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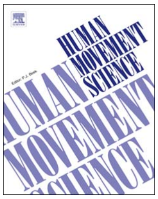

Full Length Article

Better together: Contrasting the hypotheses explaining the one-target advantage[☆]

Stephen R. Bested, John de Grosbois, Luc Tremblay[*]

Perceptual-Motor Behaviour Laboratory, Centre of Motor Control, Faculty of Kinesiology and Physical Education, University of Toronto, Toronto, ON, Canada

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ABSTRACT

Movement times are significantly shorter when moving from a start position to a single target, compared to when one has to continue onto a second target (i.e., the one-target advantage [OTA]). To explain this movement time difference, both the movement integration and the movement constraint hypotheses have been proposed. Although both hypotheses have been found to have explanatory power as to why the OTA exists, the support for each has been somewhat equivocal. The current review evaluated the relative support in the literature for these two hypotheses. Ultimately, preferential support for each theoretical explanation was found to be related to the higher indices of difficulty (IDs: Fitts, 1954) employed. That is, studies that included higher IDs (i.e., 6–8 bits) were more likely to provide more support for the movement constraint hypothesis, whereas studies employing lower IDs (i.e., 1–4 bits) were more likely to provide more support for the movement integration hypothesis. When the IDs employed were relatively intermediate (i.e., 5 bits), both hypotheses were mostly supported. Thus, task difficulty is crucial when determining which hypothesis better explains the planning and control of sequential goal-directed movements. Critically, the OTA most likely always involves integration but may also involve constraining if the accuracy demands are sufficiently high.

1. Introduction

Everyday movements are often composed of multiple segments, ranging from reaching towards an object and picking it up, to catching and throwing a baseball. Critically, there is evidence that multiple-segment movements are completed in a characteristically different manner than single-segment movements. That is, multiple-segment movements have been found to require more complex planning and online control processes relative to single-segment movements (e.g., Adam et al., 2000; Chamberlin & Magill, 1989; Fischman & Reeve, 1992). Planning and control mechanisms are also influenced by the accuracy demands of a target's index of difficulty (Fitts, 1954). According to Fitts' theorem (1954), both the target width and the distance to the target affect how fast one can move accurately to that target. Fitts created a mathematical equation to predict movement times based on target width and the amplitude of the movement (i.e., index of difficulty [ID, in bits]: see Fitts, 1954), where higher IDs (i.e., increase in amplitude and/or decrease in target width) represented more difficult movements. The current review utilized this ID metric to assess the different methodologies employed to investigate and assess the value of the proposed mechanistic explanations for the one-target advantage (i.e., OTA).

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[*] Corresponding author at: University of Toronto, Toronto, ON M5S 2W6, Canada.
E-mail address: luc.tremblay@utoronto.ca (L. Tremblay).

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In multiple-segment movements, both the planning time (i.e., reaction time) and the time taken to complete the first movement segment (i.e., movement time) have been found to increase relative to the associated times attained for a single movement performed in isolation (i.e., the OTA: Adam et al., 2000; Klapp, 1995; Klapp, 2003). Specifically regarding movement times, this OTA has been of interest to several researchers, resulting in different theoretical explanations (Adam et al., 2000; Chamberlin & Magill, 1989; Fischman & Reeve, 1992). In the current review, these main mechanistic explanations for the occurrence of the OTA have been briefly discussed, and their explanatory value as a function of movement ID have been subsequently evaluated.

