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# Preparation and execution of manual sequential aiming movements under conditions of response uncertainty

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Preparation and execution of manual sequential aiming movements under conditions of  
response uncertainty

By

Stephen R. Bested

A Thesis  
Submitted to the Faculty of Graduate Studies Research  
through the Department of Kinesiology  
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Windsor, Ontario, Canada

2014

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Preparation and execution of manual sequential aiming movements under conditions of  
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## DECLARATION OF ORIGINALITY

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## ABSTRACT

When moving from a starting position to a single target, movement time is faster than when you must continue the movement on to a second target (i.e., one-target advantage). Processes underlying both the movement integration and constraint hypotheses account for the preparation and control of sequential aiming movements. In the present experiments, we investigate the time course of these processes by varying the number of targets and target size during movement preparation and execution. Aiming movements with a stylus to one or two targets on a horizontally positioned touch screen were performed. Results revealed the emergence of the OTA only when participants knew the number of targets in advance of target presentation. It appears that the integration between the first and second segments and the constraining of limb trajectories was determined in advance of movement initiation. Implications for the results to the movement integration and movement constraint hypotheses are discussed.

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

## DEDICATION

I would like to dedicate this to my Mom and Dad. Without your support I would not be where I am today. A big thank you goes out to my Windsor Family for all of the incredible support throughout my six years here in Windsor. I would also like to dedicate this to Lauren for putting up with my long hours spent in the lab completing this and for your continuing support throughout my PhD. You are amazing! Lastly, thank you Michael for being an amazing advisor and friend the past two years. Looking forward to many more laughs in the future.

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## CHAPTER I

### OVERVIEW AND BACKGROUND OF THE STUDY

#### *Introduction*

Everyday actions contain several movement segments that are performed in series (e.g., picking up a glass of water and then drinking it, turning on a light switch and opening a door, catching and then throwing a ball). As the number of movement segments or elements increase, RT increases accordingly (Henry & Rogers, 1960). One explanation of this finding is that as the movement becomes more complex, participants need more time to program complex movements (Henry & Rogers, 1960). In addition to the increase in RT, increasing the number of segments influences how the first movement segment is executed (Fischman, 1984; Sternberg, Monsell, Knoll, & Wright, 1978). Typically, movement time is faster to the first target compared to when you must continue movement on to a second target (i.e., one-target advantage: Adam, Nieuwenstein, Huys, Paas, Kingma, Willems, & Werry, 2000). This study hopes to advance our understanding of how these multiple segment movements are prepared and executed.

#### *Reaction Time (RT)*

Response programming is considered to be a component of RT, which changes as a result of task complexity (Henry & Rogers, 1960; Klapp & Rodriguez, 1982; Klapp, 1995). Even though it has been found that as the complexity of the task increases there is a corresponding increase in RT, there is still a lack of evidence as to what component of

response complexity is responsible for this increase in RT (Henry & Rogers, 1960; Klapp & Rodriguez, 1982; Klapp, 1995). In this regard, researchers have investigated the specific effects of the number of components in a movement (Adam et al., 2000, Fischman, 1984; Rand, Alberts, Stemplach, & Bloedel, 1997; Sternberg et al., 1978), target accuracy (Lajoie & Franks, 1997; Sidaway, 1991), or response duration (Klapp & Erwin, 1976) on reaction time.

In order to investigate the influence of response complexity on RT, Klapp (1995) investigated how the number of elements and duration of the task varies between Simple and Choice RT. Conducting a series of Morse code responses, Klapp (1995) found that Simple RT did not differ between the dit versus dah (single-element) responses but did increase as the number of response elements increased (i.e. dit versus dit-dah- dah- dit). Choice RT was not affected by the number of response elements. However, duration of the single-element responses did influence choice RT. In order to explain these results, Klapp (1995) proposed a two-process model of response programming. The first process in the response programming model consisted of INT which was the programming of the internal features of a chunk (i.e., the duration of the dit or dah component in a dit-dah-dah-dit response). The second process in the response programming model was SEQ which was the ordering of these elements (i.e., the order of the dit-dah-dah-dit response). During Simple RT, INT would be programmed prior to the stimulus and SEQ would be executed during RT. As a result of this, Simple RT is influenced by the number of elements because INT was performed prior to the RT interval and SEQ takes longer to implement as the number of components increases (Klapp, 1995). For Choice RT tasks, neither INT nor SEQ can be pre-programmed prior to RT so it is assumed they must

occur in parallel during RT. Since INT takes longer than SEQ to perform, the duration of individual components impacts Choice RT (Klapp, 1995).

Following his study on Morse code responses, Klapp (2003) extended his investigation to speech articulation responses. This study revealed that when syllables could be easily grouped (i.e. chunked) together, Simple RT did not increase if the number of syllables increased, but Choice RT did. However, when the task did not favour the integration of syllables, Simple RT increased as the number of syllables increased but not Choice RT. When the number of syllables but not the internal features of the syllables were known in advance, this affected Choice RT but not Simple RT.

The finding that Choice RT relied on the number of syllables was inconsistent with Klapp's (1995) original interpretation that INT and SEQ both occurred in parallel and that INT took longer than SEQ thus influencing RT. To account for this, Klapp (2003) revised his theory proposing that instead of sequencing the number of elements or chunks, SEQ actually scans an abstract time frame. This abstract time frame specifies the order of each chunk without specific reference to the internal features of the chunks or segments. For Simple RT tasks, this time frame (SEQ) is loaded into a buffer prior to the presentation of the stimulus. During RT, SEQ is activated and scanning occurs in order to locate the starting point. Scanning time increases as the number of elements increases. For Choice RT where the number of elements is not known, the abstract time frame is retrieved during the RT interval and does not need to be scanned. Hence, Choice RT is not influenced by the number of elements.

Findings similar to Klapp (1995, 2003) have been observed in studies employing rapid aiming movements. For example, Khan, Lawrence, Buckolz, & Franks (2006)

showed that Simple RT but not Choice RT was influenced by the number of targets in an aiming sequence. Furthermore, Khan, Mourton, Buckolz, & Franks (2008a) were interested in knowing if advance information about the number of elements was an important factor on not only RT but the programming and execution of the movement. In this study participants were told in advance the number of elements in the movement, the amplitude of the movement, the number of elements and movement amplitude, or no information was given prior to the stimulus. Similar to Klapp (2003), when the entire response was cued, RT's increased as the number of elements increased. RT also increased when participants were informed in advance about the number of targets but not the amplitude of the targets. However, RT did not increase as a function of the number of elements when just the amplitude of the movement was given in advance or no information was given. These results showed that RT was only influenced when the number of elements was known in advance (Khan et al., 2008a).

In summary, it has been found in previous research that as the number of elements increase, RT increases when the number of elements is known in advance (Khan et al., 2006; Khan et al., 2008a; Klapp, 1995; Klapp, 2003). Also, RT increases when the number of elements is known in advance but not other features of the responses. RT is not affected when the number of elements is not known in advance (Khan et al., 2006; Khan et al., 2008a; Klapp, 2003).

#### *One-Target Movement time Advantage (OTA)*

As stated earlier, movement time is faster to a first target compared to when you must continue movement on to a second target (Adam, et al., 2000). It has been theorized

that this one-target advantage (OTA) is a result of programming prior to the movement and online processes that occur during movement execution. The Movement Integration Hypothesis states that response elements are stored in a buffer before the initiation of the response (Adam et al., 2000). In order for the movement to be as fluent as possible, the implementation of the second segment is performed online while the execution of the first movement is still taking place. This overlap of processes causes interference and therefore an increase in movement times to the first target (Adam et al., 2000). As an alternative to the Movement Integration Hypothesis, the Movement Constraint Hypothesis is based on the premise that variability increases as the movement progresses. Hence, in order to meet accuracy demands at the second target, the movement toward the first target must be constrained (Fischmand & Reeve, 1992). Reducing variability at the first target is achieved at the expense of longer movement times. Through a series of experiments, Adam et al. (2000) revealed that distance to the targets had no effect on the one-target advantage. However, reducing the target size of the first target did in fact eliminate the OTA. When the first target was small, pause times at the first target were increased thus separating the first and second target movements.

While the OTA for tasks in which the second target is in the same direction as the first (i.e. extension), Adam et al. (2000) showed that a two-target advantage emerged when participants moved out to the first target and then moved backwards to a second target. One explanation of this finding is that antagonist muscles that decelerate the first movement also acted as the agonist, accelerating the second movement resulting in a highly integrated movement (Adam et al., 2000).



Most research investigating the OTA has employed the use of one limb. Khan et al. (2010) examined whether the OTA would also emerge when the first and second movement segments were performed with different limbs. In this experiment, participants initiated the movement to the first target with their right limb and then switched to the left limb for the second movement segment. It was hypothesized that if the OTA was due to central processes, then the OTA would still emerge when the first and second movement segments were performed using different limbs. They showed that the use of two-limbs increased the time that was taken in order to initiate and execute the first movement in the two target sequence. Hence the OTA was present for both single and two limb conditions supporting the idea that the OTA is due to interference at a central level.

According to both the Movement Integration and Movement Constraint Hypotheses, segments are not controlled or prepared separately (Adam, Paas, Eyssem, Slingerland, Bekkering, & Drost, 1995; Khan et al., 2011; Rand, et al., 1997; Rand & Stemplach, 2000). In order to show the link between these two movements, Khan et al. (2011) investigated the role that vision had on sequential aiming movements. They proposed that vision had a dual role in these movements. First, visual feedback was used to correct errors in the limb trajectory towards the target. This resulted in a reduction of spatial variability at the targets (Also see, Sidaway, Sekiya, & Fairweather, 1995). The second influence that vision had on the sequential aiming movement task was the integration between the two response elements (Khan et al., 2011). As mentioned, the reduction of variability at the first target would have enhanced the transition between the first movement segment, and ensured accuracy at the second target (i.e. Movement Constraint hypothesis). Even if correction of the movement is occurring at the first target

due to online processes, the amplitude of the second target must be adjusted according to the end point of the first movement segment. For example, if one undershoots the first target one must increase the distance to the second target in order to be accurate and vice versa. When vision was available, this gave participants feedback of the location of the end of the movements allowing for parameters of the second movement segment to be modified accordingly. Hence, vision enabled the two segments to be performed as one fluent movement resulting in a smooth transition from the first movement segment to the second. This indicated that vision not only helps with error correction, but also helps with the integration of the two movement segments.

### *Purpose*

The purpose of the present study was to further investigate what processes occur prior to movement initiation and during movement execution. According to the Movement Integration Hypothesis, the two movement segments are constructed and loaded into a buffer prior to movement execution, but the implementation of the second movement occurs during the execution of the first element (Adam et al., 2000). Although the Movement Integration Hypothesis offers assumptions on when processes occur, the Movement Constraint Hypothesis does not specify whether the constraining of limb trajectories occurs during movement planning or during movement execution.

Prior research has shown that when participants know the number of elements in advance, RT is longer for a dual compared to a one target response (Khan et al., 2006; Khan et al., 2008a). This increase in RT did not occur when participants did not know the number of movement segments in advance (Khan et al., 2006; Khan et al., 2008a). Khan

et al. (2006) also showed that when participants knew in advance when a two target sequence was required, the first segment was programmed with a longer duration in order to monitor the movement to the first target and enhance integration between the first and second segments.

