

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

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

65 **1. Introduction**

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

79 Since the work of Henry and Rogers (1960), several studies have shown that RT
80 increases as the number of elements or the complexity of the task increases. However, this
81 relationship between RT and response complexity has been shown to be contingent on
82 participants having advance information on the number of elements in a sequence. Using morse
83 code responses, Klapp (1995) showed that reaction time was greater for a four compared to
84 single element response under simple but not choice reaction time conditions. Klapp (2003)
85 replicated these findings using speech articulation while also demonstrating that reaction time
86 was influenced by the number of syllables when participants were informed of the number of

87 syllables in advance but not other features of the response. The findings of Klapp (1995; 2003)
88 have also been extended to sequential aiming movements. Khan and colleagues (Khan,
89 Lawrence, Buckolz, & Franks, 2006; Khan, Mourton, Buckolz, & Franks, 2008a) have shown
90 that RT increased as a function of the number of targets in a sequence, only when the number of
91 targets was specified in advance of the stimulus. RT was greater for two- compared to one-target
92 responses when both the amplitude and the number of targets was specified before the stimulus
93 and when only the number of targets was known in advance.

94 In addition to these effects on RT, movement time to the first target has been shown to be
95 greater for multiple-segment sequences compared to single-segment movements (Adam et al.,
96 2000). Theoretically, the one-target advantage has been explained by the movement integration
97 hypothesis and the movement constraint hypothesis (Adam et al., 1995; Adam et al., 2000;
98 Fischman & Reeve, 1992; Khan, Sarteep, Mottram, Lawrence, & Adam, 2011). The movement
99 integration hypothesis states that movement segments are programmed and loaded into a buffer
100 before the initiation of the response (Adam et al., 2000). For the transition between movement
101 segments to be as smooth as possible, the implementation of the second segment is thought to be
102 performed while the execution of the first segment is taking place (i.e., online). This overlap of
103 processes is said to cause interference, resulting in longer movement times (MTs) to the first
104 target (Adam et al., 2000). In contrast, the movement constraint hypothesis is based on the
105 premise that variability at the proceeding targets increases as the movement progresses. Hence,
106 to meet accuracy demands at the second target, the movement toward the first target must be
107 constrained (Fischman & Reeve, 1992). Reducing variability at the first target is achieved at the
108 expense of an increase in duration of the first movement segment (Fischman & Reeve, 1992).

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

118 In a series of experiments employing reversal movements, Khan et al. (2006) showed that the
119 two-target advantage in movement time emerged for both simple and choice RT conditions.
120 However, the difference in movement time to the first target between the single- and two-
121 segment movements was less when participants knew the number of segments in advance (i.e.
122 simple RT). Also, when participants knew in advance that a two-segment response was required,
123 the presentation of a secondary probe RT task during movement execution resulted in a
124 significant loss of accuracy at the first target. Khan et al. suggested that when participants knew
125 the number of movement segments prior to the stimulus, there was a greater demand on the
126 cognitive system during movement execution. This increased demand **on the cognitive system**
127 was attributed to using visual feedback to implement the second segment during the first. This
128 process was thought to explain increases in movement times to the first target in the reversal
129 movements only when the number of segments was specified in advance (see also Khan et al.,
130 2008a). Because Khan et al. (2006) only employed reversal movements, the question remains as
131 to whether the one-target advantage that has been observed for extension movements (i.e., when

132 both movement segments in the same direction) materializes only if the number of movement
133 segments is known in advance.

134 According to the movement integration hypothesis, the two movement segments are loaded
135 into a buffer prior to response initiation. The implementation of the second segment during the
136 execution of the first causes interference and hence the one-target advantage (e.g., Adam et al.,
137 2000). Thus, the movement integration hypothesis would imply that advance knowledge of the
138 number of segments is needed for the one-target advantage to emerge. However, because one-
139 target advantage studies have typically employed blocked trial paradigms, it is unclear whether
140 the number of targets must be known in advance of the imperative (i.e., “go”) stimulus
141 presentation (i.e., prior to the RT interval) for the one-target advantage to emerge. Similarly,
142 along the lines of the movement constraint hypothesis, it is not clear whether processes prior to
143 (i.e., programming) and/or during movement execution (i.e., feedback based corrections) are
144 responsible for constraining the movement at the first target. Therefore, an important
145 consideration for the one-target advantage literature is the influence of trial ordering/sequencing
146 effects on the planning and execution of the one and two-segment movements, which may also
147 be influenced by the repetition vs. non-repetition of a movement from one trial to another.

