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Short note

Impact forces of one- and two-element target-aiming responses

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Abstract

The aim of this study was to test the target impact constraint hypothesis of the one-target advantage. The one-target advantage phenomenon reflects the finding that movements to a single target show shorter movement times than similar movements followed by a second movement toward a second target. The target impact constraint hypothesis attributes this phenomenon to differences in passive deceleration through impact with target. Specifically, larger impact forces for one-element responses than for two-element responses are hypothesized. The present study tested this hypothesis directly by measuring impact forces for one- and two-element responses. Results did not reveal any significant differences in amount of impact force as a function of response type, and, hence, did not support the target impact constraint hypothesis.

PsycINFO classification: 2330

Keywords: Impact force; Movement time; Motor control; Response execution

1. Introduction

Several researchers have reported that movements to a single target show shorter movement times than similar movements followed by a second move-
ment to a second target (e.g., Adam et al., 1993; Chamberlin and Magill, 1989; Fischman and Reeve, 1992). Even though the robustness of this *one-target advantage* phenomenon is no matter of dispute, theoretical explanation has sparked much debate.

Chamberlin and Magill (1989) interpreted the phenomenon as evidence for on-line programming of the second movement during execution of the first movement. Fischman and Reeve (1992) tested the on-line programming hypothesis by allowing subjects an unlimited amount of planning time before response initiation and by simplifying the second movement (the stylus had to be positioned above the second target instead of striking it). Even with this minimal need for on-line programming the one-target advantage remained present. On the basis of this finding, Fischman and Reeve (1992) argued for an alternative hypothesis, claiming that the requirement of producing a second movement constrains execution of the first. Specifically, according to Fischman and Reeve (1992), subjects facing a two-element response, might adopt a strategy of restraining the limb as it approaches the first target in order to smoothly and quickly execute the second movement.

Following the work of Teasdale and Schmidt (1991), who introduced *impact with target* as an important control parameter in movement organization, Adam et al. (1993) formulated a more explicit version of the constraint notion: the *target impact constraint hypothesis*. According to this hypothesis, the one-target advantage is the consequence of a motor control organization in which one-element aiming responses exploit *impact with target* as a passive control mechanism to decelerate the limb. Consequently, one-element movements might allow longer acceleration phases, larger peak velocities, and smaller deceleration phases than corresponding movements in a two-element response, hence producing the one-target advantage. Note that, according to this logic, passive deceleration through impact with target might not be an efficient strategy in a two-element response, because hitting the first target with a large impact may hinder release from this target and delay initiation and smooth execution of the second movement. Therefore, according to the target impact constraint hypothesis, the initial movement in a two-element response should be characterized by a relatively large portion of active deceleration in order to ensure impact forces that are small enough to not (or to a minimal extent) interfere with quick and smooth initiation of the second movement.

Adam et al. (1993) tested the *target impact constraint hypothesis* by asking subjects to make discrete (one-element) and reciprocal (two-element) sliding movements while manipulating the opportunity for passive deceleration through target impact by the presence or absence of a mechanical stop at the first target.
Kinematic analyses of the movements toward small targets (3 mm) showed indeed that when physical constraints of the task allowed passive deceleration through target impact, one-element movements were characterized by longer acceleration phases, larger peak velocities, and shorter deceleration phases than corresponding movements in the two-element response. When task constraints did not permit passive deceleration through target impact there was no one-target advantage. These outcomes were in line with the target impact constraint hypothesis.

The goal of the present study was to provide a more direct test of the target impact constraint hypothesis by measuring the amount of impact force at the first target. In the one-target (one-element response) condition, subjects only had to move to the first target and stop there. In the two-target (two-element response) condition, subjects first had to hit the initial target and then the second target. The target impact constraint hypothesis would predict larger impact forces in the one-target than the two-target condition, because the one-element response would rely to a greater extent on passive deceleration through target impact than the two-element response.

Since target size has been shown to influence movement time and the relative duration of the acceleration and deceleration phases (Adam, 1992; Adam et al., 1993; MacKenzie et al., 1987), target size was also manipulated by employing small, medium, and large targets (6, 12, and 24 mm, respectively).

2. Method

2.1. Subjects

Fourteen students (13 male and 1 female) participated as volunteers. They ranged in age from 20 to 26 years. All were right-handed and none had any previous experience with the task.

2.2. Apparatus

The apparatus consisted of a black, synthetic 30 × 60 cm box mounted on an 85 cm high table. For each target size, a specific target plate was constructed containing two circular copper targets. This target plate was placed on top of the box. The copper targets had diameters of 6 mm (small), 12 mm (medium), or 24 mm (large). A distance of 10 cm separated the centers of the two targets. A starting position was defined in the form of a small (diameter 4 mm) copper
disc, located 10 cm to the right of the right target. The aluminium stylus weighed 103 gram and had the shape of a pencil.