Consistent with the Movement Integration Hypothesis, Bested, Khan, Lawrence, Adam, & Buckolz (2014) reported that the OTA emerged when one and two target movements were presented in a blocked (i.e., 1,1,1,2,2,2) and alternating (i.e., 1,2,1,2,1,2) trial sequence. The OTA however did not emerge for random (i.e., 1,2,2,1,1,2) trial sequences. This research suggests that participants must know in advance the number of targets for the one-target advantage to emerge. While previous research has typically investigated the OTA by employing trial sequences in which single and two target movements are blocked, the extent to which movement segments are integrated under random trial sequences is not understood.

In the present study, a perturbation paradigm was employed to investigate preparatory and control processes when the number of segments is not known in advance. In a previous study, Khan, Tremblay, Cheng, Luis, & Mourton (2008b) perturbed the number of targets to investigate the preparation of a one and two-target movement, but with a two-target reversal movement instead of an extension. Their experiment was designed in order to understand if a reversal movement would be organized as a single action or as two separate movements. To do this, they changed the number of targets prior to the movement and during the actual movement itself (i.e., adding a second target). Four trial types were performed; one was a single-element trial, and the other three consisted of dual-element trials [i.e., simultaneous (both targets appeared at the

same time), movement onset (one target appeared, then as soon as movement began the second target appeared), and movement onset + 75ms (similar to movement onset but with a delay of 75ms)]. They found that movement time to the first target was the shortest when the second target was presented simultaneously with the first target during stimuli onset. As a result of how highly integrated these movements were with the reversal, a two-target advantage emerged (Khan et al., 2008b). This showed that the two-target movement time advantage existed only when both targets were shown at the same time. From this, Khan et al. (2008b) concluded that once movement onset had been initiated, it was difficult for participants to switch their movement patterns depending on the task demands.

Following from Khan et al. (2008b), the first experiment in this study consisted of four different trial types but with an extension movement instead of a reversal movement. In reversal movements, the integration of movement segments occurs at a peripheral level whereby the antagonist on the first segment acts as the agonist for the second segment. In contrast, Khan et al. (2010) have proposed a central locus of integration between movement segments for extension movements. Four trial types were performed; one being a single-element trial, and the other three consisted of dual-element trials [i.e., simultaneous (both targets appeared at the same time), movement onset (one target appeared then as soon as movement began the second target appeared), and movement onset + 75ms (similar movement onset but with a delay of 75 ms)]. In Experiment 2, the procedures remained the same but the second target was reduced in size from 2 ½ to 1cm during movement onset and movement onset + 75ms conditions. Also, there were two SIM conditions, one in which the second target was small and the other in which the

second target was large. As a result of conducting these two experiments, we hoped to not only understand what processes occur prior to movement initiation and during movement execution but when the constraining of these movements occurs.

To recap, the OTA has been shown in several studies (Adam et al., 2000; Bested et al., 2014; Fischmand & Reeve, 1992; Khan et al., 2006; Khan et al., 2008a; Khan et al., 2008b; Khan et al., 2010; Khan et al., 2011). The question of whether or not these movements are programmed prior to movement onset, or during the movement itself, remains unclear (Adam et al., 2000; Fischmand & Reeve, 1992; Khan et al., 2006; Khan et al., 2008a; Khan et al., 2008b; Khan et al., 2010, Khan et al., 2011). Also of interest is why the OTA emerges during a blocked and alternate sequencing but not during a random trial order (Bested et al., 2014). Using a paradigm similar to Khan et al., (2008b) but using an extension movement instead of a reversal movement, we hoped to not only analyze how integrated these two movements are, but when the programming of these movements occurred. Manipulating the second target size at different times will also help to understand when accuracy demands at the second target had an influence on constraining movements to the first target.

### *Hypotheses*

- OTA will emerge under blocked but not random conditions.
- There will be an efficient transition between elements when the number of targets is specified before movement execution (i.e., short pause times).
- Changing the number of targets at or after movement initiation will result in longer pause times at the first target.

- Movements to the first target will be constrained when the second target appears or changes size at or prior to movement integration (i.e., when the second movement is executed or organized).

## CHAPTER II

### METHODOLOGY

#### *Participants*

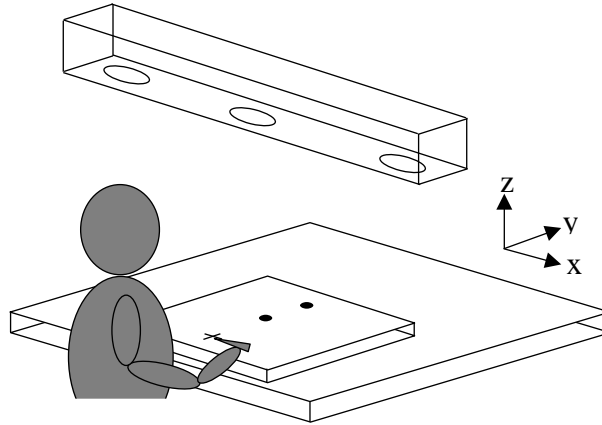
A total of 54 participants (24 in Experiment 1, 30 in Experiment 2) including both male and female University of Windsor Faculty of Human Kinetics students (19-29 yrs.) were recruited for this study. Participants were recruited by making announcements about the study during Human Kinetics classes. All participants were self-declared right hand dominant. Participants were debriefed as to what would occur during the study and signed the Consent to Participate in Research as required by Ethics (**See Appendix C**).

#### *Apparatus*

Participants were seated at a table that was 76 cm above the ground with a touch screen (21.5 cm wide x 28.5 cm long) placed flat on the table 6cm from the edge (**See Appendix A**). Participants were positioned so that their midline was centered with the middle of the touch screen and used a hand-held stylus throughout the experiment to aim to the targets. A NDI 3D Investigator (or Optotrak) was positioned on the ceiling above the table (173 cm). This three-dimensional movement analysis system uses infrared light being emitted from markers in order to track the position and movements of the participants at a sampling rate of 500 Hz. These markers were attached to a reference plane that determined where the tip of the stylus was at all times.

On the touch screen, a start position consisting of a cross (1.3 cm in diameter) and two targets were displayed (**See Figure 1**). The start position was located 4 cm (from the

center of the cross) from the proximal edge of the touch screen and in-line with the participant's body midline. The first target was located 8 cm from the start position away from the body (center to center). The second target was 8 cm from the first target (center to center). Target sizes are specified within each experiment.



**Fig. 1.** Schematic diagram 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.



CHAPTER III  
EXPERIMENT 1

*Procedures*

Participants were debriefed as to what would occur during the study and signed the Consent to Participate in research as required by Ethics (**See Appendix C**). Before testing began, participants filled out a basic demographic questionnaire. (**See Appendix B**).

To begin each trial, the start position appeared. The participants were asked to align the stylus with the center of the cross. Once aligned, a tone sounded, which acted as a warning signal for the participant. The targets were presented following an adjustable foreperiod of 1,500 - 2,500 ms.

During the experiment, four different trial types were performed with two targets 2 ½ cm in diameter. All movements were performed as an extension from the center of the participant outward. The four trial types consisted of a one-target (1T) single-element (SE) trial, and the other three consisted of two-target (2T) dual-element trials (i.e., simultaneous (SIM), movement onset (MO), and movement onset + 75ms (MO+75)). For the 1T(SE) trials, the first target was only presented. Participants were asked to lift the stylus from the start position and touch-down at the first target as quickly and accurately as possible. In the 2T(SIM) trials, both targets were displayed simultaneously. Participants were required to move to the first target and then extend their movement to the second target while coming to a complete stop at the second target. In the 2T(MO) trials, the first target was displayed at the starting position but the second target did not

appear until movement onset. For the 2T(MO+75), similar to the 2T(MO) trials, the second target did not appear until 75ms after the stylus has left the starting position. In order to make sure that instructions were given consistently, a script was read prior to practice and the testing trials (**See Appendix D**).

Prior to the testing trials, participants were given 40 blocked trials consisting of 20 1T(SE) trials and 20 2T(SIM) trials. The first four trials of all movements in the blocked and testing trials were eliminated from the analysis to account for a familiarization period to the task. The test phase involved 160 trials (100 1T(SE), 20 2T(SIM), 20 2T(MO), and 20 2T(MO+75) trials). All of these trials were randomized so that every eight trials contained five 1T(SE) trials and each of the three 2T trials (SIM, MO, and MO+75). Participants were instructed to prepare for a single target response prior to stimulus onset and to perform two target responses if a second target was to appear.

### *Data Reduction*

Filtering of the 3D position data acquired from the Optotrak was done by using a second order, dual-pass Butterworth filter with a 16Hz low pass cut-off frequency. Position data was then differentiated to obtain velocity information. Peak resultant velocity was identified for movements to each target. Location of the start of the movement was identified by working back from peak velocity in the vertical direction (i.e., z-axis) until a point that velocity was less than 15mm/s. The first movement end point was located when the peak velocity in the vertical direction fell below 15mm/s after peak velocity. This was then repeated to identify the start and end of the second

movement segment for the two-target condition. Positions at the end of each movement and at peak resultant velocity were recorded in the primary direction of movement (i.e. y-axis) and perpendicular to the primary direction (x-axis) (Khan, et al., 2011).

### *Dependent Measures*

Our dependent measures consisted of (RT), movement time to the first target (MT1), movement time from the first to the second target (MT2), pause time at the first target (PT), constant errors in the primary direction of the movement measured from the center of the target (negative if undershot target or positive if overshoot the target (CEy1, CEy2)), constant error in the direction perpendicular to the primary direction movement (i.e., error to the right of the center of the target was positive and error to the left of the target is negative (CEx1, CEx2)). The kinematic variables peak velocity, time to peak velocity and time after peak velocity were also recorded. To investigate the overall variability in the x and y planes, ellipse areas were calculated at the end of each movement (EA1, EA2) and also at peak velocity (EAPKV1, EAPKV2). This was achieved by using participants standard deviations of the positions of the y and x axes for the end of the movement and using the x, y, z positions for the peak velocity ( $EA = \pi \times SDy \times SDx$ ,  $EAPKV = \pi \times SDy \times SDx \times SDz$ ) (Hansen, Elliott, & Khan, 2008).

### *Data Analysis*

The pre-test blocked condition was analyzed using a dependent t-test to test the difference between the one target and two target movements. For the random test trials, individual participant means and standard deviations (for ellipse areas) were submitted to

a repeated measures ANOVA with four levels (SE, SIM, MO, and MO+75). A Bonferroni post hoc analysis was conducted to locate significant differences. Statistical significance was assessed at  $p < .05$ .

**Results Experiment 1**

All means and standard deviations of all dependent variables are presented in

*Table 1* for both the blocked and random conditions.