148 When performing a voluntary movement, the preparation and organization of the motor
149 response may be facilitated if the movement is the same as on the preceding trial. Indeed, there
150 may be a benefit in having to reproduce the same movement compared to preparing and
151 organizing a different movement (e.g., Fischman & Lim, 1991; Rosenbaum, Weber, Hazelett, &
152 Hindorff, 1986; Rosenbaum & Jorgensen, 1992). For instance, Rosenbaum and Jorgensen (1992)
153 had participants touch one end of a dowel (i.e., black or white end) to a corresponding number
154 located on the edge of a shelf on a 14-shelf bookcase. When the task was performed top-to-

155 bottom or bottom-to-top of the bookcase, the participants' grasping orientation (i.e., thumb-up
156 vs. thumb-down) was influenced by the previous trial. Rosenbaum and Jorgensen (1992) argued
157 that it was more cost effective to perform the same grasp that was performed on the previous
158 trial. Such an inter-trial influence could also be explained by a visual and/or proprioceptive
159 reference arising from the previous trial (see also Cheng, Luis, & Tremblay, 2008; Cheng,
160 Manson, Kennedy, & Tremblay, 2013; Whitwell, Lambert, & Goodale, 2008; Zelaznik,
161 Hawkins, & Kesselburgh, 1983). Altogether, even when the number of movement segments is
162 known, it is possible that the repetition vs. alternation of the number segments can facilitate vs.
163 impede the preparation of a movement, which in turn could have an impact on the emergence of
164 the one-target advantage.

165 To investigate both the influence of the knowledge of the number of segments as well as the
166 inter-trial influence on the one-target advantage, the current study employed blocked, alternate
167 and random trial sequences with one- and two-segment extension movements. First, the blocked,
168 alternate, and random sequences were employed to test if the presence of the one-target
169 advantage, depends on knowledge of the number of segments in advance of the imperative
170 stimulus. If the one-target advantage is contingent on prior knowledge of the number of
171 segments (i.e., the predictability factor), then the one-target advantage should emerge during the
172 blocked and alternate conditions but not the random condition. This finding would imply that the
173 integration of segments during movement execution is dependent on planning processes prior to
174 the RT interval, thus demonstrating interdependency between preplanning and online processes.
175 In contrast, if the one-target advantage emerges across all sequencing conditions, such results
176 would represent evidence that the implementation of the second segment during the first is not
177 contingent on processes prior to the imperative stimulus. Second, the results of the blocked and

178 alternate sequences were contrasted to investigate the inter-trial influence on how the planning
179 and execution processes on a trial influence the same processes on the next trial. If the inter-trial
180 influences (i.e., repetition) have a significant impact on the preparation and integration of
181 multiple segments, evidence of the processes underlying the one-target advantage would emerge
182 in the blocked compared to the alternate condition. These findings would have implications for
183 both the movement integration and movement constraint hypotheses. Following from the
184 assumptions underlying the movement integration hypothesis, the specific roles of advance
185 information and repetition on the construction and execution of integrated movement sequences
186 would be delineated.

187

188 **2. Methods**

189 *2.1. Participants*

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

195 *2.2. Apparatus*

196 Participants were seated in front of a horizontal tabletop that was 76 cm above the
197 ground. A Toshiba Portege M750-10J touch screen laptop (21.5 cm wide x 28.5 cm long) was
198 placed on the table in front of the participant (see Figure 1). Participants were positioned so that
199 their midline was centered with the middle of the touch screen. Participants performed aiming

200 movements using a stylus on the touch screen. The targets were presented on the touch screen
201 with the use of Labview software (National Instruments, Austin, TX, USA). Four infra-red
202 emitting diodes (IRED) were placed around the laptop's touch screen to determine the reference
203 plane and four IREDs were placed on a reference plane attached to the stylus to determine the
204 pen tip and track the aiming movements. Positional data of the IREDs were obtained from a NDI
205 3D Investigator (Northern Digital Inc., Waterloo, ON, CA) and was further analyzed with the use
206 of Labview software (National Instruments Inc., Austin, TX, USA).

