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Acta Psychologica

DOI:
10.1016/j.actpsy.2018.03.005

Published: 01/05/2018

Peer reviewed version

Dyfyniad o'r fersiwn a gyhoeddwyd / Citation for published version (APA):
Bested, S. R., Khan, M., Lawrence, G., & Tremblay, L. (2018). What’s your number? The effects of trial order on the one-target advantage. *Acta Psychologica*, *186*(May), 110-117. https://doi.org/10.1016/j.actpsy.2018.03.005

What's your number? The effects of trial order on the one-target advantage

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Author Note

This research was supported in part by grants from the Natural Sciences and Engineering Research Council of Canada (NSERC), Ontario Research Fund (ORF), and the University of Windsor Graduate Student Assistantship.

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Abstract

When moving our upper-limb towards a single target, movement times are typically shorter than when movement to a second target is required. This is known as the one-target advantage. Most studies that have demonstrated the one-target advantage have employed separate trial blocks for the one- and two-segment movements. To test if the presence of the one-target advantage depends on advance knowledge of the number of segments, the present study investigated whether the one-target advantage would emerge under different trial orders/sequences. One- and two-segment responses were organized in blocked (i.e., 1-1-1, 2-2-2), alternating (i.e., 1-2-1-2-1-2), and random (i.e., 1-1-2-1-2-2) trial sequences. Similar to previous studies, where only blocked schedules have typically been utilized, the one-target advantage emerged during the blocked and alternate conditions, but not in the random condition. This finding indicates that the one-target advantage is contingent on participants knowing the number of movement segments prior to stimulus onset.

Keywords: one-target advantage, reaction time, movement constraint hypothesis, movement integration hypothesis

What's your number? The effects of trial order on the one-target advantage

1. Introduction

Everyday actions often contain several movement segments that are performed in series (e.g., picking up a glass of water and drinking it, turning on a light switch and opening a door, catching and then throwing a ball). When movements are comprised of a sequence of segments, reaction time (RT) is typically longer for multiple- compared to single-segment responses. This finding has been shown to be contingent on participants having advance knowledge of the number of segments (e.g., Klapp, 1995; 2003). Likewise, for movements involving multiple targets in a sequence, the time taken to reach the first target is typically longer than if the same first segment is executed in isolation (i.e., one-target advantage: Adam et al., 2000; Chamberlin & Magill, 1989; Fischman & Reeve, 1992). While the effect of response complexity on RT has been shown to depend on knowledge of the number of segments prior to stimulus presentation, there has been no systematic investigation of how the one-target advantage in movement time is influenced by the availability of advance information of the number of segments to be performed.

Since the work of Henry and Rogers (1960), several studies have shown that RT increases as the number of elements or the complexity of the task increases. However, this relationship between RT and response complexity has been shown to be contingent on participants having advance information on the number of elements in a sequence. Using morse code responses, Klapp (1995) showed that reaction time was greater for a four compared to single element response under simple but not choice reaction time conditions. Klapp (2003) replicated these findings using speech articulation while also demonstrating that reaction time was influenced by the number of syllables when participants were informed of the number of syllables in advance but not other features of the response. The findings of Klapp (1995; 2003) have also been extended to sequential aiming movements. Khan and colleagues (Khan, Lawrence, Buckolz, & Franks, 2006; Khan, Mourton, Buckolz, & Franks, 2008a) have shown that RT increased as a function of the number of targets in a sequence, only when the number of targets was specified in advance of the stimulus. RT was greater for two- compared to one-target responses when both the amplitude and the number of targets was specified before the stimulus and when only the number of targets was known in advance.

In addition to these effects on RT, movement time to the first target has been shown to be greater for multiple-segment sequences compared to single-segment movements (Adam et al., 2000). Theoretically, the one-target advantage has been explained by the movement integration hypothesis and the movement constraint hypothesis (Adam et al., 1995; Adam et al., 2000; Fischman & Reeve, 1992; Khan, Sarteep, Mottram, Lawrence, & Adam, 2011). The movement integration hypothesis states that movement segments are programmed and loaded into a buffer before the initiation of the response (Adam et al., 2000). For the transition between movement segments to be as smooth as possible, the implementation of the second segment is thought to be performed while the execution of the first segment is taking place (i.e., online). This overlap of processes is said to cause interference, resulting in longer movement times (MTs) to the first target (Adam et al., 2000). In contrast, the movement constraint hypothesis is based on the premise that variability at the proceeding targets increases as the movement progresses. Hence, to meet accuracy demands at the second target, the movement toward the first target must be constrained (Fischman & Reeve, 1992). Reducing variability at the first target is achieved at the expense of an increase in duration of the first movement segment (Fischman & Reeve, 1992).

According to both the movement integration and movement constraint hypotheses, movement segments are not controlled or prepared separately and instead share a functional dependence (Adam et al., 1995; Khan, Sarteep, Mottram, Lawrence, & Adam, 2011; Rand, Alberts, Stelmach, & Bloedel, 1997; Rand & Stelmach, 2000). For movements involving a reversal in direction at the first target, the nature of the integration between movement segments is more at the peripheral level whereby the antagonist muscles that decelerate the first movement also act as the agonist accelerating the second movement. In these cases, a two-target advantage may occur in which movement times to the first target are shorter for two- compared to single-segment responses (Adam et al., 2000).

In a series of experiments employing reversal movements, Khan et al. (2006) showed that the two-target advantage in movement time emerged for both simple and choice RT conditions. However, the difference in movement time to the first target between the single- and two-segment movements was less when participants knew the number of segments in advance (i.e. simple RT). Also, when participants knew in advance that a two-segment response was required, the presentation of a secondary probe RT task during movement execution resulted in a significant loss of accuracy at the first target. Khan et al. suggested that when participants knew the number of movement segments prior to the stimulus, there was a greater demand on the cognitive system during movement execution. This increased demand **on the cognitive system** was attributed to using visual feedback to implement the second segment during the first. This process was thought to explain increases in movement times to the first target in the reversal movements only when the number of segments was specified in advance (see also Khan et al., 2008a). Because Khan et al. (2006) only employed reversal movements, the question remains as to whether the one-target advantage that has been observed for extension movements (i.e., when both movement segments in the same direction) materializes only if the number of movement segments is known in advance.

