand in which the second segment was either in the same or opposite direction to the first segment, and two target movements in which the hand was switched at the first target with the direction of the second segment either in the same or opposite direction to that of the first. Consistent with past research, we expected that the one target movement time advantage would emerge for single hand and two hand movements in which the second segment is in the same direction as the first. This finding would imply a cognitive locus of interference giving rise to the one target advantage. For single hand movements in which the second segment involves a reversal in direction, the one target movement time advantage should not emerge. This is because of the integration of muscular forces between the two segments whereby the antagonist of the first segment also serves as the agonist for the second segment. However, for reversal movements where the second segment is performed with a different hand than that used to move to the first, we expected the one target movement time advantage to be reinstated because of the lack of muscular integration at the peripheral level. That is, because the neuromechanical advantage of the bi-phasic muscle activation pattern is removed within two target two hand reversal movements, it was expected that the integration between the first and second elements would be governed by the processes within the movement integration hypothesis i.e., the implementation of the second segment would be performed concurrently with the execution of the first, resulting in increased cognitive processing load during response execution and a lengthening of movement time to the first target (compared to single target tasks).

1. Method

1.1. Participants

25 participants (14 men & 11 women; age = 22.5 years, SD = 4.1 years, age range = 18–33 years) volunteered to participate. All were