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



211

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

217 2.3. *Task and Procedure*

218 The task required participants to perform one- and two-segment aiming movements. At
219 the beginning of each trial, the start position was presented and participants were required to
220 align the stylus on its center. Once aligned, a tone sounded, which acted as a warning signal for
221 the participant. Following a variable foreperiod of 1500-2500 ms, one or two targets were

222 presented, which acted as the imperative (i.e., “go”) stimulus. In the one-segment trials,
223 participants were required to lift the stylus from the start position and touch down at the first
224 target. In the two-segment trials, participants were required to move to the first target and then
225 continue their movement in order to touch down on the second target. In both trials, participants
226 were asked to move as quickly and accurately as possible. To ensure that participants performed
227 the task accurately, the background of the task turned from white to light red if they had missed a
228 target.

229 The one- and two-segment trials were presented to participants in blocked, alternate, and
230 random orders. During the blocked condition, participants were told that they would perform 20
231 one-segment trials before performing 20 two-segment trials or vice versa (i.e. 1-1-1...2-2-2 or 2-
232 2-2...1-1-1). In the alternate condition, they were told that the one- and two-segment trials were
233 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
234 random condition, they were told that the one- and two-segment trials were going to be presented
235 in no fixed order (i.e. 1-1-2-1-2-2). In the random condition, the number of repeat trials were
236 controlled in that participants did not perform the same trial more than 3 consecutive times in a
237 row. Each condition consisted of a total of 40 (20 one- and 20 two-segment) trials giving a total
238 of 120 (40 blocked, 40 alternate, and 40 random) trials during the experiment. The order of the
239 conditions was counterbalanced between participants. Participants were asked after each
240 condition if they wanted to take a short break (2-3 minutes) or continue to the next block of
241 trials. They were instructed before each block which condition they would be performing (i.e.,
242 blocked, alternate, or random) and what that entailed. For each block of trials, the first 4 trials of
243 both the one- and two-segment movements were considered practice trials and were not used for
244 data analysis, leaving 32 testing trials for each condition.

245 2.4. *Data Reduction*

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

253 2.5. *Dependent measures and analyses*

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

261 The variables associated with the first movement segment (i.e., RT, MT1, PV1, TPV1,
262 TAPV1, EvPV1, and Ea1) were analyzed using separate 3 Condition (blocked, alternate,
263 random) \times 2 Segment (one- and, two-) repeated measures ANOVAs. The variables associated
264 with the second movement segment, (i.e., MT2, PV2, TPV2, TAPV2, EvPV2, and Ea2) were
265 analyzed using separate 3 Condition (blocked, alternate, random) one-way ANOVAs. Significant
266 interactions were broken down using Tukeys HSD post-hoc tests ($p < .05$). Means and between

267 subject *SDs* are reported in Table 1 for the first movement segment and Table 2 for the second
 268 movement segment.

269 Table 1

270 *The first movement segment's means and between subject SDs for the one-segment (1S) and two-*
 271 *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)

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

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286 Table 2

287 *The second movement segment's means and between*288 *subject SDs for the two-segment (2S) task as a function*289 *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)

290

291 *Note.* MT2 = movement time, TPV2 = time to peak

292 velocity, TAPV2 = time after peak velocity, PV2 = peak

293 velocity, EvPV2 = ellipsoid volume at peak velocity,

294 and Ea2 = ellipse area at the end of the movement (i.e.,

295 variability in extent and direction).

296

297 **3. Results**298 *3.1. Reaction time*299 A significant main effect of Condition, $F(2, 46) = 16.012, p < .001, \eta_p^2 = .41$, and a300 significant Condition \times Segment interaction, $F(2, 46) = 6.71, p < .005, \eta_p^2 = .23$, were found.

301 However, the main effect of Segment did not reach significance, $F(1, 23) = .105, p = .749, \eta_p^2 =$
302 $.01$. Breakdown of the interaction (HSD = 9.58 ms) revealed that RTs were significantly shorter
303 in the one- compared to the two-segment task in the blocked condition whereas there were no
304 differences found for the alternate and random conditions (see Table 1 and Figure 2 panel A).
305 Also, RTs for the one-segment task were shorter for both the blocked (217 ms) and alternate
306 (224 ms) conditions compared to the random (243 ms) condition, while RTs for the two-segment
307 task were shorter in the alternate (223 ms) compared to the random (236 ms) condition.