**Table 1**

Experiment 1 Means (standard deviations) of reaction time (RT), movement time to the first target (MT1), y constant error at the first target (CEy1), x constant error at the first target (CEx1, time to peak velocity of the first movement (tPKV1), time after peak velocity of the first movement (taPKV1), peak velocity at the first target (PKV1), ellipsoid volume at peak velocity of the first movement segment (EvPKV1), ellipse area at the end of movement 1 (EaEnd1), hit percentage at target 1 (H%T1), pause time after the first movement at the first target (PT), movement time from the first to the second target (MT2), y constant error at the second target (CEy2), x constant error at the second target (CEx2), time to peak velocity of the second movement (tPKV2), time after peak velocity of the second movement (taPKV2), peak velocity at the second target (PKV2), ellipsoid volume at peak velocity of the second movement segment (EvPKV2), ellipse area at the end of movement 2 (EaEnd2), and hit percentage at target 2 (H%T2), for the one-target (1T) and two-target (2T) tasks in the blocked and the one-target [1T(SE)], simultaneous [2T( SIM)], movement onset (MO), and movement onset plus 75ms (MO + 75) random conditions.

	Blocked		Random			
	1T(SE)	2T(SIM)	1T(SE)	2T(SIM)	2T(MO)	2T(MO + 75)
RT (ms)	230 (32)	230 (33)	254 (40)	243 (35)	250 (37)	253 (46)
MT1 (ms)	190 (32)	224 (35)	210 (28)	205 (30)	210 (29)	210 (28)
CEy1 (mm)	-0.6 (3.6)	1.7 (3.3)	0.3 (3.2)	0.8 (3.3)	0.2 (3.6)	0.3 (3.1)
CEx1 (mm)	0.9 (2.4)	0.3 (2.1)	0.4 (2.2)	0.5 (2.1)	0.5 (2.2)	0.4 (2.0)
tPKV1 (ms)	78 (21)	93 (18)	87 (15)	85 (15)	88 (15)	87 (16)
taPKV1 (ms)	111 (27)	128 (30)	124 (21)	121 (23)	122 (22)	123 (21)
PKV1 (mm/s)	740 (79)	662 (66)	660 (72)	682 (65)	666 (76)	664 (70)
EvPKV1(mm <sup>3</sup> )	113 (78)	118 (87)	137 (73)	121 (83)	134 (97)	119 (84)
EaEnd1	28 (12)	22 (9)	23 (7)	22 (8)	25 (11)	20 (8.2)
H%T1	.99 (.01)	.99 (.05)	.99 (.005)	.99 (.01)	.99 (.01)	1 (0)
PT (ms)		49 (23)		72 (35)	134 (28)	196 (35)

MT2 (ms)	214 (28)	212 (23)	218 (28)	221 (29)
CEy2 (mm)	-1.0 (3.9)	-1.3 (4.1)	-1.8 (4.1)	0.13 (3.3)
CEx2 (mm)	0.3 (2.6)	-0.2 (1.8)	0.7 (2.3)	1.3 (3.8)
tPKV2 (ms)	105 (15)	102 (29)	101 (30)	99 (30)
taPKV2 (ms)	109 (21)	119 (31)	126 (29)	130 (28)
PKV2 (mm/s)	604 (98)	607 (89)	611 (98)	635 (115)
EvPKV2(mm <sup>3</sup> )	184 (124)	158 (83)	175 (101)	214 (149)
EaEnd2	32 (21)	27 (9)	31 (11)	25 (10)
H%T2	.99 (.01)	.99 (.02)	.99 (.01)	1 (0)

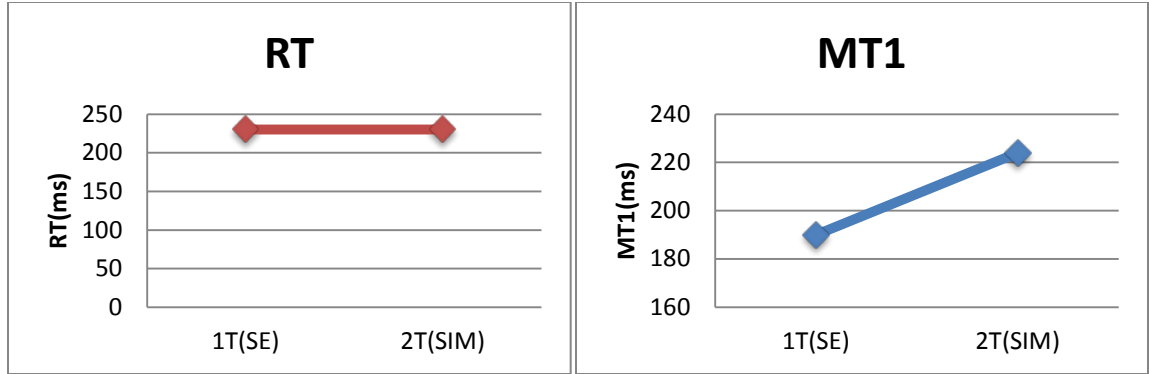
### **Blocked Condition**

#### *Reaction time*

The analysis of RT revealed a non-significant difference between the 1T(SE) movements (230 ms) and the 2T(SIM) movements (230 ms),  $t(23) = -.151$ ,  $p > .05$  (see *Figure 2*).

#### *Movement time*

The analysis of MT1 revealed significantly shorter movement times for the 1T(SE) movements (190ms) compared to the 2T(SIM) movements (224ms),  $t(23) = -6.379$ ,  $p < .001$  (see *Figure 2*).



**Fig. 2.** Reaction times (RTs) and Movement times during the first movement (MT1) of the blocked condition.

*Target hit rates*

There were no significant differences in target hit rates at the first target between the 1T(SE) movements (mean = .99) and 2T(SIM) movements (mean = .99),  $p > .05$ .

*Peak velocity*

The analysis of PKV1 revealed that peak velocities were higher for the 1T(SE) movements (740 mm/s) when compared to the 2T(SIM) movements (662 mm/s),  $t(23) = 4.412$ ,  $p < .001$ .

*Time to Peak velocity*

The analysis of TPKV1 revealed that peak velocity was reached earlier in the 1T(SE) movements (78ms) than the 2T(SIMS) movements (93ms),  $t(23) = -5.748$ ,  $p < .001$ .

*Time after Peak velocity*

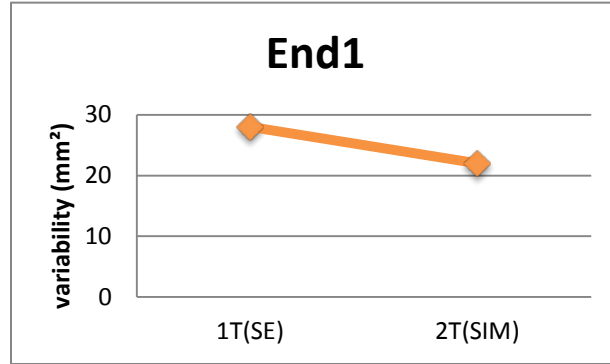
Analysis of taPKV1 also revealed that the time spent after peak velocity was shorter for the 1T(SE) movements (111 ms) when compared to the 2T(SIM) movements (128 ms),  $t(23) = -3.721$ ,  $p < .001$ .

*Time to Peak velocity / Time after Peak velocity*

There were no significant differences of tPKV1/taPKV1 during the first movement,  $p > .05$ .

*Variability*

The analysis of ellipsoid volume at peak velocity of the first movement revealed no significant difference between the 1T(SE) movements and the 2T(SIM) movements;  $t(23) = -.375, p > .05$ . The analysis of ellipse areas at the end of the first movement segment revealed that the 1T(SE) movements had higher variability at the first target ( $28\text{mm}^2$ ) when compared to the 2T(SIM) condition ( $22\text{mm}^2$ ),  $t(23) = 2.580, p < .05$ . This revealed that participants constrained their movements more at the first target for the 2 target compared to the 1 target movements (see *Figure 3*).



**Fig. 3.** Ellipse areas for the one-target (1T) and two-target (2T) tasks in the blocked condition at the end of the first movement (EaEnd1).

**Random Condition**

*Reaction time*

The analysis of RT revealed a significant main effect of condition,  $F(2.035, 46.808) = 7.590, p < .005$ . This main effect indicated that the 1T movements (254 ms), had longer RTs compared to the 2T(SIM) movements (243 ms). The 2T(SIM)

movements (243 ms) had shorter RTs when compared to the 2T(MO) movements (250 ms) and 2T(MO + 75) movements (253 ms) (see Figure 4).

*Movement time*

The analysis of MT1 revealed a significant main effect of condition,  $F(3, 69) = 7.178, p < .001$ . The 2T(SIM) movements (205 ms) had faster MT1s compared to all other conditions(see Figure 4). Analysis of MT2 approached statistical significance,  $F(1.197, 27.538) = 3.451, p = .067$ .

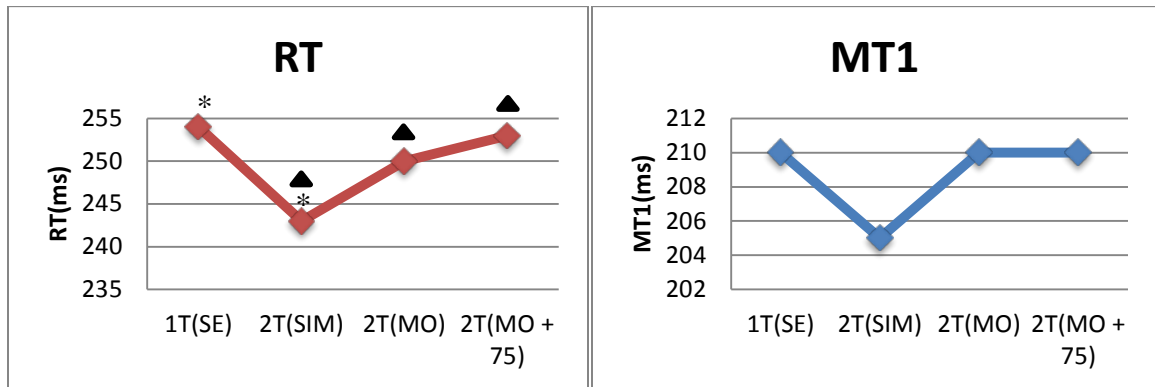


Fig. 4. Reaction times (RTs) and Movement times during the first movement (MT1) of the random condition.

*Pause time*

The analysis of PT revealed a significant main effect of condition,  $F(1.329, 30.571) = 146.434, p < .001$ . PTs increased in duration between the 2T(SIM) movements (72 ms), 2T(MO) movements (134 ms), and 2T(MO + 75) movements (196 ms).

*Target hit rates*

There was no significant difference in target hit rates at the first target for the one target movements (mean = .99),  $p > .05$ . The analysis of target hit rates at the second target also indicated no significant differences (mean = .99),  $p > .05$ .



*Peak velocity*

The analysis of PKV1 revealed a significant main effect of condition,  $F(1.825, 41.964) = 7.295$ ,  $p < .005$ . This main effect indicated that the 2T(SIM) movements (682 mm/s) had higher peak velocities compared to the 1T(SE) movements (660 mm/s),  $p < .005$ . There was no significant difference between the other movement types. The analysis of PKV2 approached significance,  $F(1.220, 28.058) = 3.832$ ,  $p = .053$ .

*Time to Peak velocity*

The analysis of TPKV1 revealed a significant main effect of condition,  $F(3, 69) = 5.193$ ,  $p < .005$ . Peak velocity was reached later in the 1T(SE) movements (87ms) than the 2T(SIM) movements (85ms). The analysis of TPKV2 revealed no significant main effect of condition,  $F(2, 46) = .732$ ,  $p > .05$ .