According to the movement integration hypothesis, the two movement segments are loaded into a buffer prior to response initiation. The implementation of the second segment during the execution of the first causes interference and hence the one-target advantage (e.g., Adam et al., 2000). Thus, the movement integration hypothesis would imply that advance knowledge of the number of segments is needed for the one-target advantage to emerge. However, because one-target advantage studies have typically employed blocked trial paradigms, it is unclear whether the number of targets must be known in advance of the imperative (i.e., “go”) stimulus presentation (i.e., prior to the RT interval) for the one-target advantage to emerge. Similarly, along the lines of the movement constraint hypothesis, it is not clear whether processes prior to (i.e., programming) and/or during movement execution (i.e., feedback based corrections) are responsible for constraining the movement at the first target. Therefore, an important consideration for the one-target advantage literature is the influence of trial ordering/sequencing effects on the planning and execution of the one and two-segment movements, which may also be influenced by the repetition vs. non-repetition of a movement from one trial to another.

When performing a voluntary movement, the preparation and organization of the motor response may be facilitated if the movement is the same as on the preceding trial. Indeed, there may be a benefit in having to reproduce the same movement compared to preparing and organizing a different movement (e.g., Fischman & Lim, 1991; Rosenbaum, Weber, Hazelett, & Hindorff, 1986; Rosenbaum & Jorgensen, 1992). For instance, Rosenbaum and Jorgensen (1992) had participants touch one end of a dowel (i.e., black or white end) to a corresponding number located on the edge of a shelf on a 14-shelf bookcase. When the task was performed top-to-bottom or bottom-to-top of the bookcase, the participants' grasping orientation (i.e., thumb-up vs. thumb-down) was influenced by the previous trial. Rosenbaum and Jorgensen (1992) argued that it was more cost effective to perform the same grasp that was performed on the previous trial. Such an inter-trial influence could also be explained by a visual and/or proprioceptive reference arising from the previous trial (see also Cheng, Luis, & Tremblay, 2008; Cheng, Manson, Kennedy, & Tremblay, 2013; Whitwell, Lambert, & Goodale, 2008; Zelaznik, Hawkins, & Kisselburgh, 1983). Altogether, even when the number of movement segments is known, it is possible that the repetition vs. alternation of the number segments can facilitate vs. impede the preparation of a movement, which in turn could have an impact on the emergence of the one-target advantage.

To investigate both the influence of the knowledge of the number of segments as well as the inter-trial influence on the one-target advantage, the current study employed blocked, alternate and random trial sequences with one- and two-segment extension movements. First, the blocked, alternate, and random sequences were employed to test if the presence of the one-target advantage, depends on knowledge of the number of segments in advance of the imperative stimulus. If the one-target advantage is contingent on prior knowledge of the number of segments (i.e., the predictability factor), then the one-target advantage should emerge during the blocked and alternate conditions but not the random condition. This finding would imply that the integration of segments during movement execution is dependent on planning processes prior to the RT interval, thus demonstrating interdependency between preplanning and online processes. In contrast, if the one-target advantage emerges across all sequencing conditions, such results would represent evidence that the implementation of the second segment during the first is not contingent on processes prior to the imperative stimulus. Second, the results of the blocked and alternate sequences were contrasted to investigate the inter-trial influence on how the planning and execution processes on a trial influence the same processes on the next trial. If the inter-trial influences (i.e., repetition) have a significant impact on the preparation and integration of multiple segments, evidence of the processes underlying the one-target advantage would emerge in the blocked compared to the alternate condition. These findings would have implications for both the movement integration and movement constraint hypotheses. Following from the assumptions underlying the movement integration hypothesis, the specific roles of advance information and repetition on the construction and execution of integrated movement sequences would be delineated.

2. Methods

2.1. Participants

Twenty-four students from the University of Windsor volunteered to participate in the study (male = 16; female = 8; M = 24 yrs, range = 20-28 yrs,). All participants were self-declared right-hand dominant and had normal to corrected-to-normal vision. Each participant signed a consent form before taking part and the study was approved by the Research Ethics Board at the University of Windsor.

2.2. Apparatus

Participants were seated in front of a horizontal tabletop that was 76 cm above the ground. A Toshiba Portege M750-10J touch screen laptop (21.5 cm wide x 28.5 cm long) was placed on the table in front of the participant (see Figure 1). Participants were positioned so that their midline was centered with the middle of the touch screen. Participants performed aiming movements using a stylus on the touch screen. The targets were presented on the touch screen with the use of Labview software (National Instruments, Austin, TX, USA). Four infra-red emitting diodes (IRED) were placed around the laptop's touch screen to determine the reference plane and four IREDs were placed on a reference plane attached to the stylus to determine the pen tip and track the aiming movements. Positional data of the IREDs were obtained from a NDI 3D Investigator (Northern Digital Inc., Waterloo, ON, CA) and was further analyzed with the use of Labview software (National Instruments Inc., Austin, TX, USA).

A start position consisting of a cross (1.3 x 1.3 cm) and two circular targets (2 cm in diameter) were displayed on the touch screen. The start position was located 4 cm from the proximal edge of the touch screen, whereas the first and second target were located 8 cm and 16 cm (centre to centre) from the start position, respectively (see Figure 1).

Figure 1. 3D rendering of the experimental set-up. Participants sat in front of a table in which they performed the manual aiming movements on a tablet that was facing upwards. Movements were made away from the body (i.e., y-axis) using a stylus to touch down on the targets. Kinematic data of the stylus was recorded by using an Optotrak 3D motion capture system, which was mounted on the ceiling above the table.

2.3. Task and Procedure

The task required participants to perform one- and two-segment aiming movements. At the beginning of each trial, the start position was presented and participants were required to align the stylus on its center. Once aligned, a tone sounded, which acted as a warning signal for the participant. Following a variable foreperiod of 1500-2500 ms, one or two targets were presented**,** which acted as the imperative (i.e., “go”) stimulus. In the one-segment trials, participants were required to lift the stylus from the start position and touch down at the first target. In the two-segment trials, participants were required to move to the first target and then continue their movement in order to touch down on the second target. In both trials, participants were asked to move as quickly and accurately as possible. To ensure that participants performed the task accurately, the background of the task turned from white to light red if they had missed a target.