308 3.2. Movement time

309 The analysis of MT1 revealed a significant main effect of Segment, $F(1, 23) = 70.4, p <$
310 $.001, \eta_p^2 = .75$, as well as a significant Condition \times Segment interaction, $F(2, 46) = 70.4, p <$
311 $.001, \eta_p^2 = .75$. The main effect of Condition did not reach significance, $F(2, 46) = 2.15, p =$
312 $.129, \eta_p^2 = .09$. Breakdown of the interaction (HSD = 7.75 ms) indicated that MT1s were shorter
313 in the one- compared to the two-segment tasks in both the blocked and alternate conditions (see
314 Table 1 and Figure 2 panel B). There were no significant differences between the one- and two-
315 segment tasks in the random condition. For the one-segment task, MT1s were shorter in the
316 blocked (189 ms) compared to both the alternate (201 ms) and random (217 ms) conditions,
317 while MT1s were shorter in the alternate (201 ms) compared to the random (217 ms) condition.
318 For the two-segment task, MT1s were longer in the blocked (232 ms) compared to the alternate
319 (218 ms) and random (217 ms) conditions. The analysis of MT2 did not reveal any significant
320 effect of Condition, $F(2, 46) = .324, p = .725, \eta_p^2 = .01$.

321 3.3. Time to Peak velocity

322 Analysis of TPV1 revealed a significant main effect of Segment, $F(1, 23) = 9.35, p < .01, \eta_p^2 =$
323 $.29$, and a significant Condition \times Segment interaction, $F(2, 46) = 35.5, p < .001, \eta_p^2 = .61$. The
324 main effect of Condition did not reach significance, $F(2, 46) = 1.12, p = .334, \eta_p^2 = .05$.
325 Breakdown of the interaction (HSD = 5.87 ms) revealed that only the blocked condition led to
326 shorter TPV1 in the one- compared to the two-segment task (see Table 1 and Figure 2 panel C).
327 For the one-segment task, TPV1s were shorter in the blocked (87 ms) compared to both the
328 alternate (94 ms) and random (100 ms) conditions, while TPV1s were also shorter in the
329 alternate (94 ms) when compared to the random (100 ms) condition. For the two-segment task,
330 TPV1s were longer in the blocked (102 ms) when compared to the alternate (94 ms) condition.
331 Analysis of TPV2 revealed no significant differences between Conditions, $F(2, 46) = 1.83, p =$
332 $.172, \eta_p^2 = .08$.

333 3.4. Time after Peak velocity

334 Analysis of TAPV1 revealed a significant main effect of Segment, $F(1, 23) = 51.3, p <$
335 $.001, \eta_p^2 = .70$, as well as a significant Condition \times Segment interaction, $F(2, 46) = 16.9, p <$
336 $.001, \eta_p^2 = .42$. The main effect of Condition did not reach significance, $F(2, 46) = .504, p =$
337 $.607, \eta_p^2 = .02$. Breakdown of the interaction (HSD = 11.27 ms) indicated that TAPV1 was
338 significantly greater in the two- compared to one-segment tasks in both the blocked and alternate
339 conditions (see Table 1 and Figure 2 panel D). No significant differences were observed in the
340 random condition. For the one-segment task, TAPV1s were shorter in the blocked (102 ms)
341 when compared to the random (117 ms) condition. The analysis of TAPV2 revealed no
342 significant differences between Condition, $F(2, 46) = 2.46, p = .097, \eta_p^2 = .01$.

343 3.4. Peak velocity

344 The analysis of PV1 revealed a significant main effect of Segment, $F(1, 23) = 23.1, p <$
345 $.001, \eta_p^2 = .49$, and a significant Condition \times Segment interaction, $F(1.45, 33.4) = 24.3, p < .001,$
346 $\eta_p^2 = .51$, but no main effect of Condition, $F(1.44, 33.2) = .468, p = .629, \eta_p^2 = .02$. Breakdown
347 of the interaction (HSD = 25.06 mm/s) indicated that PV1 in the blocked condition was
348 significantly greater for the one- compared to the two-segment tasks whereas there were no
349 significant differences in PV1 between tasks in the alternate and random conditions (see Table 1
350 and Figure 2 panel E). For the one-segment task, PV1s were greater in the blocked (678 mm/s)
351 when compared to both the alternate (636 mm/s) and random (631 mm/s) conditions. Analysis of
352 PV2, revealed no significant differences between Conditions, $F(1.46, 33.5) = .642, p = .485, \eta_p^2$
353 $= .03$.