Movement time registration took place by means of an electrical circuit. This circuit included the starting position, the two targets and the stylus. Impact force on the first target was measured by four strain gauges built in a simple DC Wheatstone bridge arrangement. The gauges were located on four plates, surrounding the center of the target, and were oriented to measure forces perpendicular to the surface of the target. A calibration session ensured that the bridge was linear within the range of interest.

The stylus, target plates, and Wheatstone bridge arrangement were interfaced with an IBM-AT computer. Sampling rate was 4000 Hz.

2.3. Procedure

Subjects stood in front of a table on which the aiming apparatus was mounted. They were asked to hold the stylus up-right (i.e., vertically) with their right hand, and to place the stylus at the starting position. The goal was either to move as quickly as possible to the first target and stop (i.e., the one-element response) or to strike the first target and move on to the second target (i.e., the two-element response). In order to ensure optimal response preparation, response initiation was under subject control.

Three target sizes (6, 12, and 24 mm) were combined with two response types (the one-element and two-element response), resulting in six movement conditions. All subjects performed in all six conditions, creating a complete within-subject design. Subjects performed 5 practice trials followed by 10 test trials in each condition. Intertrial intervals were about 20 s. A trial was repeated if a subject missed a target. Order of movement conditions was random with the restriction that one- and two-element responses at a specific target size always followed each other.

2.4. Data analysis

The analogue voltage signals derived from the strain gauges were amplified, low-pass filtered with a cutoff frequency of 2 kHz, and then sampled (4 kHz) and digitized by means of a DAQ board (AT-2150-C + ). The resulting force

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In total, 5.2% of all trials were repeated. Small targets were missed more often than medium and large targets (11.4%, 3.9%, and 0.4%, respectively).
signal showed two clearly distinguishable components (see Fig. 1). First, a narrow, short duration (about 2–3 ms), high frequency ‘peak’ force signal that reflected impact (collision) of the stylus with the target. Second, a broad, longer duration (about 60–200 ms), low frequency force signal that reflected continued contact of the stylus with the target. Only the first signal was considered in this study. From this signal the maximal impact force was obtained ($F_{\text{max}}$) and the impact impulse ($\int F dt$), which integrates impact force over time.  

In addition to the above measures of target impact, the following dependent measures were calculated: (1) movement time 1 (MT1): the interval between departure of the stylus on the starting point and arrival on the first target; (2) movement time 2 (MT2): the interval between departure of the stylus on the first target and arrival on the second target.

The rationale for including impact impulse in the present analysis was the very short duration of the ‘peak’ force signal which might render accurate sampling of $F_{\text{max}}$ difficult. The impact impulse ($\int F dt$), which integrates impact force over time, attenuates this potential problem by incorporating a larger number of samples. The strong correlation between $F_{\text{max}}$ and $\int F dt$ ($r = 0.92$), however, suggests that the present sampling rate (4000 Hz) was sufficiently high to reliably assess $F_{\text{max}}$. Moreover, it should be noted that, because $\int F dt = \text{mass} \cdot \text{velocity}$, impact impulse can be considered a direct index of impact velocity of the stylus.

Fig. 1. Example of the force signal recorded on the first target during a two-element aiming response toward large targets. The short duration, ‘peak’ force signal reflects impact (collision) of the stylus with the first target.
target and arrival on the second target; (3) dwell time: the amount of time the stylus was in physical contact with the first target. All dependent measures were formed from the average of the subject’s 10 test trials.

The dependent variables MT1, impact force ($F_{\text{max}}$) and impact impulse ($\int F \, dt$) were entered in a 2 (response type) $\times$ 3 (target size) within-subject analysis of variance (ANOVA). Whenever appropriate, the Huynh–Feldt correction was applied in order to control for violations of assumptions of homogeneity of variance and covariance.

3. Results

Mean values of the different movement characteristics as a function of response type and target size are presented in Table 1.

3.1. MT1

The significant main effect of target size, $F(2,26) = 67.69$, $p < 0.001$, indicated longer movement times for smaller targets (381, 474, and 583 ms for large, medium, and small targets, respectively). More importantly, the significant main effect of response type, $F(1,13) = 21.14$, $p < 0.001$, indicated that MT1 was significantly shorter for the one-element response ($M = 461$ ms) than for the two-element response ($M = 498$ ms). This one-target advantage phenomenon of 37 ms was independent of target size as indicated by the absence of an interaction between type of response and target size, $F(2,26) = 0.68$, $p > 0.5$.