The one- and two-segment trials were presented to participants in blocked, alternate, and random orders. During the blocked condition, participants were told that they would perform 20 one-segment trials before performing 20 two-segment trials or vice versa (i.e. 1-1-1…2-2-2 or 2-2-2…1-1-1). In the alternate condition, they were told that the one- and two-segment trials were going to be presented in a fixed order one after the other (i.e. 1-2-1-2-1-2 or 2-1-2-1-2-1). In the random condition, they were told that the one- and two-segment trials were going to be presented in no fixed order (i.e. 1-1-2-1-2-2). In the random condition, the number of repeat trials were controlled in that participants did not perform the same trial more than 3 consecutive times in a row. Each condition consisted of a total of 40 (20 one- and 20 two-segment) trials giving a total of 120 (40 blocked, 40 alternate, and 40 random) trials during the experiment. The order of the conditions was counterbalanced between participants. Participants were asked after each condition if they wanted to take a short break (2-3 minutes) or continue to the next block of trials. They were instructed before each block which condition they would be performing (i.e., blocked, alternate, or random) and what that entailed. For each block of trials, the first 4 trials of both the one- and two-segment movements were considered practice trials and were not used for data analysis, leaving 32 testing trials for each condition.

2.4. Data Reduction

IRED position data were filtered using a second order, dual-pass, Butterworth, 16Hz low pass cut-off filter. Velocity information was then calculated from position data to obtain peak resultant velocity for each movement segment. Working backwards from peak velocity, movement start was determined as the point at which vertical velocity fell below 15 mm/s. The end of the first movement was defined at the point following peak velocity whereby vertical velocity fell below 15 mm/s. For two-segment movements, this process was repeated to identify the start and end of the second movement segment.

2.5. Dependent measures and analyses

The dependent measures consisted of reaction time (RT), movement time to the first target (MT1), movement time from the first to the second target (MT2), peak velocity during the first movement segment (PV1), peak velocity during the second movement segment (PV2), and time to and time after these velocity landmarks (TPV1, TPV2, and TAPV1, TAPV2, respectively)[2]. Our error measures at both target one and target two consisted of ellipse areas at movement end (Ea1, Ea2), and variability during peak velocity was measured using ellipsoid volumes (EvPV1, EvPV2)[3].

The variables associated with the first movement segment (i.e., RT, MT1, PV1, TPV1, TAPV1, EvPV1, and Ea1) were analyzed using separate 3 Condition (blocked, alternate, random) × 2 Segment (one- and, two-) repeated measures ANOVAs. The variables associated with the second movement segment, (i.e., MT2, PV2, TPV2, TAPV2, EvPV2, and Ea2) were analyzed using separate 3 Condition (blocked, alternate, random) one-way ANOVAs. Significant interactions were broken down using Tukeys HSD post-hoc tests ($p < .05$). Means and between subject *SDs* are reported in Table 1 for the first movement segment and Table 2 for the second movement segment.

Table 1

The first movement segment's means and between subject SDs for the one-segment (1S) and two-segment (2S) tasks as a function of condition (blocked, alternating, and random).

	Blocked		Alternate		Random	
	1S	2S	1S	2S	1S	2S
RT (ms)	217 (22)	227 (35)	224 (28)	223 (25)	243 (35)	236 (38)
MT1 (ms)	189 (28)	232 (38)	201 (29)	218 (33)	217 (24)	217 (23)
TPV1 (ms)	87 (16)	102 (18)	94 (18)	94 (16)	100 (17)	97 (15)
TAPV1 (ms)	102 (21)	130 (32)	107 (23)	124 (27)	117 (23)	120 (23)
PV1 (mm/s)	678 (116)	607 (96)	636 (117)	622 (114)	631 (105)	624 (111)
EvPV1 (mm^3)	169 (186)	157 (162)	182 (168)	130 (103)	145 (99)	140 (107)
Ea1 (mm^2)	31 (14)	22 (7.7)	26 (9.8)	23 (8.4)	24 (10)	25 (11)

Note. RT = reaction time, MT1 = movement time, TPV1 = time to peak velocity, TAPV1 = time after peak velocity, PV1 = peak velocity, EvPV1 = ellipsoid volume at peak velocity, and Ea1 = ellipse area at the end of the movement (i.e., variability in extent and direction).

Table 2

The second movement segment's means and between subject SDs for the two-segment (2S) task as a function of condition (blocked, alternating, and random).

	Blocked	Alternate	Random
MT2 (ms)	216 (25)	213 (29)	214 (28)
TPV2 (ms)	107 (16)	112 (23)	107 (17)
TAPV2 (ms)	109 (18)	101 (22)	106 (21)
PV2 (mm/s)	575 (71)	582 (89)	588 (66)
EvPV2 (mm^3)	175 (153)	192 (148)	165 (118)
Ea2 (mm^2)	30 (20)	31 (13)	38 (50)

Note. MT2 = movement time, TPV2 = time to peak velocity, TAPV2 = time after peak velocity, PV2 = peak velocity, EvPV2 = ellipsoid volume at peak velocity, and Ea2 = ellipse area at the end of the movement (i.e., variability in extent and direction).

3. Results

3.1. Reaction time

A significant main effect of Condition, $F(2, 46) = 16.012$, $p < .001$, $\eta_p^2 = .41$, and a significant Condition × Segment interaction, $F(2, 46) = 6.71$, $p < .005$, $\eta_p^2 = .23$, were found.

However, the main effect of Segment did not reach significance, $F(1, 23) = .105$, $p = .749$, $\eta_p^2 = .01$. Breakdown of the interaction (HSD = 9.58 ms) revealed that RTs were significantly shorter in the one- compared to the two-segment task in the blocked condition whereas there were no differences found for the alternate and random conditions (see Table 1 and Figure 2 panel A). Also, RTs for the one-segment task were shorter for both the blocked (217 ms) and alternate (224 ms) conditions compared to the random (243 ms) condition, while RTs for the two-segment task were shorter in the alternate (223 ms) compared to the random (236 ms) condition.