354 3.5. Variability

355 The analysis of ellipsoid volume at peak velocity of the first movement (EvPV1) revealed
356 a significant main effect of Segment, $F(1, 23) = 4.44, p < .05, \eta_p^2 = .16$ with EvPV1 being
357 significantly greater in the one-segment (M: 165 mm³, SD: 154) compared to the two-segment
358 (M: 142 mm³, SD: 126) task (see Table 1). The effect of Condition, $F(2, 46) = .240, p = .788, \eta_p^2$
359 $= .01$, and the Condition \times Segment interaction, $F(2, 46) = 8.26, p = .227, \eta_p^2 = .06$, did not reach
360 significance.

361 The analysis of ellipse areas at the end of the first movement segment (Ea1) revealed
362 both a significant main effect of Segment, $F(1, 23) = 5.96, p < .05, \eta_p^2 = .21$, and a significant
363 Condition \times Segment interaction, $F(2, 46) = 4.87, p < .05, \eta_p^2 = .18$. The main effect of
364 Condition did not reach significance, $F(2, 46) = .419, p = .66, \eta_p^2 = .02$. Breakdown of the
365 interaction (HSD = 6.48 mm²) indicated that only in the blocked condition, variability was
366 greater in the one- compared to two-segment task (see Table 1 and Figure 2 panel F). For the

367 one-segment task, Ea1s were greater in the blocked (31 mm²) when compared to the random (24
368 mm²) condition.

369 The analysis of EvPV2 together with the analysis of the Ea2 did not reveal any
370 significant effects or interactions ($F_s < .54, p_s > .49$).

371

372

373 3.6. *Supplementary Analysis*

374 In order to further investigate sequential effects in the random condition, an analysis of
375 trial order was performed. To conduct this analysis, trials were sorted based on the order in
376 which they occurred (1x1: one-segment movement following a one-segment movement, 1x2:
377 one-segment movement following a two-segment movement, 2x1: two-segment movement
378 following a one-segment movement, 2x2: two-segment movement following a two-segment
379 movement). Separate 2 Current Movement (one- or two-segments) \times 2 Previous Movement
380 (one- or two-segments) repeated measures ANOVAs were conducted on RT and MT1. The
381 analysis of sequential effects on RT yielded no significant main effect for Current Movement,
382 $F(1, 23) = 3.50, p = .074, \eta_p^2 = .13$ or Previous Movement, $F(1, 23) = .021, p = .885, \eta_p^2 = .00$.
383 The Current Movement \times Previous Movement interaction did not reach significance, $F(1, 23) =$
384 $2.16, p = .155, \eta_p^2 = .09$. The analysis on MT1 yielded no significant main effect for Current
385 Movement, $F(1, 23) = .269, p = .609, \eta_p^2 = .01$ or Previous Movement, $F(1, 23) = 0.04, p = .843,$
386 $\eta_p^2 = .00$. The Current Movement \times Previous Movement interaction did not reach significance,
387 $F(1, 23) = 2.06, p = .165, \eta_p^2 = .08$.