<table>
<thead>
<tr>
<th>Number of targets</th>
<th>Target size</th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
<td>Medium</td>
<td>Large</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>MT1 (ms)</td>
<td>559</td>
<td>607</td>
<td>457</td>
<td>491</td>
<td>366</td>
</tr>
<tr>
<td>$F_{\text{max}}$ (N)</td>
<td>60</td>
<td>54</td>
<td>73</td>
<td>74</td>
<td>88</td>
</tr>
<tr>
<td>$\int F , dt$ (N$\cdot$ms)</td>
<td>35</td>
<td>33</td>
<td>44</td>
<td>43</td>
<td>57</td>
</tr>
<tr>
<td>Dwell time (ms)</td>
<td>108</td>
<td>80</td>
<td>61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MT2 (ms)</td>
<td>563</td>
<td>413</td>
<td>345</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MT1 = movement time to first target; MT2 = movement time to second target.
3.2. Impact

The significant main effect of target size, $F(2,26) = 14.95$, $p < 0.001$, indicated progressively greater impact forces ($F_{\text{max}}$) for larger targets (57, 74, and 89 N for small, medium, and large targets, respectively). Most importantly, however, the main effect of response type was not significant, $F(1,13) < 1$, $p > 0.4$. This outcome demonstrated that impact forces ($F_{\text{max}}$) for the one-element response ($M = 73.6$ N) were not significantly different from those for the two-element response ($M = 72.3$ N). There was no interaction between response type and target size, $F(2,26) = 1.91$, $p > 0.15$.

A similar picture emerged for impact impulse ($\int F \, dt$). Larger impact impulses for larger targets, $F(2,26) = 13.99$, $p < 0.001$ (34, 44, and 55 Nms for small, medium, and large targets, respectively), but no main effect for response type, $F(1,13) = 2.33$, $p > 0.1$ (45.1 and 43.6 Nms for the one- and two-element response, respectively), nor an interaction between response type and target size, $F(2,26) = 0.62$, $p > 0.5$.

3.3. Dwell time and MT2

Both dwell time and MT2 increased significantly as a function of decreasing target size (see Table 1; $F(2,26) = 9.96$, $p < 0.01$ and $F(2,26) = 43.29$, $p < 0.001$, respectively).

4. Discussion

Impact force and impact impulse varied systematically as a function of target size and movement time. That is, the smaller the targets, the slower the movements and the smaller the amount of impact at target 1. This finding is in agreement with the observations of Worringham (1987) and supports the idea of a more precise and controlled target approach for smaller targets.

However, and most importantly, no differences were found between one- and two-element responses in terms of the amount of impact at target 1. Specifically, the critical finding of this study was that the observed one-target advantage was not associated with observable differences in impact. This outcome is at odds with the target impact constraint hypothesis. Apparently, subjects do not hit the first target in a one-element response with a larger impact force than the corresponding movement in a two-element response. This conclusion raises two issues.
First, how to reconcile the present findings with the results of our previous study (Adam et al., 1993), which showed that shorter MT1s of a one-element response were characterized by a larger peak velocity and a shorter normalized deceleration phase than the corresponding movement in a two-element response. Two observations seem relevant. First, larger peak velocities and shorter normalized deceleration phases might not necessarily translate to larger impact forces. It is logically possible that larger peak velocities and shorter normalized deceleration phases are compensated for (neutralized) by larger (i.e., more powerful) active deceleration forces in order to ensure a 'soft' landing. Second, the observed discrepancy might, perhaps, be related to differences in movement requirements. Adam et al. (1993) used sliding movements over the surface of a digitizer, and, moreover, employed a two-element response that required the second movement to reverse movement direction on the first target. In contrast, the present study used tapping movements through the air, and the two-element response required subjects to continue the second movement in the direction of the first movement. Evidently, the control mechanisms underlying reversals of sliding movements and continuations of tapping movements might be substantially different (see e.g., Adam et al., 1995; Enoka, 1988). Acknowledging these differences, Adam et al. (1993) cautioned that their findings and interpretations might not generalize to multi-element movements executed in the same direction.

Given that the target impact constraint hypothesis does not seem to be a viable account of the one-target advantage, the second issue raised by the present findings is the question of an alternative interpretation. Perhaps, a promising direction for alternative interpretation would be an approach that focuses on the kinematics of the one-target advantage. Insight into the details of the kinematic profile of one- and two-element tapping responses (especially velocity-time and acceleration-time functions) might reveal where in the movement and how the one-target advantage phenomenon manifests itself.

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References