3.2. *Movement time*

The analysis of MT1 revealed a significant main effect of Segment, $F(1, 23) = 70.4$, $p < .001$, $\eta_p^2 = .75$, as well as a significant Condition × Segment interaction, $F(2, 46) = 70.4$, $p < .001$, $\eta_p^2 = .75$. The main effect of Condition did not reach significance, $F(2, 46) = 2.15$, $p = .129$, $\eta_p^2 = .09$. Breakdown of the interaction (HSD = 7.75 ms) indicated that MT1s were shorter in the one- compared to the two-segment tasks in both the blocked and alternate conditions (see Table 1 and Figure 2 panel B). There were no significant differences between the one- and two-segment tasks in the random condition. For the one-segment task, MT1s were shorter in the blocked (189 ms) compared to both the alternate (201 ms) and random (217 ms) conditions, while MT1s were shorter in the alternate (201 ms) compared to the random (217 ms) condition. For the two-segment task, MT1s were longer in the blocked (232 ms) compared to the alternate (218 ms) and random (217 ms) conditions. The analysis of MT2 did not reveal any significant effect of Condition, $F(2, 46) = .324$, $p = .725$, $\eta_p^2 = .01$.

3.3. *Time to Peak velocity*

Analysis of TPV1 revealed a significant main effect of Segment, *F*(1, 23) = 9.35, $p < .01$, $\eta_p^2 = .29$, and a significant Condition × Segment interaction, *F*(2, 46) = 35.5, $p < .001$, $\eta_p^2 = .61$. The main effect of Condition did not reach significance, *F*(2, 46) = 1.12, $p = .334$, $\eta_p^2 = .05$. Breakdown of the interaction (HSD = 5.87 ms) revealed that only the blocked condition led to shorter TPV1 in the one- compared to the two-segment task (see Table 1 and Figure 2 panel C). For the one-segment task, TPV1s were shorter in the blocked (87 ms) compared to both the alternate (94 ms) and random (100 ms) conditions, while TPV1s were also shorter in the alternate (94 ms) when compared to the random (100 ms) condition. For the two-segment task, TPV1s were longer in the blocked (102 ms) when compared to the alternate (94 ms) condition. Analysis of TPV2 revealed no significant differences between Conditions, *F*(2, 46) = 1.83, $p = .172$, $\eta_p^2 = .08$.

3.4. Time after Peak velocity

Analysis of TAPV1 revealed a significant main effect of Segment, *F*(1, 23) = 51.3, $p < .001$, $\eta_p^2 = .70$, as well as a significant Condition × Segment interaction, *F*(2, 46) = 16.9, $p < .001$, $\eta_p^2 = .42$. The main effect of Condition did not reach significance, *F*(2, 46) = .504, $p = .607$, $\eta_p^2 = .02$. Breakdown of the interaction (HSD = 11.27 ms) indicated that TAPV1 was significantly greater in the two- compared to one-segment tasks in both the blocked and alternate conditions (see Table 1and Figure 2 panel D). No significant differences were observed in the random condition. For the one-segment task, TAPV1s were shorter in the blocked (102 ms) when compared to the random (117 ms) condition. The analysis of TAPV2 revealed no significant differences between Condition, *F*(2, 46) = 2.46, $p = .097$, $\eta_p^2 = .01$.

3.4. Peak velocity

The analysis of PV1 revealed a significant main effect of Segment, $F(1, 23) = 23.1$, $p < .001$, $\eta_p^2 = .49$, and a significant Condition × Segment interaction, $F(1.45, 33.4) = 24.3$, $p < .001$, $\eta_p^2 = .51$, but no main effect of Condition, $F(1.44, 33.2) = .468$, $p = .629$, $\eta_p^2 = .02$. Breakdown of the interaction (HSD = 25.06 mm/s) indicated that PV1 in the blocked condition was significantly greater for the one- compared to the two-segment tasks whereas there were no significant differences in PV1 between tasks in the alternate and random conditions (see Table 1 and Figure 2 panel E). For the one-segment task, PV1s were greater in the blocked (678 mm/s) when compared to both the alternate (636 mm/s) and random (631 mm/s) conditions. Analysis of PV2, revealed no significant differences between Conditions, $F(1.46, 33.5) = .642$, $p = .485$. $\eta_p^2 = .03$.

3.5. Variability

The analysis of ellipsoid volume at peak velocity of the first movement (EvPV1) revealed a significant main effect of Segment, $F(1, 23) = 4.44$, $p < .05$, $\eta_p^2 = .16$) with EvPV1 being significantly greater in the one-segment (M: 165 mm^3, SD: 154) compared to the two-segment (M: 142 mm^3, SD: 126) task (see Table 1). The effect of Condition, $F(2, 46) = .240$, $p = .788$, $\eta_p^2 = .01$, and the Condition × Segment interaction, $F(2, 46) = 8.26$, $p = .227$, $\eta_p^2 = .06$, did not reach significance.

The analysis of ellipse areas at the end of the first movement segment (Ea1) revealed both a significant main effect of Segment, $F(1, 23) = 5.96$, $p < .05$, $\eta_p^2 = .21$, and a significant Condition × Segment interaction, $F(2, 46) = 4.87$, $p < .05$, $\eta_p^2 = .18$. The main effect of Condition did not reach significance, $F(2, 46) = .419$, $p = .66$, $\eta_p^2 = .02$. Breakdown of the interaction (HSD = 6.48 mm^2) indicated that only in the blocked condition, variability was greater in the one- compared to two-segment task (see Table 1 and Figure 2 panel F). For the one-segment task, Ea1s were greater in the blocked (31 mm^2) when compared to the random (24 mm^2) condition.

The analysis of EvPV2 together with the analysis of the Ea2 did not reveal any significant effects or interactions (*Fs* < .54, *ps* > .49).