388

389

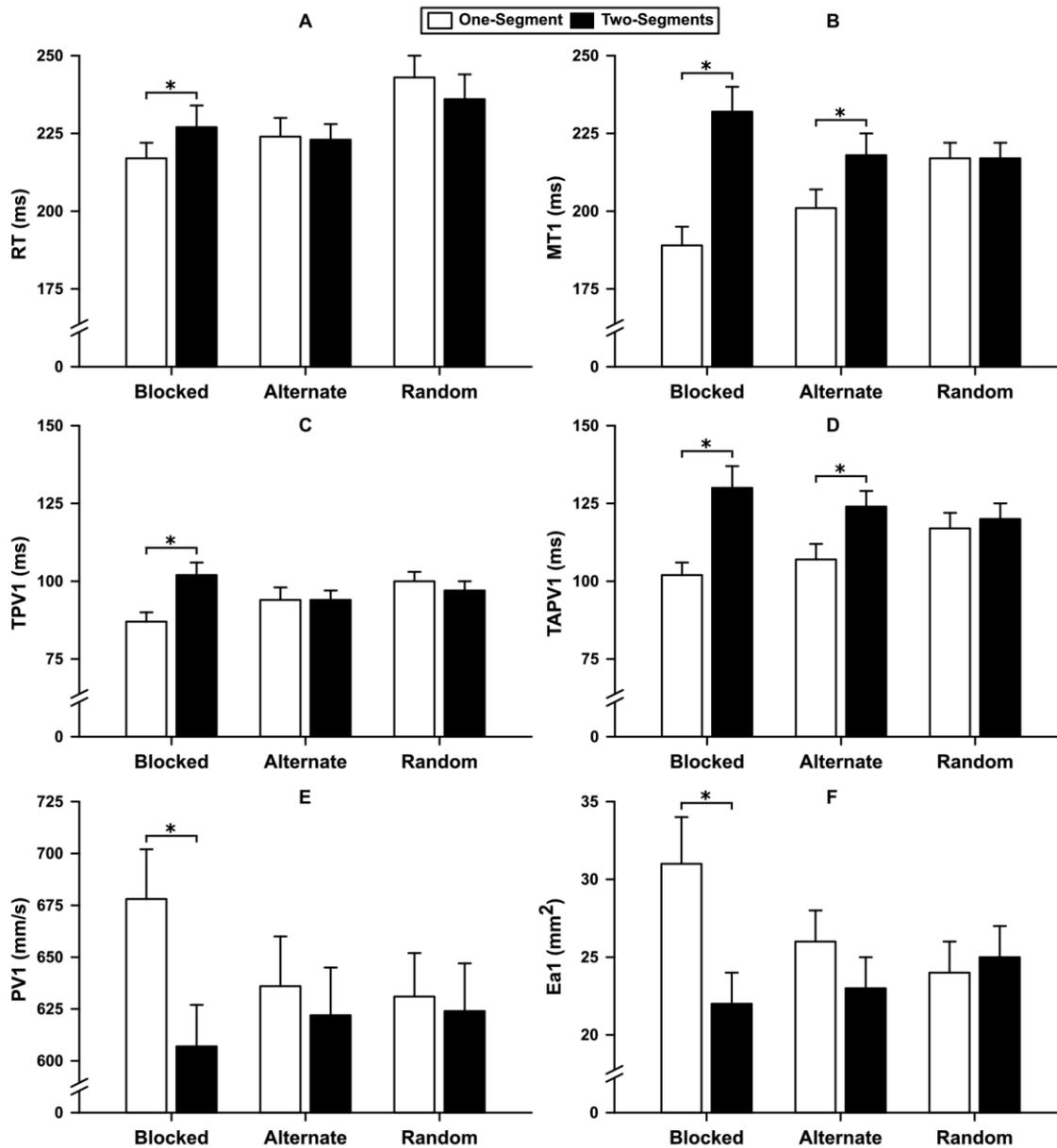
390 Table 3

391 *The Random conditions first movement segment's means and between*
 392 *subject SDs for the one-segment (1S) and two-segment (2S) tasks as a*
 393 *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)

394 *Note.* RT = reaction time, MT1 = movement time, 1-1 = one-segment
 395 movement following a one-segment movement, 1-2 = one-segment
 396 movement following a two-segment movement, 2-1 = two-segment
 397 movement following a one-segment movement, 2-2 = two-segment
 398 movement following a two-segment movement.

399



400

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

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

408 **4. Discussion**

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

420 Consistent with previous research (Klapp 1995; 2003), RTs in the blocked condition were
421 shorter in the one- compared to the two-segment task. However, differences in RT did not
422 emerge for the alternate condition when comparing between the one- and two-segment tasks.
423 Although this was the case, when comparing across conditions, RTs were still shorter in the one-
424 segment task for both the blocked and alternate conditions when compared to the random
425 condition which is consistent with previous research. In previous studies employing aiming
426 tasks (Khan et al., 2006; 2008a), RT was greater for two- compared to single target responses
427 when the numbers of segments was known in advance but the number of targets also changed
428 from trial to trial. In those studies, a reversal aiming task was employed whereas an extension