*Time after Peak velocity*

The analysis of taPKV1 revealed a non-significant main effect of condition,  $F(2.069, 47.597) = 1.960$ ,  $p > .05$ . The analysis of taPKV2 revealed a significant main effect of condition,  $F(1.267, 29.145) = 8.032$ ,  $p < .05$ . Breakdown of this main effect revealed that the time spent after peak velocity was shorter for the 2T(SIM) movements (119 ms) when compared to the 2T(MO + 75) movements (130 ms). Also, the time spent after peak velocity was shorter for the 2T(MO) movements (126 ms) when compared to the 2T(MO + 75) movements (130 ms).

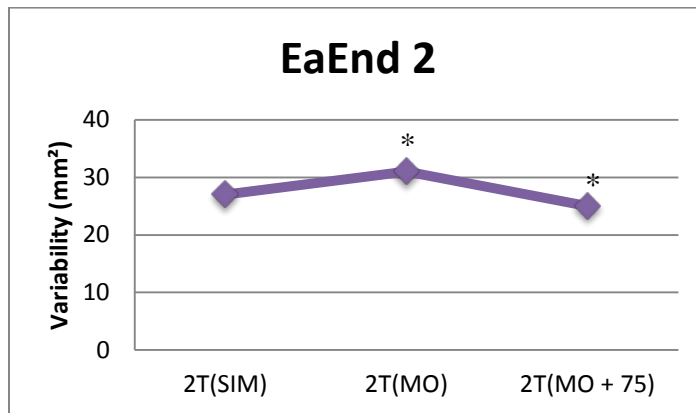
*Time to Peak velocity/ Time after Peak velocity*

Analysis of tPKV2/tapKV2 revealed a significant main effect of condition,  $F(1.599, 36.768) = 5.990, p < .01$ . 2T(SIM) movements (.912) had less corrections being made during the movement when compared to the 2T(MO + 75) movements (.796),  $p < .05$ .

*Variability*

The analysis of ellipsoid volume at peak velocity of the first movement revealed a non-significant main effect of condition,  $F(3, 69) = 1.108, p > .05$ . The analysis of ellipse areas at the end of the first movement segment also revealed a non-significant main effect of condition,  $F(1.577, 36.282) = 1.506, p > .05$ .

The analysis of ellipsoid volume at peak velocity of the second movement revealed a non-significant main effect of condition,  $F(2, 46) = 2.520, p > .05$ . The analysis of ellipse areas at the end of the second movement revealed a significant main effect of condition,  $F(2, 46) = 3.536, p < .05$ . This revealed that during the 2T(MO + 75) movements (25mm<sup>2</sup>), participants constrained their movements more when compared to the 2T(MO) movements (31mm<sup>2</sup>).



**Fig. 5.** Ellipse areas for the two-target (2T) tasks in the random condition at the end of the second movement (EaEnd2).

## **Discussion Experiment 1**

### *Blocked Condition*

Research has previously revealed that RT increases as the complexity of a task increases (i.e. one to a two-target movement) (Khan et al., 2006; Khan et al., 2008a; Klapp, 1995; Klapp, 2003). However, contradictory to previous literature, our study did not find an increase in RT when comparing the 1T(SE) movements to the 2T(SIM) movements during the blocked trials. Even though RT's in this study did not support previous literature, the MT1 results were consistent with previous studies. In past research, movement time was faster when moving to a single target compared to when one must continue their movement on to a second sequential target (Adam et al., 2000). When investigating multiple segment movements, the OTA has been shown to be robust (Adam, et., 2000; Khan et al., 2011; Khan et al., 2008a). In the present experiment, the one target advantage was also present as movement times to the first target in the 1T(SE) were shorter (190ms) when compared to the 2T(SIM) movement (224ms).

The present findings add support to both the movement integration and movement constraint hypotheses. It has been theorized that the OTA is a result of programming that occurs prior to the movement (Adam et al., 2000). The movement integration hypothesis states that responses are programmed and stored in a buffer prior to response initiation (Adam et al., 2000). Since in the blocked trials participants knew in advance the number of targets that were to appear, this allowed for the programming of the movements prior to stimulus onset and before a response was initiated. As a result of this pre-programming, execution of the second movement occurred during the first and caused

slower peak velocities in the 2T(SIM) first movement due to interference of the two processes. Not only did this interference result in slower velocities at the first movement but resulted in a longer time period for participants to reach their peak velocities and longer time spent after peak velocity. Since there were significant differences both prior to and after peak velocity it is hard to identify when the interference or second movement was integrated during the first. However, it is still clear that the integration of the second movement does in fact cause interference which resulted in longer movement times to the first target.

Alternatively, though integration may be the cause for the first movement to be slower during the 2T(SIM) blocked movement, there is evidence that supports the movement constraint hypothesis as well. The movement constraint hypothesis would suggest that in order for one to be accurate at the second target one must constrain their movements at the first. This results in longer movement times and the OTA to emerge (Fischmand & Reeve, 1992). This constraining of the first movement was present in our given study. Not only were movement times slower for the first movement in the 2T(SIM) when compared to the 1T(SE) movement, they also had more time after peak velocity during movement to the first target. During the 1T(SE) movement participants had shorter times (111ms) when compared to the 2T(SIM) movement (128ms). This finding also supports the movement constraint hypothesis because the extra time spent after peak velocity is the result of constraining at the first target. Furthermore, the key supporting evidence of constraining of the movement was identified by analyzing variability at the first target. This revealed that participants had more variability at the first target during the 1T(SE) movement (28mm<sup>2</sup>) when compared to the 2T(SIM)

movement (22mm<sup>2</sup>). Participants constrained their movements more at the first target during the 2T(SIM) movement in order to be accurate at the second target.

### *Random Condition*

As mentioned previously, when participants know in advance the number of targets, RT increases as the number of targets increases (Khan et al., 2006; Khan et al., 2008a; Klapp, 1995; Klapp, 2003). When investigating the OTA under conditions of response uncertainty in which the number of targets is not known in advance, Bested et al. (2014) found that there was no difference in RT across the different movements. However, the current findings revealed a different pattern of results. RT during the 1T(SE) was longer than the 2T(SIM) movement. It was also found that the 2T(SIM) movement had shorter RT's when compared to the 2T(MO) and 2T(MO + 75) movements. This finding suggests that participants may have adopted a strategy under conditions of response uncertainty of preparing for the worst case scenario (i.e., for the more complex two target movement).

Previous research has shown that the OTA does not emerge under random sequencing (Bested et al., 2014). The OTA emerged in the blocked condition and did not emerge under random sequencing. However, in our study a very small but significant two-target advantage emerged under the random sequencing. A two-target advantage is specified as when movement times to the first target are faster in a dual-element response when compared to a single-element response (Adam et al., 1993; Khan et al., 2006; Khan et al., 2008b). Not only was MT1 shorter in the 2T(SIM) movement when compared to all other movements but RT was also the shortest for the 2T(SIM) movement. This data

indicates that when participants were not informed in advance the number of targets, even when participants were instructed to prepare for the single target, participants still prepared for the 2T(SIM) condition. Similar to the Khan et al., (2008b) study, this revealed that the 2T(SIM) was programmed as a single unit of action and that once movement had been initiated it was very difficult to change how the movements were organised. This was demonstrated not only by MT1's and RT's but also by pause times. Pause times increased at the first target between the 2T(SIM) movements (72ms), 2T(MO) movements (134ms), and the 2T(MO = 75) movements (196ms). This revealed that participants had to separate the movement into two separate units when the task became more complex. Participants were not able to change how the movement was organised once executed and resulted in longer pause times at the first target in order to adjust as complexity of the movement increased.

Our research supports the notion that in order for the OTA to emerge, participants must know the number of movement segments that are to be executed in advance. This was shown by the OTA appearing under the blocked but not the random condition. Instead of the OTA not appearing in the random condition, a two-target advantage was present. Even though it was a small two-target advantage, this supports the idea that participants prepare for the worst case scenario as proposed by Bested et al., (2014).

## CHAPTER IV

### EXPERIMENT 2

#### *Procedures*

Experiment 2 had a similar paradigm to Experiment 1. However, instead of manipulating the number of targets, in this experiment the size of the second target was varied. During the experiment, five different trial types were performed with a 60% reduction in size occurring to the second target (i.e., from 2.5 to 1 cm). The first target always remained the same size of 2 ½ cm in diameter. Of the five trial types, one was a single-element trial, and the other four consisted of dual-element trials (i.e., simultaneous large second target (the first and second target were 2 ½ cm in diameter [SIML]), simultaneous small second target (the first target was again 2 ½ cm in diameter however the second target was 1 cm in diameter [SIMS]), movement onset (MO), and movement onset + 75ms (MO+75)). For the single-element (SE) trials, the first target was only presented. Participants were asked to lift the stylus from the start position and touch-down at the first target as quickly and accurately as possible. In the 2T(SIML) and 2T(SIMS) trials, both targets were displayed simultaneously. Participants were required to move to the first target and then extend their movement to the second target while coming to a complete stop at the second target. In the 2T(MO) trials, both targets were displayed at the start of the trial but the second target was reduced in size from the 2 ½ cm target to a 1cm target during movement onset. For the 2T(MO+75) trials, similar to the 2T(MO) trials the second target was reduced in size but not until 75ms after the stylus has left the starting position.

Prior to the testing trials, participants were given 60 blocked trials consisting of 20 1T(SE) trials, 20 2T(SIML) trials, and 20 2T(SIMS) trials that were counterbalanced. The first four trials of all movements in both the blocked and testing trials were eliminated to account for a familiarization period to the task. The test phase involved 180 trials (100 1T[SE], 20 2T[SIML], 20 2T[SIMS], 20 2T[MO], and 20 2T[MO+75]). All of these trials were randomized in a fashion so that every nine trials contained five 1T(SE) trials and each of the four 2T trials (SIML, SIMS, MO, and MO+75). Participants were instructed to prepare for a 1T(SE) response prior to stimulus onset and to perform 2T responses if a second target was to appear.

#### *Data Reduction*

Data reduction was done similar to Experiment 1.

#### *Dependent Measures*

Dependent measures were similar to Experiment 1.

#### *Data Analysis*

The blocked condition was analyzed using a repeated measures ANOVA with three levels [1T(SE), 2T(SIML), 2T(SIMS)] to test the differences between the one target and two target movements. For the random test trials, individual participant means and standard deviations (for ellipse areas) were submitted to a repeated measures ANOVA with five levels (SE, SIML, SIMS, MO MO+75). A bonferroni post hoc analysis was conducted to locate significant differences. Statistical significance was assessed at  $p < .05$ .



## Experiment 2 Results

All means and standard deviations of all dependent variables are presented in

*Table 1* for both the blocked and random conditions.