1.1. Main mechanistic explanations for the OTA

One of the first theoretical explanations for the occurrence of the OTA was proposed by Chamberlin and Magill (1989) through the investigation of reaction times and movement times in multiple-segment movements. Across three experiments, participants completed sequential[1] movements towards one, two, or three targets. The required responses were either known in advance of the go-signal (i.e., simple reaction time condition), or unknown until the go-signal (i.e., choice reaction time condition). In the simple reaction time condition, reaction times increased as the number of targets increased. In contrast, no differences associated with the number of targets were found in the choice reaction time condition (Chamberlin & Magill, 1989; see also Klapp, 1995). Regarding potential movement time differences between these conditions, Chamberlin and Magill (1989) hypothesized that both movement segments could likely be planned in their entirety prior to the onset of the first movement segment. If this hypothesis held true, then the observed movement times would be the same during the first segment when performed in isolation, as compared to when a second movement was performed. Contrary to this prediction, Chamberlin and Magill (1989) found that in the simple reaction time condition, the movement times to the first target also increased as the number of movement segments increased. In contrast, the choice reaction time task did not yield an increase in movement time for the first movement segment, which was consistent with the above reaction time findings. This increase in movement time to the first target led Chamberlin and Magill (1989) to hypothesize that incomplete planning was occurring prior to response initiation. They proposed that the increase in movement time to the first target was the result of the online programming of the second movement occurring during the first (i.e., the online programming hypothesis).

Challenging Chamberlin and Magill's (1989) online programming hypothesis, Fischman and Reeve (1992) proposed that the observed increases in movement time to the first target were the result of constraining the endpoint of the first movement segment (i.e., the movement constraint hypothesis). This constraining would allow one to meet the accuracy demands at the second target through the reduction of their limb position variability at the first target, which required a longer deceleration phase towards the first target (i.e., time taken between peak velocity and contact with the first target). Fischman and Reeve's (1992) alternative explanation relied on the premise that, as a movement progresses, variability increases (i.e., errors will accumulate monotonically with time, if uncorrected: e.g., Sidaway, Sekiya, & Fairweather, 1995). To test this movement constraint hypothesis, two experiments were conducted. The first experiment proposed that, if no contact was required at the second target, participants would completely plan the movement prior to initiation and not need to constrain the first movement segment. Thus, the first experiment involved three conditions: a one-tap (i.e., one target), a two-tap (i.e., two targets), and a tap-and-lift condition (i.e., instead of making contact at the second target location, participants were instructed to hover above the second target). Although movement times to the first target increased between the one- and two-tap conditions, movement time to the first target also increased between the one-tap and the tap-and-lift condition as well. That is, even though the second movement did not always require target impact, the second movement always induced constraining of the first movement segment (i.e., a temporal cost) when compared to the one-tap condition. Thus, the movement time results provided clear evidence for the movement constraint hypothesis. However, the reaction time results of the first experiment did not rule out the online programming hypothesis because reaction times did not significantly vary across the two-tap and tap-and-lift conditions. In their second experiment, Fischman and Reeve (1992) gave participants an unlimited amount of response planning time (i.e., an unconstrained reaction time) to ensure that the entire movement could be programmed in advance. That is, participants were instructed to wait until their entire response was planned before executing their movement as quickly and accurately as possible. While participants took on average 1836 ms to 2032 ms to plan their movements, the movement times for the first segment was still shorter when performed in isolation in contrast to one followed by a second movement segment (i.e., the OTA emerged). It was therefore argued that regardless of the instructions to pre-plan the entire movement, participants constrained their movements to the first target to meet the accuracy demands associated with the second target. Thus, Fischman and Reeve (1992) argued that the movement constraint hypothesis best explained why the OTA emerged. More recently, another hypothesis was developed to help clarify the observed reaction time effects as well.

The most recent explanation of the OTA was developed by Adam et al. (2000) which was called the movement integration hypothesis. Adam et al. (2000) stated that the observed increases in reaction times and movement times were both due to the advance preparation and the online implementation of the second movement segment during the execution of the first movement segment. To prepare the movement segments in advance, elements of both segments were said to be stored in a “buffer” prior to movement execution (Adam et al., 2000). To integrate the two segments, the second was implemented (i.e., read from a “buffer”) online while the first was being performed. Because of the second movement segment being prepared while the first was being executed, movement times to the first target increased (Adam et al., 2000). Adam et al. (2000) hypothesized and found that the OTA would emerge in all directions except during a reversal movement. That is, the antagonist muscles that decelerate the first segment of a

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[1] Notably, when only one target was reached towards, the movement was inherently discrete rather than sequential.