429 task was used in the present study. It has been shown that the two segments in reversal
430 movements are highly integrated at the peripheral (i.e., muscular) level (see Adam et al., 2000;
431 Khan, Tremblay, Cheng, Luis, & Mourton, 2008b). Hence, when the two segments are prepared
432 as a single unit of action, it may be that RT increases as a function of the number of targets. This
433 increase in RT may not only result when advance information is given on the number of targets
434 but also when the number of targets changes from trial to trial. However, the two segments of an
435 extension task are integrated at the central rather than peripheral level (Reilly, Lawrence,
436 Mottram, & Khan, 2017). This may account for the lack of differences found when comparing
437 the one- to the two-segment task in the alternate condition. For extension movements, segments
438 may be loaded into a buffer as separate units prior to **response initiation** and hence the
439 integration between segments is enhanced only when the number of targets is repeated from trial
440 to trial (i.e., blocked condition).

441 Along the lines of the movement integration hypothesis, Adam et al. (2000) suggested
442 that movement segments are prepared and loaded into a buffer prior to response initiation. In the
443 present study we tested whether knowing the number of segments in advance of the RT interval
444 should be a crucial factor for the one-target advantage to emerge. The results revealed that
445 movement time to the first target was shorter in the one- compared to the two-target task (i.e., the
446 OTA emerged) in the blocked and alternate conditions but not the random condition. Even when
447 the number of targets was repeated from trial to trial in the random condition (one-segment
448 repeated = 219 ms, two-segment repeated = 219 ms), the one-target advantage did not emerge.
449 This indicates that knowing the number of targets in advance of the imperative stimulus is a
450 critical factor underlying the one-target advantage. Variables typically associated with motor
451 planning (e.g., time to peak velocity, peak velocity) (see Chua & Elliott, 1993), only yielded

452 differences between one- and two-segment movements in the blocked condition (see Figure 2).
453 In contrast, the time spent after peak velocity was greater for the two- compared to one-segment
454 movements in the blocked and alternate conditions but not in the random condition. Combined,
455 these results beg the question as to whether evidence for the movement integration hypothesis
456 (Adam et al., 2000) should be observed before or after peak velocity. Based on evidence from a
457 blocked protocol and the parsing of movements using peak velocity, van Doorn (2008) suggested
458 that the integration of movement segments should be reflected prior to peak limb velocity. While
459 such a result may only be limited to situations where the same movement is repeated in
460 succession, the present results imply that the process of implementing the second element during
461 execution of the first may be responsible for the lengthening of time after peak velocity in both
462 the blocked and alternate conditions.

463 While movement times to the first target were shorter in the one compared to two-target
464 movements in the blocked and alternate conditions, the processes underlying the one-target
465 advantage may be fundamentally different under both trial sequence conditions. Indeed, the
466 magnitude of the one-target advantage was greater in the blocked compared to alternate
467 condition as reflected in both the time to peak velocity and the time after peak velocity.
468 Fischman & Reeve (1992) suggested that to meet accuracy demands at the second target, the
469 trajectory towards the first has to be restricted or constrained. Although the time spent after peak
470 velocity was longer for two- compared to one-segment trials in the blocked and alternate
471 conditions, variability ellipses at the end of the first movement segment were smaller for the two-
472 compared to the one-segment trials only in the blocked condition. Hence, movements to the first
473 target were constrained to meet accuracy demands at the second target (see also Sidaway,
474 Sekiya, & Fairweather, 1995) only when the same number of targets to be reached was repeated

475 trial after trial. Again, both prior knowledge of the number of segments and the repetition of the
476 same movement over several trials was required for these presumed online constraining
477 mechanisms to be implemented. As a result, the greater OTA in the blocked compared to
478 alternative condition may be reflective of a cumulative effect of the separate processes within the
479 movement integration hypothesis and movement constraint hypothesis. Therefore, further
480 consideration needs to be given to the factors (i.e., prior knowledge and trial repetition) that
481 influence constraining of limb trajectories during the execution of multiple-segment movements.