**Table 2**

Experiment 1 Means (standard deviations) of reaction time (RT), movement time to the first target (MT1), y constant error at the first target (CEy1), x constant error at the first target (CEx1, time to peak velocity of the first movement (tPKV1), time after peak velocity of the first movement (taPKV1), peak velocity at the first target (PKV1), ellipsoid volume at peak velocity of the first movement segment (EvPKV1), ellipse area at the end of movement 1 (EaEnd1), hit percentage at target 1 (H%T1), pause time after the first movement at the first target (PT), movement time from the first to the second target (MT2), y constant error at the second target (CEy2), x constant error at the second target (CEx2), time to peak velocity of the second movement (tPKV2), time after peak velocity of the second movement (taPKV2), peak velocity at the second target (PKV2), ellipsoid volume at peak velocity of the second movement segment (EvPKV2), ellipse area at the end of movement 2 (EaEnd2), and hit percentage at target 2 (H%T2), for the one-target (1T[SE]), two-target simultaneous-large (2T[SIML]), and two-target simultaneous-small (2T[SIMS]) tasks in the blocked and the one-target [1T(SE)], simultaneous-large [2T( SIM)], simultaneous-small (2T[SIMS]), movement onset (MO), and movement onset plus 75ms (MO + 75) random conditions.

	Blocked			Random				
	1T(SE)	2T(SIML)	2T(SIMS)	1T(SE)	2T(SIML)	2T(SIMS)	2T(MO)	2T(MO + 75)
RT (ms)	235 (38)	245 (38)	253 (43)	267 (40)	258 (40)	261 (43)	255 (42)	254 (39)
MT1 (ms)	201 (27)	232 (33)	244 (39)	221 (32)	223 (31)	224 (29)	226 (31)	226 (31)
CEy1 (mm)	-1.9 (3.6)	0.3 (3.3)	-0.002 (2.8)	-0.6 (2.8)	-0.1 (3)	0.3 (3.1)	0.4 (3.3)	-0.02 (3.1)
CEx1 (mm)	0.7 (2.1)	0.9 (2.1)	1.1 (1.9)	0.9 (2.1)	1.2 (2)	1.3 (2.2)	1.2 (2.1)	1.2 (2.1)
tPKV1 (ms)	93 (20)	106 (18)	107 (19)	102 (17)	99 (17)	100 (17)	101 (18)	102 (18)
taPKV1 (ms)	108 (20)	126 (24)	138 (26)	120 (20)	124 (20)	124 (19)	125 (19)	124 (20)
PKV1 (mm/s)	644 (80)	591 (66)	557 (58)	603 (65)	601 (64)	599 (58)	596 (66)	603 (61)
EvPKV1 (mm <sup>3</sup> )	120 (86)	154 (109)	146 (114)	149 (85)	138 (99)	147 (117)	161 (128)	130 (93)
EaEnd1	24 (8.9)	22 (11)	18 (7.4)	21 (5.9)	19 (8.4)	21 (8.3)	22 (9.8)	20 (8.1)
H%T1	.99 (.01)	.99 (.01)	1 (0)	.99 (.002)	1 (0)	.99 (.01)	.99 (.01)	.99 (.01)
PT (ms)		69 (28)	74 (33)		78 (27)	78 (29)	79 (28)	78 (28)
MT2 (ms)		216 (36)	244 (50)		223 (31)	236 (35)	233 (35)	234 (35)
CEy2 (mm)		-2.4 (3.5)	-2 (2.7)		-3.2 (3.1)	-2.2 (2.7)	-2.5 (2.8)	-2.7 (3.1)
CEx2 (mm)		0.6 (2)	0.4 (1.9)		0.9 (2)	0.7 (1.9)	0.7 (2)	0.6 (1.9)
tPKV2 (ms)		106 (21)	108 (24)		108 (16)	106 (15)	109 (17)	110 (16)
taPKV2 (ms)		110 (22)	135 (35)		115 (24)	130 (28)	125 (27)	123 (28)

PKV2 (mm/s)	568 (95)	508 (90)	536 (82)	514 (83)	519 (84)	516 (80)
EvPKV2 (mm <sup>3</sup> )	193 (182)	165 (92)	144 (116)	178 (174)	160 (111)	160 (90)
EaEnd2	24 (12)	16 (9)	20 (8)	15 (5)	18 (5)	18 (6)
H%T2	.99 (.03)	.96 (.04)	.99 (.01)	.96 (.04)	.95 (.06)	.94 (.06)

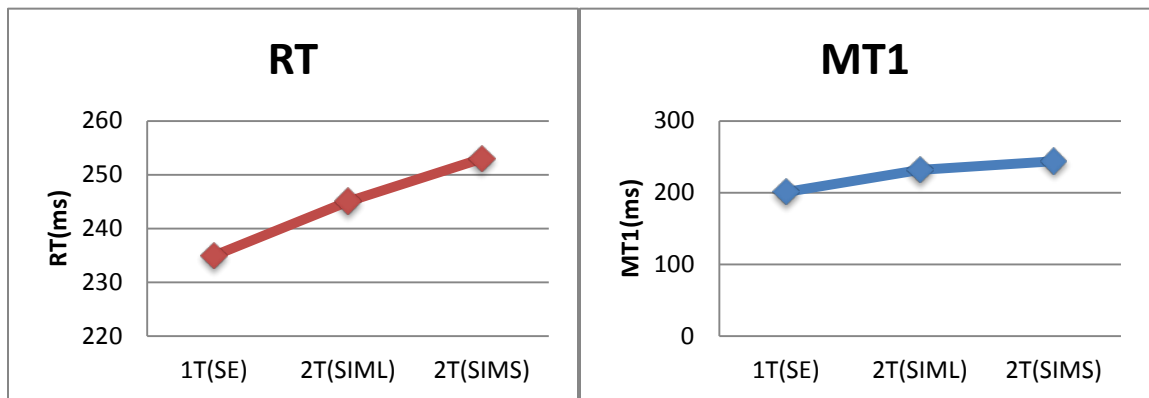
## Blocked Condition

### Reaction time

The analysis of RT revealed a significant main effect of condition,  $F(2, 58) = 4.160$ ,  $p < .05$ . This main effect indicated that the 1T(SE) movements (235 ms) had shorter RTs compared to the 2T(SIMS) movements, (253 ms) (see *Figure 6*).

### Movement time

The analysis of MT1 revealed a significant main effect of condition,  $F(2, 58) = 39.635$ ,  $p < .001$ . The 1T(SE) movements (201 ms) had faster MT1s compared to all other conditions (see *Figure 6*). Analysis of MT2 also revealed that 2T(SIML) movements (216 ms) had shorter movement times when compared to the 2T(SIMS) movements (244 ms),  $p < .001$ .



**Fig. 6.** Reaction times (RTs) and Movement times during the first movement (MT1) of the blocked condition.

*Pause time*

There were no significant differences in PT between the 2T(SIML), and 2T(SIMS) movements,  $p > .05$ .

*Target hit rates*

There were no significant differences in target hit rates at the first target between the 1T(SE) movements (mean = .99), 2T(SIM) movements (mean = .99) and 2T(SIMS) movements (mean = 1),  $p > .05$ . Analysis of target hit rates at the second target revealed higher target hit rates for the 2T(SIML) movements (mean = .99) compared to the 2T(SIMS) movements (mean = .96),  $t(29) = 2.864$ ,  $p < .01$ .

*Peak velocity*

The analysis of PKV1 revealed a significant main effect of condition,  $F(2, 58) = 20.330$ ,  $p < .001$ . This main effect indicated that the 1T(SE) movements (644 mm/s) had higher peak velocities compared to the 2T(SIML) movements (591 mm/s), and the 2T(SIMS) movements (557 mm/s),  $p < .005$ ). The main effect also indicated that the 2T(SIML) movements had higher peak velocities when compared to the 2T(SIMS) movements. Analysis of PKV2 revealed that the 2T(SIML) movements (568 mm/s) had higher peak velocities when compared to the 2T(SIMS) movements (508 mm/s),  $t(29) = 5.770$ ,  $p < .001$ .

*Time to Peak velocity*

TPKV1 revealed a significant main effect of condition,  $F(2, 58) = 19.649$ ,  $p < .001$ . Breakdown of this main effect revealed that the 1T(SE) movements reached peak

velocity faster (93 ms) when compare to the 2T(SIML) movements (106 ms), and the 2T(SIMS) movements (107 ms),  $p < .001$ . The analysis of TPKV2 revealed no significant difference between conditions,  $t(29) = -.505$ ,  $p > .05$ .

#### *Time after Peak velocity*

The analysis of taPKV1 revealed a significant main effect of condition,  $F(1.573, 45.627) = 30.332$ ,  $p < .001$ . Breakdown of this main effect indicated that less time was spent after peak velocity for the 1T(SE) movements (108 ms) when compared to the 2T(SIML) movements (126 ms), and the 2T(SIMS) movements (138 ms). The main effect also revealed that less time was spent after peak velocity for the 2T(SIML) movements (126 ms) when compared to the 2T(SIMS) movements (138 ms). Analysis of taPKV2 revealed that the time spent after peak velocity was shorter for the 2T(SIML) movements (110 ms) 2T(SIML) movements when compared to the 2T(SIMS) movements (135 ms),  $t(29) = -5.553$ ,  $p = < .001$ .

#### *Time to Peak velocity / Time after Peak velocity*

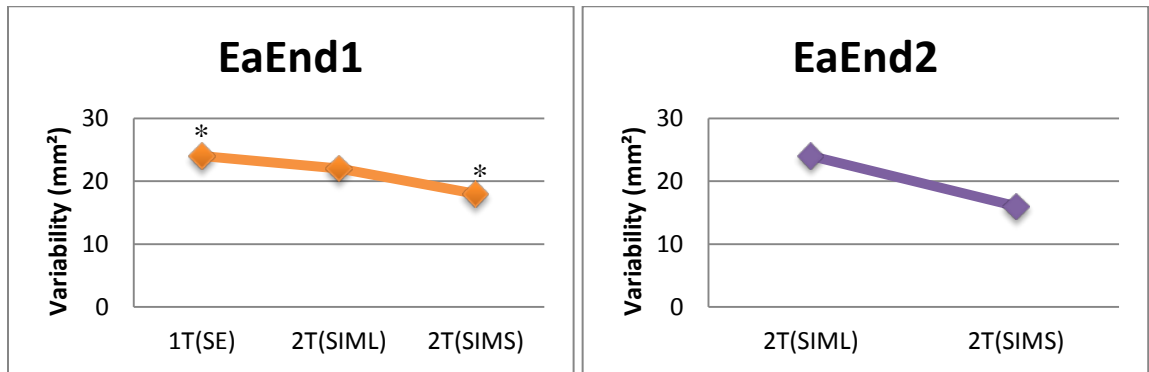
Analysis of tPKV2/taPKV2 revealed a significant main effect of condition,  $F(1.339, 38.824) = 4.423$ ,  $p < .05$ . The main effect revealed that participants constrained their movements less during the 2T(SIML) movements (.872) when compared to the 2T(SIMS) movements (.792),  $p < .005$ .

#### *Variability*

The analysis of ellipsoid volume at peak velocity of the first movement revealed no significant main effect,  $F(2, 58) = 1.030$ ,  $p > .05$ . The analysis of ellipse areas at the

end of the first movement segment revealed a significant main effect of condition,  $F(2, 58) = 3.928, p < .05$ . Breakdown of this main effect revealed that the 1T(SE) had more variability at the first target ( $24\text{mm}^2$ ) when compared to the 2T(SIMS) condition ( $18\text{mm}^2$ ). This revealed that participants constrained their movements more at the first target for the 2T(SIMS) movements compared to the 1T(SE) movements (see *Figure 7*).