3.6. Supplementary Analysis

In order to further investigate sequential effects in the random condition, an analysis of trial order was performed. To conduct this analysis, trials were sorted based on the order in which they occurred (1x1: one-segment movement following a one-segment movement, 1x2: one-segment movement following a two-segment movement, 2x1: two-segment movement following a one-segment movement, 2x2: two-segment movement following a two-segment movement). Separate 2 Current Movement (one- or two-segments) × 2 Previous Movement (one- or two-segments) repeated measures ANOVAs were conducted on RT and MT1. The analysis of sequential effects on RT yielded no significant main effect for Current Movement, $F(1, 23) = 3.50$, $p = .074$, $\eta_p^2 = .13$ or Previous Movement, $F(1, 23) = .021$, $p = .885$, $\eta_p^2 = .00$. The Current Movement × Previous Movement interaction did not reach significance, $F(1, 23) = 2.16$, $p = .155$, $\eta_p^2 = .09$. The analysis on MT1 yielded no significant main effect for Current Movement, $F(1, 23) = .269$, $p = .609$, $\eta_p^2 = .01$ or Previous Movement, $F(1, 23) = 0.04$, $p = .843$, $\eta_p^2 = .00$. The Current Movement × Previous Movement interaction did not reach significance, $F(1, 23) = 2.06$, $p = .165$, $\eta_p^2 = .08$.

Table 3

The Random conditions first movement segment’s means and between subject SDs for the one-segment (1S) and two-segment (2S) tasks as a function of order in which they appeared.

	1-1	1-2	2-1	2-2
RT (ms)	245 (44)	241 (35)	234 (38)	239 (40)
MT1 (ms)	219 (28)	217 (22)	215 (23)	219 (24)

Note. RT = reaction time, MT1 = movement time, 1-1 = one-segment movement following a one-segment movement, 1-2 = one-segment movement following a two-segment movement, 2-1= two-segment movement following a one-segment movement, 2-2 = two-segment movement following a two-segment movement.

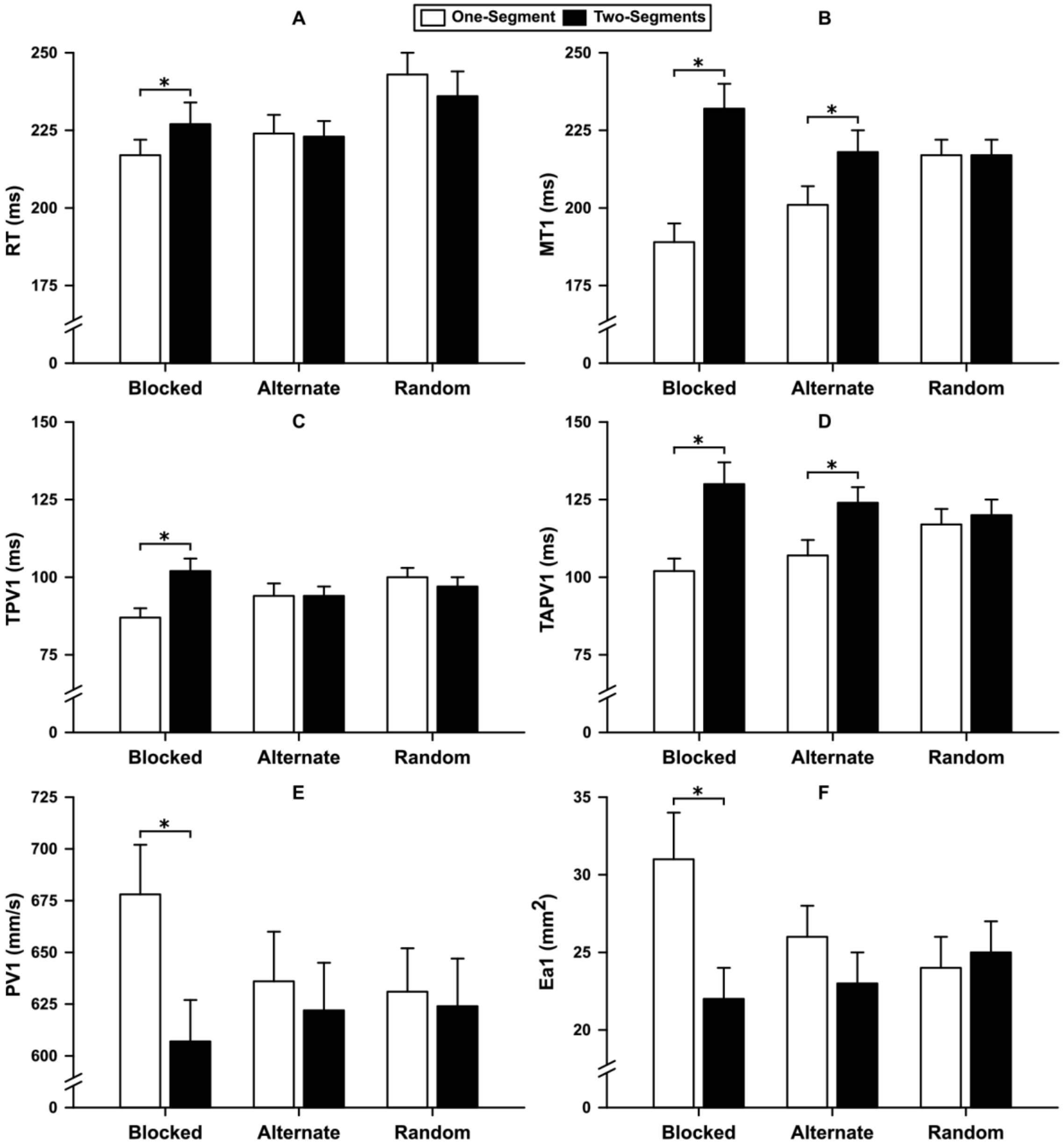

Figure 2. A: Reaction times (RTs), B: Movement times of the first movement segment (MT1), C: Time to peak velocity (TPV1) of the first movement segment, D: Time after peak velocity (TAPV1) of the first movement segment, E: Peak velocity of the first movement segment (PV1), and F: Ellipse areas (Ea1) at the end of the first movement segment for each condition (blocked, alternate, and random) as a function of the number of segments (one- or

two). Error bars represent standard error values. *Note only within condition differences are identified.