482 Previous research has shown that when participants knew the number of segments in
483 advance of the imperative stimulus, the presentation of a dual task probe significantly reduced
484 accuracy at the first target (Khan et al., 2006). Because of the high demands placed on the visual
485 system during a reaching movement, the probe presumably overloaded the system, resulting in a
486 decline in accuracy. Following from this study, Khan et al. (2011) have proposed that vision
487 plays a dual role in the integration of segments in multiple target aiming. First, vision is used for
488 error detection and correction processes during execution of the first segment to reduce spatial
489 variability at the first target. This reduction in variability reduces endpoint uncertainty at the first
490 target thereby simplifying the specification of spatial parameters needed for accuracy at the
491 second target. Second, vision is used to continuously monitor the trajectory of the first segment
492 in order to time the implementation of the second segment. Along the lines of the movement
493 integration hypothesis, this online visual regulation ensures a smooth transition between
494 movement segments. In the blocked condition of the present study, both the time to peak
495 velocity and the time spent after peak velocity were longer and peak velocity was lower for the
496 two- compared to one-segment task. Further, there was less variability at the first target in the
497 two- compared to one-segment task. Hence, it appears that under the blocked condition, vision

498 was playing a dual role in both the integration and constraining of movement segments.
499 Movements were programmed with lower velocities to utilize vision to constrain endpoints at the
500 first target while also providing information to regulate the timing of the implementation of the
501 second segment. Hence, under the blocked condition, there is evidence supporting both the
502 movement integration and constraint hypotheses.

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

518 Although the one-target advantage emerged in the alternate condition, this was
519 predominantly due to the greater time spent after peak velocity in the two- compared to the one-
520 segment movements. There was no difference in the time to peak velocity between the tasks in

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

529 **5. Conclusion**

530 Overall, the current study showed that the one-target advantage is influenced by prior
531 knowledge of the number of segments and by trial ordering/ sequencing. The results were
532 consistent with previous research, which showed that RT was longer for multiple- than single-
533 segment responses when the number of segments was known in advance (Klapp, 1995; 2003;
534 Khan et al., 2006; 2008a). Such RT differences may be the result of the same type of movement
535 performed in succession and resulting in streamlined planning processes. Similarly, the one-
536 target advantage observed in movement time was present only when the number of segments was
537 known in advance of the RT interval (i.e., blocked and alternate conditions). These results
538 supported the movement integration hypothesis and its assumptions underlying movement
539 planning processes. One caveat was that the timing of the implementation of the second segment
540 appeared to shift to after peak limb velocity in the alternate condition (cf. van Doorn, 2008). In
541 contrast, the current study offered support for the movement constraint hypothesis only when
542 participants knew the number of segments in advance and the number of segments did not
543 change from trial to trial (i.e., the blocked condition). Although vision likely plays a role in

544 constraining movement trajectories online and regulating the implementation of the second
545 segment (e.g., Khan et al., 2006), such online processes were significantly influenced by
546 planning processes and trial to trial effects. Overall, the movement integration hypothesis may
547 provide the best explanation for the one-target advantage but such a phenomenon requires at
548 least knowing the number of segments in advance. The current results indicate that the
549 movement integration hypothesis may be underlying the OTA in the blocked and alternate
550 conditions whereas there is the additional processes of constraining movements at the first target
551 in the blocked condition. The latter may be a consequence of larger error tolerances when trial
552 types are repeated. In summary, knowing the number of targets in advance underlies the
553 assumptions of the movement integration hypothesis while trial repetition may be facilitating
554 movement variability constraint and error tolerances. This brings forward two
555 recommendations.

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

562

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Footnotes

647

¹At the time that this research was collected Stephen R. Bsted was working on his

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652

²Although the movement constraint hypothesis does not specify whether constraining of

653

endpoints at the first target is due to programming or online feedback based error correction

654

processes, the present study investigated the effect of trial sequencing on these processes by

655

parsing movements into time before and after peak velocity (Chua & Elliott, 1993).

656

³As per Hansen, Elliott, & Khan (2008), in the y axis (extent) target undershoot was -ve

657

and target overshoot +ve, in the x axis (direction) error to the right of the target was +ve and

658

error to the left of the target was -ve. Ea1 and Ea2 were measured by calculating ellipse areas

659

using within-subject standard deviations of the x and y positions at the end of the movement (Ea

660

= $\pi \times SD_x \times SD_y$) written as mm². EvPV1 and EvPV2 were calculated using the within-subject

661

standard deviations of the positions of the x, y, and z axis at peak velocity (EvPV = $\pi \times SD_x \times$

662

$SD_y \times SD_z$) and is written as mm³ because of the three dimensional values used.