The analysis of ellipsoid volume at peak velocity of the second movement was non-significant,  $t(29) = .878, p > .05$ . The analysis of ellipse areas at the end of the second movement revealed a significant difference;  $t(29) = 3.256, p < .005$ . This indicated that the 2T(SIMS) movements ( $16\text{mm}^2$ ) constrained more at the end of the second movement when compared to the 2T(SIML) movements ( $24\text{mm}^2$ ) (see *Figure 7*).



**Fig. 7.** Ellipse areas for the one-target (1T) and two-target (2T) tasks in the blocked condition at the end of the first movement (EaEnd1) and the end of the second movement (EaEnd2).

## Random Condition

### *Reaction time*

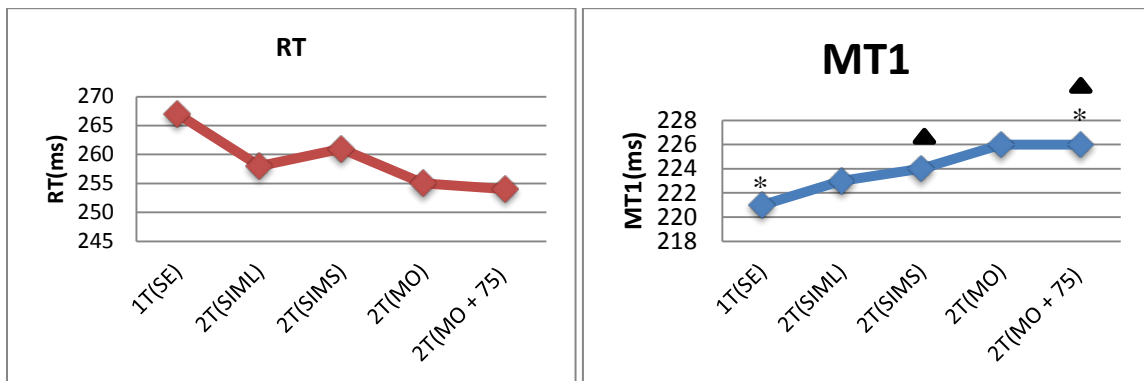
The analysis of RT revealed a significant main effect of condition,  $F(4, 116) = 5.437, p < .001$ . This main effect indicated that the 1T(SE) movements ( $267\text{ ms}$ ) had

longer RTs compared to the 2T(SIML) movements (258 ms), 2T(MO) movements (255 ms), and 2T(MO + 75) movements (254 ms) (see *Figure 8*).

*Movement time*

The analysis of MT1 revealed a significant main effect of condition,  $F(3.131, 90.804) = 4.171, p < .05$ . This main effect indicated that the 1T(SE) movements (221 ms), had shorter MT1's compared to the 2T(MO + 75) movements (226 ms). It also revealed that the 2T(SIML) movements (223 ms) had shorter MT1's compared to the 2T(MO + 75) movements (226 ms),  $p < .01$  (see *Figure 8*).

The analysis of MT2 revealed a significant main effect of condition,  $F(2.086, 60.5) = 29.784, p < .001$ . MT2 in the 2T(SIML) movements (223 ms) had shorter movement times when compared to all other conditions.



**Fig. 8.** Reaction times (RTs) and Movement times during the first movement (MT1) of the random condition.

*Pause time*

The analysis of PT revealed a non-significant main effect of condition,  $F(2.247, 65.149) = .104, p > .05$ .

### *Target hit rates*

There was no significant difference in target hit rates at the first target for the one target movements (mean = .99),  $p > .05$ . The analysis of H%T2 indicated a significant main effect of condition,  $F(3, 87) = 9.811$ ,  $p < .001$ . Breakdown of this main effect revealed that the 2T(SIML) movements (.998) had more target hits at the second target when compared to all other movements.

### *Peak velocity*

The analysis of PKV1 revealed a non-significant main effect of condition,  $F(4, 116) = 1.098$ ,  $p > .005$ . The analysis of PKV2 revealed a significant main effect of condition,  $F(2.285, 66.269) = 12.801$ ,  $p < .001$ . Peak velocity for the 2T(SIML) movements (536 mm/s) was higher compared to the other movements,  $p < .005$ .

### *Time to Peak velocity*

The analysis of TPKV1 revealed a non-significant main effect of condition,  $F(3.084, 89.438) = 2.184$ ,  $p > .05$ . The analysis of TPKV2 revealed a significant main effect of condition,  $F(3, 87) = 2.799$ ,  $p < .05$ . Peak velocity was reached earlier in the 2T(SIMS) movements (106 ms) when compared to the 2T(MO + 75) movements (110 ms).

### *Time after Peak velocity*

The analysis of taPKV1 revealed a significant main effect of condition,  $F(4, 116) = 4.954$ ,  $p < .005$ . Breakdown of this main effect revealed that the time spent after peak velocity was shorter for the 1T(SE) movements (120 ms) when compared to the

2T(SIML) movements (124 ms), the 2T(MO) movements (125 ms), and the 2T(MO + 75) movements (124 ms). The analysis of taPKV2 revealed a significant main effect of condition,  $F(3, 87) = 26.627, p < .001$ . Breakdown of this main effect revealed that participants spent less time after peak velocity during the 2T(SIML) movements (114 ms) when compared to all other movements,  $p < .001$ . The main effect also revealed that the 2T(SIMS) movements (130 ms) spent more time after peak velocity when compared to the 2T(MO) movements (125 ms), and the 2T(MO + 75) movements (123 ms).

*Time to Peak velocity/ Time after Peak velocity*

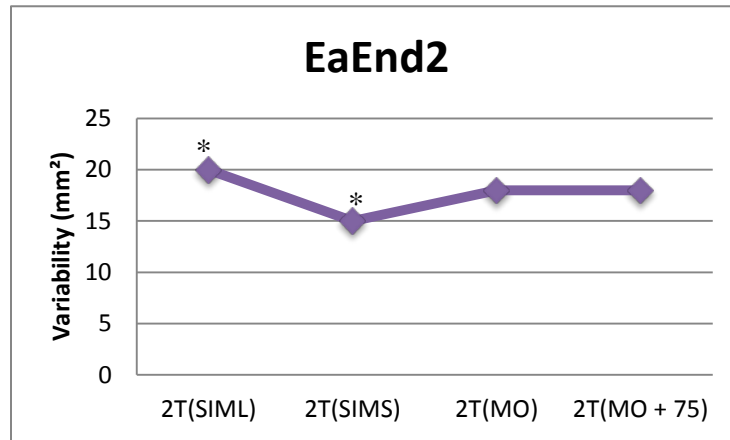
Analysis of tPKV1/taPKV1 revealed a significant main effect of condition,  $F(4, 116) = 3.914, p < .01$ . The main effect revealed that participants constrained their movements less during the 1T(SE) movements (.865) when compared to the 2T(SIML) movements (.807),  $p < .001$ . Analysis of tPKV2/taPKV2 revealed a significant main effect of condition,  $F(3, 87) = 13.309, p < .001$ . The main effect revealed that participants made less corrections during the 2T(SIML) movements (.983) when compared to the 2T(SIMS) movements (.857) and the 2T(MO) movements (.910),  $p < .05$ . The main effect also revealed that more corrections were being made during the 2T(SIMS) movements (.857) when compared to the 2T(MO + 75) movements (.936),  $p < .01$ .

*Variability*

The analysis of ellipsoid volume at peak velocity of the first movement, revealed a non-significant main effect of condition,  $F(2.633, 76.345) = 1.112, p > .05$ . The analysis of ellipse areas at the end of the first movement segment also revealed a non-



significant main effect of condition,  $F(4, 116) = .803, p > .05$ . The analysis of ellipsoid volume at peak velocity of the second movement, revealed a non-significant main effect of condition,  $F(1.780, 51.618) = .940, p > .05$ . The analysis of ellipse areas at the end of the second movement revealed a significant main effect of condition,  $F(3, 87) = 4.935, p < .005$ . This revealed that during the 2T(SIMS) condition ( $15\text{mm}^2$ ), participants constrained their movements more when compared to the 2T(SIML) condition, ( $20\text{mm}^2$ ).



**Fig. 9.** Ellipse areas for the two-target (2T) tasks in the random condition at the end of the second movement (EaEnd2).

## Discussion Experiment 2

### *Blocked Condition*

Consistent with previous literature, RT increased as complexity of the task increased (Khan et al., 2006; Khan et al., 2008a; Klapp, 1995; Klapp, 2003). RT was shorter in the 1T(SE) movement, (235ms) when compared to the 2T(SIMS) movement, (253ms).

The complexity of the task also had an influence on movement time. The OTA emerged during the blocked condition between the 1T(SE) movement (201ms) and the

2T(SIML) movement (232ms). This finding is in support of the movement integration hypothesis. As a result of participants knowing the number of targets that were to appear in advance, this allowed for the pre-programming of movements prior to the presentation of the stimulus. This pre-programming enabled activation of the second movement during the first and caused interference. Our research supports this because not only were peak velocities slower in the 2T(SIML) movement but it also took participants more time to reach peak velocity and spent more time after peak velocity.

A greater OTA also emerged between the 1T(SE) movement (201ms) and the 2T(SIMS) movement (244ms) supporting the movement constraint hypothesis. The OTA emerged during this condition as a result of the smaller second target. The smaller second target resulted in slower movements to the first target in order to meet accuracy demands at the first and then the second sequential target. In order to be accurate at the second target participants must constrain their movements to the first target (Fischman & Reeve, 1992). Consistent with the movement constraint hypothesis, participants constrained their movements more at the first target during the 2T(SIMS) movement (18mm<sup>2</sup>) compared to the 1T(SE) movement (24mm<sup>2</sup>). Not only did participants constrain their movements at the first target in order to be accurate at the second target, but constraining was also evident between the 2T(SIMS) movement (16mm<sup>2</sup>) and the 2T(SIML) movement (24mm<sup>2</sup>). This constraining resulted in longer MT's in the first and second movements, lower peak velocities, more time to reach peak velocity, and more time after peak velocity. This support for the movement constraint hypothesis shows that in order to be accurate at the second target participants constrained their movement to the first thus resulting in longer movement times and the emergence of the OTA.

*Random Condition*

Under conditions of response uncertainty, there is usually no difference in RT between movements regardless of movement complexity (Bested et al., 2014; Khan et al., 2006; Khan et al., 2008a; Khan et al., 2011; Klapp, 1995; Klapp, 2003). In contrast to these findings, the present study showed that RT was faster for the 2T movements when compared to the 1T(SE) movements. This finding suggests that participants were preparing for the worst case scenario. This is surprising because the 1T(SE) movements appeared more frequently (5/9 trials) than the other movements. Participants were also instructed to prepare for the 1T(SE) movement and that they would be appearing more frequently.

As in the previous experiment, the OTA did not emerge when comparing the 1T(SE) movement and the 2T(SIML) movement. However, the 1T(SE) had significantly shorter MT1's (221ms) when compared to the 2T(MO + 75) movement (226ms). Another interesting finding is that the 2T(SIML) movement had significantly shorter MT1's (223ms) when compared to the 2T(MO + 75) movement (226ms). This finding shows that the interference caused by the reduction of the second target after movement onset resulted in longer movement times to the first target.