4. Discussion

The time spent initiating and moving from a start position to a target is typically shorter than when a second movement segment is executed after the first (i.e., the one-target advantage: Adam et al., 2000; Chamberlin & Magill, 1989; Fischman & Reeve, 1992). Typically, this one-target advantage has emerged when one- and two-segment movements were performed on separate blocks of trials. However, while the influence of advance information about the number of segments on reaction time has been systematically investigated (Klapp, 1995; 2003, Khan et al; 2006; 2008a), the influence of trial sequence on the one-target movement time advantage is not well understood. In the present study, the first goal was to test whether the one-target advantage depended on the availability of advance information about the number of segments. The second goal was to test whether repeating the same movement from trial to trial had an impact on the one-target advantage.

Consistent with previous research (Klapp 1995; 2003), RTs in the blocked condition were shorter in the one- compared to the two-segment task. However, differences in RT did not emerge for the alternate condition when comparing between the one- and two-segment tasks. Although this was the case, when comparing across conditions, RTs were still shorter in the one-segment task for both the blocked and alternate conditions when compared to the random condition which is consistent with previous research. In previous studies employing aiming tasks (Khan et al., 2006; 2008a), RT was greater for two- compared to single target responses when the numbers of segments was known in advance but the number of targets also changed from trial to trial. In those studies, a reversal aiming task was employed whereas an extension task was used in the present study**.** It has been shown that the two segments in reversal movements are highly integrated at the peripheral (i.e., muscular) level (see Adam et al., 2000; Khan, Tremblay, Cheng, Luis, & Mourton, 2008b). Hence, when the two segments are prepared as a single unit of action, it may be that RT increases as a function of the number of targets. This increase in RT may not only result when advance information is given on the number of targets but also when the number of targets changes from trial to trial. However, the two segments of an extension task are integrated at the central rather than peripheral level (Reilly, Lawrence, Mottram, & Khan, 2017). This may account for the lack of differences found when comparing the one- to the two-segment task in the alternate condition. For extension movements, segments may be loaded into a buffer as separate units prior to **response initiation** and hence the integration between segments is enhanced only when the number of targets is repeated from trial to trial (i.e., blocked condition).

Along the lines of the movement integration hypothesis, Adam et al. (2000) suggested that movement segments are prepared and loaded into a buffer prior to response initiation. In the present study we tested whether knowing the number of segments in advance of the RT interval should be a crucial factor for the one-target advantage to emerge. The results revealed that movement time to the first target was shorter in the one- compared to the two-target task (i.e., the OTA emerged) in the blocked and alternate conditions but not the random condition. Even when the number of targets was repeated from trial to trial in the random condition (one-segment repeated = 219 ms, two-segment repeated = 219 ms), the one-target advantage did not emerge. This indicates that knowing the number of targets in advance of the imperative stimulus is a critical factor underlying the one-target advantage. Variables typically associated with motor planning (e.g., time to peak velocity, peak velocity) (see Chua & Elliott, 1993), only yielded differences between one- and two-segment movements in the blocked condition (see Figure 2). In contrast, the time spent after peak velocity was greater for the two- compared to one-segment movements in the blocked and alternate conditions but not in the random condition. Combined, these results beg the question as to whether evidence for the movement integration hypothesis (Adam et al., 2000) should be observed before or after peak velocity. Based on evidence from a blocked protocol and the parsing of movements using peak velocity, van Doorn (2008) suggested that the integration of movement segments should be reflected prior to peak limb velocity. While such a result may only be limited to situations where the same movement is repeated in succession, the present results imply that the process of implementing the second element during execution of the first may be responsible for the lengthening of time after peak velocity in both the blocked and alternate conditions.

While movement times to the first target were shorter in the one compared to two-target movements in the blocked and alternate conditions, the processes underlying the one-target advantage may be fundamentally different under both trial sequence conditions. Indeed, the magnitude of the one-target advantage was greater in the blocked compared to alternate condition as reflected in both the time to peak velocity and the time after peak velocity. Fischman & Reeve (1992) suggested that to meet accuracy demands at the second target, the trajectory towards the first has to be restricted or constrained. Although the time spent after peak velocity was longer for two- compared to one-segment trials in the blocked and alternate conditions, variability ellipses at the end of the first movement segment were smaller for the two- compared to the one-segment trials only in the blocked condition. Hence, movements to the first target were constrained to meet accuracy demands at the second target (see also Sidaway, Sekiya, & Fairweather, 1995) only when the same number of targets to be reached was repeated trial after trial. Again, both prior knowledge of the number of segments and the repetition of the same movement over several trials was required for these presumed online constraining mechanisms to be implemented. As a result, the greater OTA in the blocked compared to alternative condition may be reflective of a cumulative effect of the separate processes within the movement integration hypothesis and movement constraint hypothesis. Therefore, further consideration needs to be given to the factors (i.e., prior knowledge and trial repetition) that influence constraining of limb trajectories during the execution of multiple-segment movements.

Previous research has shown that when participants knew the number of segments in advance of the imperative stimulus, the presentation of a dual task probe significantly reduced accuracy at the first target (Khan et al., 2006). Because of the high demands placed on the visual system during a reaching movement, the probe presumably overloaded the system, resulting in a decline in accuracy. Following from this study, Khan et al. (2011) have proposed that vision plays a dual role in the integration of segments in multiple target aiming. First, vision is used for error detection and correction processes during execution of the first segment to reduce spatial variability at the first target. This reduction in variability reduces endpoint uncertainly at the first target thereby simplifying the specification of spatial parameters needed for accuracy at the second target. Second, vision is used to continuously monitor the trajectory of the first segment in order to time the implementation of the second segment. Along the lines of the movement integration hypothesis, this online visual regulation ensures a smooth transition between movement segments. In the blocked condition of the present study, both the time to peak velocity and the time spent after peak velocity were longer and peak velocity was lower for the two- compared to one-segment task. Further, there was less variability at the first target in the two- compared to one-segment task. Hence, it appears that under the blocked condition, vision was playing a dual role in both the integration and constraining of movement segments. Movements were programmed with lower velocities to utilize vision to constrain endpoints at the first target while also providing information to regulate the timing of the implementation of the second segment. Hence, under the blocked condition, there is evidence supporting both the movement integration and constraint hypotheses.