Even though the two-target advantage did not emerge as it did in experiment one, there is still much support that participants were preparing for the worst case scenario. Movement times in the 2T(SIML) condition were the shortest when compared to all other movements. Peak velocity in the second movement was also the fastest under the 2T(SIML) movements when compared to all other movements and participants spent less

time after peak velocity in the second movement. Participants also constrained less at the second target for the 2T(SIML) movements when compared to the 2T(SIMS) movements and had the highest accuracy at the second target during the 2T(SIML) movements when compared to all other movements. The speed and accuracy of the second movement during the 2T(SIML) movements shows support that participants prepared for the 2T(SIML) movements in advance. The lack of accuracy at the second target for all of the other two-target movements could be a result of the 2T(SIML) movements being programmed as a single unit of action. Thus, once movement had been initiated, it was difficult to change how the movements were organised resulting in inaccurate movements to the second target.

## CHAPTER V

### GENERAL DISCUSSION

In day-to-day life, one performs a variety of movements that are performed in sequence. As these movements become more complex RT increases (Henry & Rogers, 1960). Previous research investigating multiple-segment movements has found that when moving to a single target, movement time is faster when one must continue on to a second sequential target (i.e., the one-target advantage) (Adam et al., 2000). This one-target advantage (OTA) appears only when participants know the number of targets in advance (Bested et al., 2014). The purpose of the present study was to further our understanding of how these movements are programmed prior to response initiation and controlled during movement execution under conditions of response uncertainty. To do this we manipulated the time course of these processes by varying the number of targets and target size prior to and during movement execution.

To recap, in experiment one it was found that there was no increase in RT when comparing the 1T(SE) and 2T(SIM) movements during the blocked condition. This contradicted previous literature that states that as complexity of a task increases, RT increases accordingly (Henry & Rogers, 1960; Klapp, 1995; Klapp, 2003; Khan et al., 2006; Khan et al., 2008a). In experiment two, our findings in the blocked condition replicated previous findings that RT increases as complexity of a task increases (Henry & Rogers, 1960; Klapp, 1995; Klapp, 2003). However, this increase in RT only occurred when comparing the 1T(SE) movements and the 2T(SIMS) movements, and not between the 1T(SE) movements and the 2T(SIML) movements. Unlike Klapp's (1995) experiment when RT increased when comparing a one-item condition to a two-item

condition, our increase in RT only became present when the second item was found to be more difficult than the first (smaller second target). This supports the idea that accuracy demands also affect the complexity of a task and can compound the effects of the number of elements (Khan et al., 2006).

During the blocked condition in both experiments, the OTA did emerge with shorter MT1's in the 1T(SE) movements when compared to the 2T(SIM) movements. Evidence supporting both the movement constraint and integration hypotheses was identified when analyzing these movements. The movement constraint hypothesis states that in order to be accurate at the second target, participants must constrain their movements to the first (Fischmand & Reeve, 1992). This constraining was identified between the 1T(SE) movements and the 2T(SIM) movements with less variability found at the first target in the 2T(SIM) movements. A larger OTA also emerged when comparing the 1T(SE) movement and the 2T(SIMS) movements in experiment two. Evidence of constraining more at the first target supports Fischmand & Reeve's (1992) finding that reducing the second target size resulted in participants constraining their movements to the first target. Participants took longer to reach peak velocity during the first movement and spent more time after peak velocity during the 2T(SIM) movements. This constraining of the first movement resulted in longer movement times to the first target and caused the OTA to emerge.

Even though the results support the movement constraint hypothesis, there was also evidence for the movement integration hypothesis. The movement integration hypothesis states that both movements are stored in a buffer prior to movement onset. In order to make the movement as fluent as possible, the second movement is implemented

during the first. The overlapping of these two processes can cause interference resulting in the emergence of the OTA (Adam et al., 2000). In order for the OTA to emerge participants had to know the number of targets in advance. This gave participants the information needed in order to pre-program and store both movements in a buffer prior to the presentation of the stimulus. Further evidence of this interference during the first movement was supported by the longer time spent to reach peak velocity, the longer time period spent after peak velocity and the slower velocity times found during the 2T(SIM) movements.

During the random condition in experiment one, our study supported the idea that participants prepare for the worst case scenario under response uncertainty (Bested et al., 2014). Even though participants were instructed to prepare for the 1T(SE) movements and that they would be appearing more frequently, participants still adopted the strategy of preparing for the more complex movements (i.e., 2T[SIM] movements). This was supported with shorter RT's and MT1's for the 2T(SIM) movements when compared to all other movements.

Results of experiment two in the random condition did not reveal a two-target advantage as in experiment one. However, longer MT1's were discovered when comparing the 1T(SE) movements to the 2T(MO + 75) movements and when comparing the 2T(SIML) movements to the 2T(MO + 75) movements. This was perhaps the outcome of interference from the target size changing during the movement, resulting in longer MT1's and thus supporting the movement integration hypothesis. Although the two-target advantage did not emerge, there is still support for the idea that participants prepared for the worst case scenario (Bested et al., 2014). Shorter MT2's were found in

the 2T(SIML) movements when compared to the other two-target movements as well as increased accuracy at the second target.

Several of our hypotheses in this study were supported. We hypothesized that the OTA would emerge under blocked but not the random condition which was in fact the case in both experiments (Bested et al., 2014). However, the presence of the two-target advantage emerged under the random condition was unexpected. This was surprising because the two-target advantage had only appeared during two-target reversal movements and not during extension movements (Khan et al., 2008b). We expected that the OTA would not emerge and that there would be no difference between the MT1's under random sequencing. This finding revealed that when participants were preparing for the worst case scenario, this resulted in slower movement times to the first target of tasks that would be interpreted as less difficult. Instead of being more efficient, the result of this pre-programming resulted in longer MT's and longer RT's in less complex tasks.

When participants knew the number of targets in prior to movement onset, it was shown that there was a smooth transition between the two-movements in the random condition in experiment one. This was supported by shorter pause times at the first target in the 2T(SIM) movements when compared to all other movements. Pause times increased as complexity of the task increased and the complexity resulted in the two movements being executed separately.

Participants constrained their movements to the first target when the number of targets was known in advance but no difference was found between movements under response uncertainty. This may have been the result of participants not being able to switch the motor program once it had been initiated. Another explanation could be the



result of the movement being separated into two independent movements as revealed by longer pause times.

Previous research investigating reversal movements has shown that the integration of the two movements occurs at the peripheral level whereby the antagonist acting on the first movement acts as the agonist on the second movement. This results in a highly integrated movement at the peripheral level (Khan et al., 2008b). In contrast, for extension movements this integration between movements has been shown to be at the cognitive level since the OTA emerges when the two segments are performed with different limbs (Khan et al., 2010). The present results reveal that even though participants took on average over 200ms to perform the first movement, this was not enough time to correct or change the motor program once it had been initiated. Adapting to a change in task requirements on or after movement onset is very difficult at the cognitive level for these manual sequential aiming movements.

Further investigation is needed in order to understand why the OTA emerges under blocked but not random sequencing. To do so, one might eliminate all of the movement onset and movement onset plus delay conditions in order to simplify the task and include an alternating condition in addition to the blocked and random conditions. Investigating these three movements under blocked, alternating and random conditions should give us greater insight as to when participants constrain their movements and if these two movements can be integrated as one fluent movement under response uncertainty. Adding the alternating condition will help to see if participants prepare and execute the same motor program during both the SIMS and SIML movements regardless of the size of the second target.

Both the movement integration and movement constraint hypothesis have been proposed to explain why the OTA emerges (Adam et al., 2000; Fischman & Reeve, 1992; Khan et al., 2010; Khan et al., 2011). Information from this study has led us to support the idea that both the movement integration and movement constraint hypothesis both play a role in the emergence of the OTA. The random condition shows that it is very difficult to change a movement once it has already been initiated. If the movement conditions change after the response is initiated, this results in longer pause times and the movements can no longer be integrated. Hence, prior knowledge is critical for the operations of both the movement integration and constraint hypotheses to play a role in the integration between movement segments.

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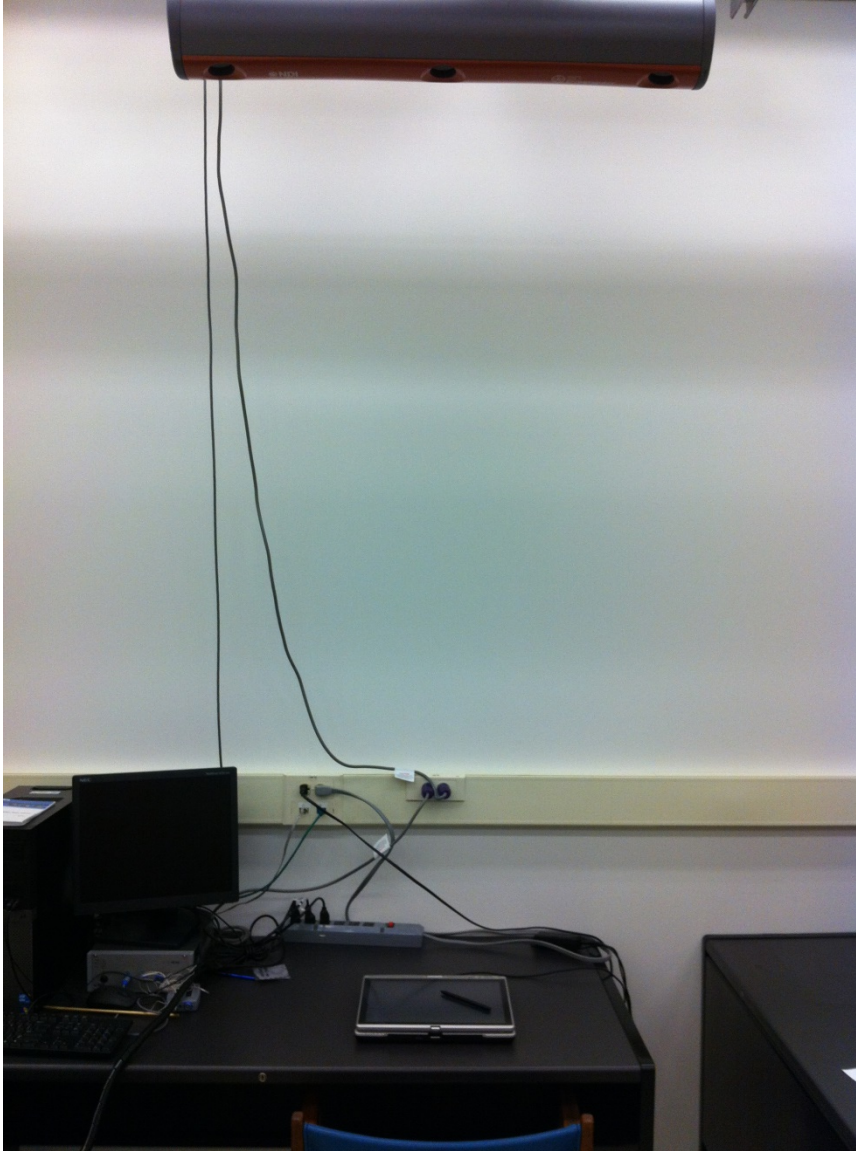
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APPENDICES