While the difference in variability at the first target between the one- and two-target movements in the blocked condition offers support for the movement constraint hypothesis, it should be noted that this difference was due to an elevated level of endpoint variability in the one-target condition when compared to the alternate and random conditions. Hence, it may be that when one-target responses are repeated in a sequence, error (or variability) tolerance is heightened and movement times are reduced due to a speed accuracy tradeoff (Brenner & Smeets, 2011). Participants may have opted to use feedback from the previous trial with the advance information given about the up and coming trial (i.e., one- or two-segment movement: Herbort, Mathew, & Kunde, 2017). In single target movements, vision plays a role in adjusting movement programming from trial to trial (offline visual feedback processing) as well as during movement execution to correct errors in the limb trajectory (online visual feedback processing: Mackrous & Proteau, 2007). In the blocked condition, both the time to peak velocity and the time after peak velocity for the one-target movements were less when compared to the alternate and random conditions. This implies that heightened levels of variability were tolerated as a result of both programming and online processes.

Although the one-target advantage emerged in the alternate condition, this was predominantly due to the greater time spent after peak velocity in the two- compared to the one-segment movements. There was no difference in the time to peak velocity between the tasks in the alternate condition. Furthermore, in contrast to the blocked condition, there was no difference in the variability of movement endpoints at the first target between the one- and two-segment movements. Hence, it appears that in the alternate condition, the one-target advantage emerges due to the use of vision after peak velocity in regulating the timing of the second segment. It does not appear that visual feedback played a dual role in constraining endpoints at the first target. Combining the current results with those from Khan et al. (2006; 2011) provide compelling evidence that the organization of multiple-segment movements, incorporates both planning and online control mechanisms.

5. Conclusion

Overall, the current study showed that the one-target advantage is influenced by prior knowledge of the number of segments and by trial ordering/ sequencing. The results were consistent with previous research, which showed that RT was longer for multiple- than single-segment responses when the number of segments was known in advance (Klapp, 1995; 2003; Khan et al., 2006; 2008a). Such RT differences may be the result of the same type of movement performed in succession and resulting in streamlined planning processes. Similarly, the one-target advantage observed in movement time was present only when the number of segments was known in advance of the RT interval (i.e., blocked and alternate conditions). These results supported the movement integration hypothesis and its assumptions underlying movement planning processes. One caveat was that the timing of the implementation of the second segment appeared to shift to after peak limb velocity in the alternate condition (cf. van Doorn, 2008). In contrast, the current study offered support for the movement constraint hypothesis only when participants knew the number of segments in advance and the number of segments did not change from trial to trial (i.e., the blocked condition). Although vision likely plays a role in constraining movement trajectories online and regulating the implementation of the second segment (e.g., Khan et al., 2006), such online processes were significantly influenced by planning processes and trial to trial effects. Overall, the movement integration hypothesis may provide the best explanation for the one-target advantage but such a phenomenon requires at least knowing the number of segments in advance. The current results indicate that the movement integration hypothesis may be underlying the OTA in the blocked and alternate conditions whereas there is the additional processes of constraining movements at the first target in the blocked condition. The latter may be a consequence of larger error tolerances when trial types are repeated. In summary, knowing the number of targets in advance underlies the assumptions of the movement integration hypothesis while trial repetition may be facilitating movement variability constraint and error tolerances. This brings forward two recommendations.

First, future investigations of the organization of multiple-segment movements should also control for planning and online control mechanisms via the knowledge about the upcoming trial and sequences. Second, one should be careful when applying the concept of the one-target advantage to practical situations where the environment is unpredictable. These associations between planning and online control represent a promising avenue of research for understanding the preparation and execution of sequential movements.

References

Adam, J. J., Nieuwenstein, J. H., Huys, R., Paas, F.G.W. C., Kingma, H., Willems, P., & Werry, M. (2000). Control of rapid aimed hand movements: The one-target advantage. *Journal of Experimental Psychology: Human Perception and Performance, 26(1),* 295-312. doi:10.1037/0096-1523.26.1.295

Adam, J. J., Paas, F. G. W. C., Eyssem, I. C. J. M., Slingerland, H., Bekkering, H., & Drost, M. R. (1995).The control of two-element, reciprocal aiming movements: Evidence of chunking. *Human Movement Science, 14,* 1-11. doi:10.1016/0167-9457(94)00044-F

Brenner, E., & Smeets, J.B.J. (2011). Quickly 'learning' to move optimally. *Experimental Brain Research, 213,* 153-161. doi:10.1007/s00221-011-2786-9

Chamberlin, C. J., & Magill, R. A. (1989). Preparation and control of rapid, multisegmented responses in simple and choice environments. *Research Quarterly for Exercise and Sport, 60*, 256-267. doi:10.1080/02701367.1989.10607449

Cheng, D. T., Luis, M., & Tremblay, L. (2008). Randomizing visual feedback in manual aiming: reminiscence of the previous trial condition and prior knowledge of feedback availability. *Experimental Brain Research, 189(4),* 403-410. doi:10.1007/s00221-008-1436-3

Cheng, D. T., Manson, G. A., Kennedy, A., & Tremblay, L. (2013). Facilitating the Use of Online Visual Feedback: Advance Information and the Inter-Trial Interval? *Motor Control, 17(2),* 111-122. doi:10.1123/mcj.17.2.111

Chua, R., & Elliott, D. (1993). Visual regulation of manual aiming. Human Movement Science, 12(4), 365-401. doi:10.1016/0167-9457(93)90026-l

Fischman, M. G., & Lim, C. H. (1991). Influence of Extended Practice on Programming Time, Movement Time, and Transfer in Simple Target-Striking Responses. *Journal of Motor Behavior, 23(1),* 39-50. doi:10.1080/00222895.1991.9941592

Fischman, M. G., & Reeve, T. G. (1992). Slower movement times may not necessarily imply on-line programming. *Journal of Human Movement Studies, 22*, 131-144.

Hansen, S., Elliott, D., & Khan, M. A. (2008). Quantifying the Variability of Three-Dimensional Aiming Movements Using Ellipsoids. *Motor Control, 12(3),* 241-251. doi:10.1123/mcj.12.3.241

Henry, F. M., & Rogers, D. E. (1960). Increased response latency for complicated movements and a “memory drum” theory of neuromotor reaction. *Research Quarterly for Exercise and Sport, 31,* 448-458. doi:10.1080/10671188.1960.10762052

Herbort, O., Mathew, H., & Kunde, W. (2017). Habit outweighs planning in grasp selection for object manipulation. *Cognitive psychology, 92,* 127-140. doi:10.1016/j.cogpsych.2016.11.008

Khan, M. A., Lawrence, G. P., Buckolz, E., & Franks, I. M. (2006). Programming strategies for rapid aiming movements under simple and choice reaction time conditions. *The Quarterly Journal of Experimental Psychology, 59(3),* 524-542. doi:10.1080/02724980443000809

Khan, M. A., Mourton, S., Buckolz, E., & Franks, I. M. (2008a). The influence of advance information on the response complexity effect in manual aiming movements. *Acta Psychologica, 127(1),* 154-162. doi:10.1016/j.actpsy.2007.04.001

Khan, M. A., Sarteep, S., Mottram, T. M., Lawrence, G. P., & Adam, J. J. (2011). The dual role of vision in sequential aiming movements. *Acta Psychologica*, *136*, 425-431. doi:10.1016/j.actpsy.2011.01.010

Khan, M. A., Tremblay, L., Cheng, D. T., Luis, M., & Mourton, S. J. (2008b). The preparation and control of reversal movements as a single unit of action. *Experimental Brain Research, 187(1),* 33-40. doi:10.1007/s00221-008-1275-2

Klapp, S. T. (1995). Motor response programming during simple and choice reaction time: the role of practice. *Journal of Experimental Psychology: Human Perception and Performance,* 21, 1015-1027. doi:10.1037/0096-1523.21.5.1015

Klapp, S. T. (2003). Reaction time analysis of two types of motor preparation for speech articulation: Acton as a sequence of chunks. *Journal of Motor Behaviour, 35(2)*, 135-150. doi:10.1080/00222890309602129

Mackrous, I., & Proteau, L. (2007). Specificity of practice results from differences in movement planning strategies. *Experimental Brain Research, 183,* 181-193. doi: 10.1007/s00221-007-1031-z

Rand, M. K., Alberts, J. L., Stelmach, G. E., & Bloedel, J. R. (1997). The influence of movement segment difficulty on movements with two-stroke sequence. *Experimental Brain Research, 115*, 137-146. doi:10.1007/pl00005673

Rand, M. K., & Stelmach, G. E. (2000). Segment interdependency and difficulty in two-stroke sequences. *Experimental Brain Research*, *134*, 228-236. doi:10.1007/s002210000450

Reilly, N.E., Lawrence, G.P., Mottram, T., & Khan, M.A. (2017). Adults with Down syndrome demonstrate peripheral not central deficits when integrating movements during multiple target sequences. *Journal of Motor learning and development*, *5*(1), 82-102. doi.org/10.1123/jmld.2015-0045

Rosenbaum, D. A., & Jorgensen, M. J. (1992). Planning macroscopic aspects of manual control. *Human Movement Science, 11(1-2),* 61-69. doi:10.1016/0167-9457(92)90050-l

Rosenbaum, D. A., Weber, R. J., Hazelett, W. M., & Hindorff, V. (1986). The parameter remapping effect in human performance: Evidence from tongue twisters and finger fumblers. *Journal of Memory and Language, 25(6),* 710-725. doi:10.1016/0749-596x(86)90045-8

Sidaway, B., Sekiya, H., & Fairweather, M. (1995). Movement variability as a function of accuracy demand in programmed serial aiming responses. *Journal of Motor Behavior, 27(1)*, 67-76. doi:10.1080/00222895.1995.9941700

van Doorn, R. R. A. (2008). The Temporal Locus of the One-Target Advantage in Rapid Aimed Movements. *Motor Control, 12(2),* 109-121. doi:10.1123/mcj.12.2.109

Whitwell, R. L., Lambert, L., & Goodale, M., A. (2008). Grasping future events: explicit knowledge of the availability of visual feedback fails to reliably influence prehension. *Experimental Brain Research,188,* 603-611. doi:10.1007/s00221-008-1395-8

Zelaznik, H. N., Hawkins, B., & Kisselburgh, L. (1983). Rapid visual feedback processing in single-aiming movements. *Journal of Motor Behavior, 15(3)*, 217-236. doi:10.1080/00222895.1983.10735298

Footnotes

[1] At the time that this research was collected Stephen R. Bested was working on his M.H.K at the University of Windsor and is currently studying his PhD at the University of Toronto. Present address: [c] Graduate Department of Exercise Sciences, Faculty of Kinesiology and Physical Education, Perceptual Motor Behaviour Lab, Centre of Motor Control, University of Toronto, Toronto, ON, M5S 2W6, Canada.

[2] Although the movement constraint hypothesis does not specify whether constraining of endpoints at the first target is due to programming or online feedback based error correction processes, the present study investigated the effect of trial sequencing on these processes by parsing movements into time before and after peak velocity (Chua & Elliott, 1993).

[3] As per Hansen, Elliott, & Khan (2008), in the y axis (extent) target undershoot was –ve and target overshoot +ve, in the x axis (direction) error to the right of the target was +ve and error to the left of the target was –ve. Ea1 and Ea2 were measured by calculating ellipse areas using within-subject standard deviations of the x and y positions at the end of the movement ($Ea = \pi \times SDx \times SDy$) written as mm^2. EvPV1 and EvPV2 were calculated using the within-subject standard deviations of the positions of the x, y, and z axis at peak velocity ($EvPV = \pi \times SDx \times SDy \times SDz$) and is written as mm^3 because of the three dimensional values used.