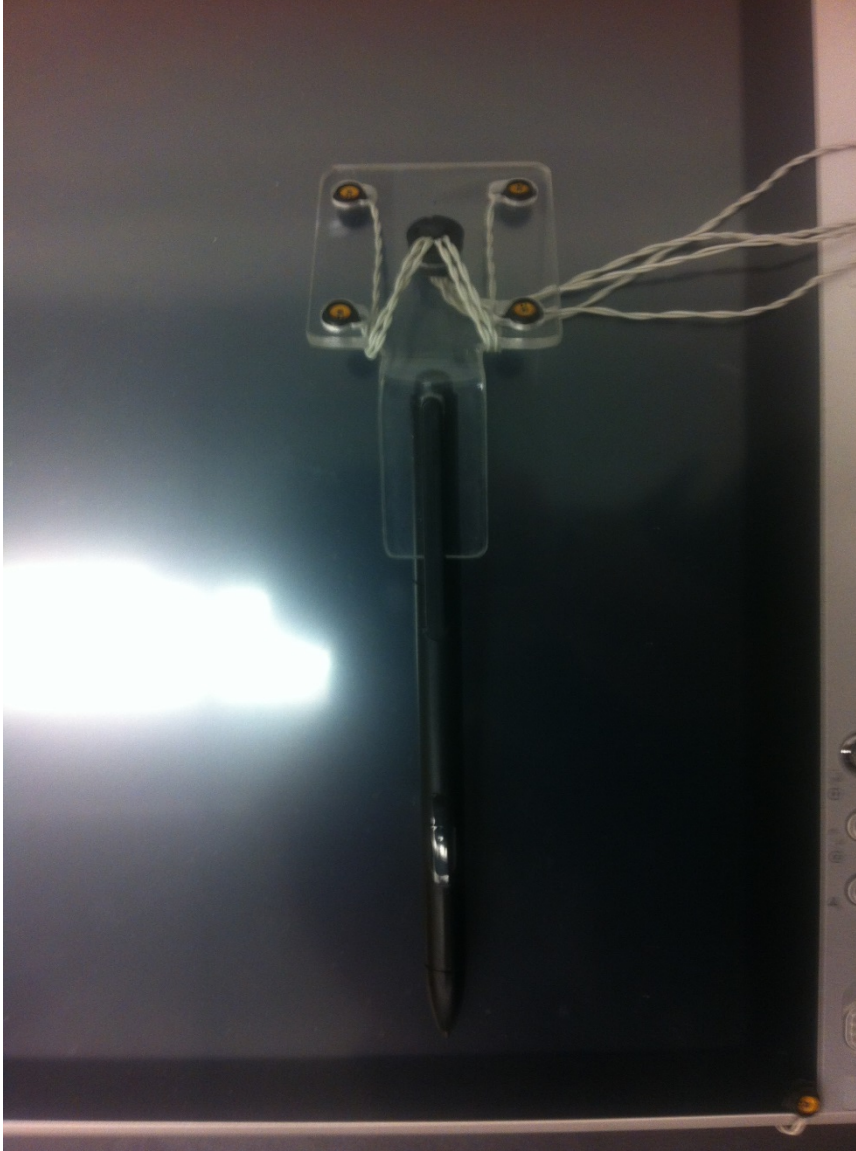
Appendix A – Experiment Set-up



Tablet experimental set-up.

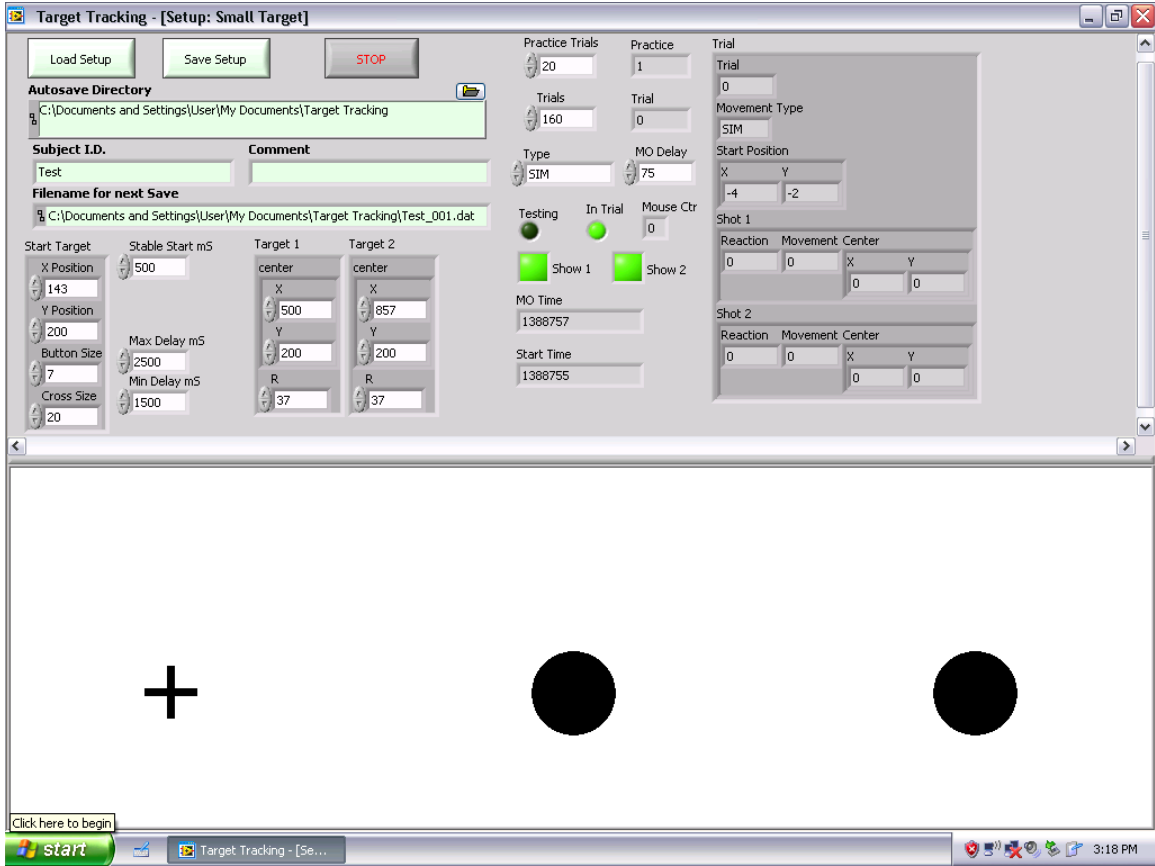


OptoTrak set-up.

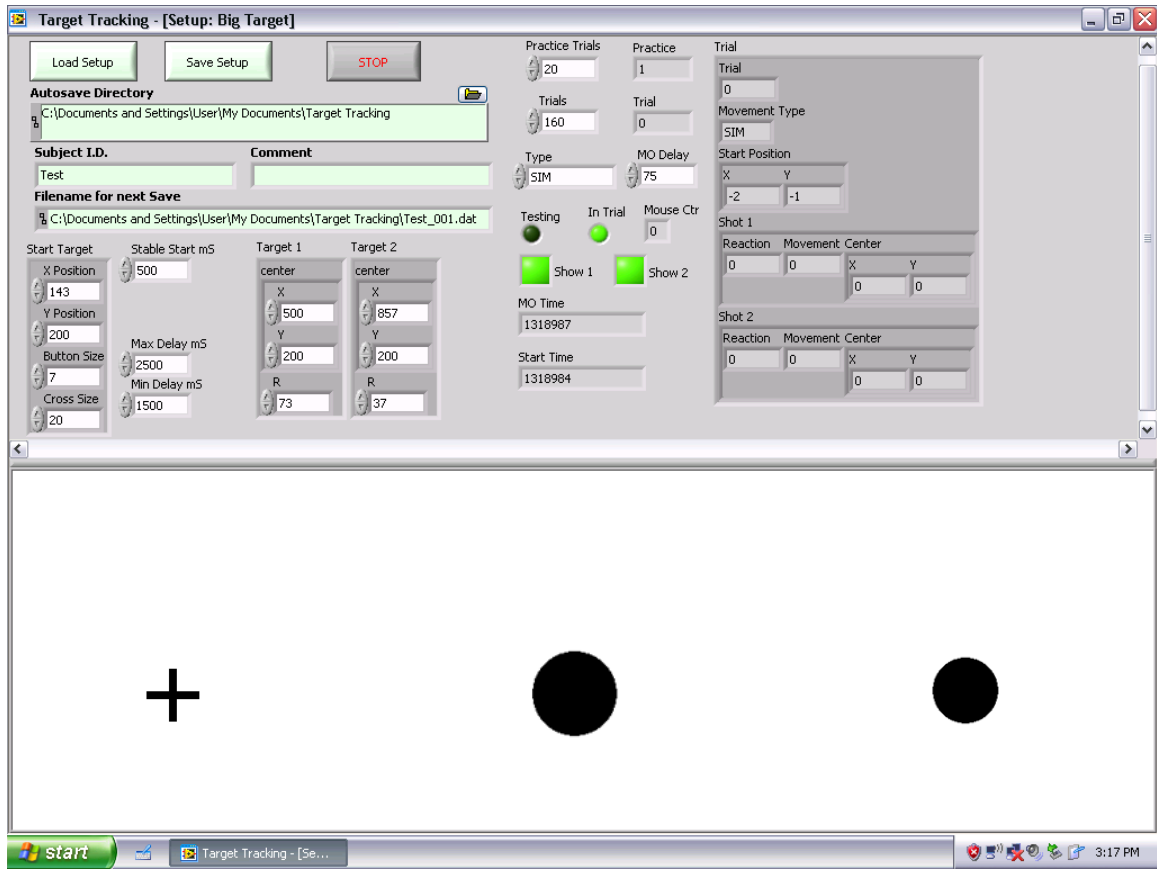


Stylus marker set-up with pen tip reference point.





Experiment 1 LabView Setup.



Experiment 2 LabView setup.

Appendix B – Collection Checklist

Participant Name \_\_\_\_\_ Age \_\_\_\_\_ Gender \_\_\_\_\_

Participant I.D. \_\_\_\_\_ Condition \_\_\_\_\_

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## Appendix C – Consent to Participate in Research



### CONSENT TO PARTICIPATE IN RESEARCH

#### **Title of Study: Preparation of an Extension Movement in a One and Two-Target Aiming Movement**

You are asked to participate in a research study conducted by Dr. Michael Khan and Mr. Stephen Bested, from the Kinesiology Department at the University of Windsor. The results from this study will be used for an independent study for Stephen Bested as a course credit. If you have any questions or concerns about the research, please feel to contact Stephen Bested: (519) 300-2369, and Dr. Michael Khan: (519) 253-3000 ext.2432.

#### **PURPOSE OF THE STUDY**

The purpose of this study is to investigate the preparatory and control processes underlying the one-target advantage by adding or removing a target prior to movement initiation and during movement execution.

#### **PROCEDURES**

If you volunteer to participate in this study, you will be asked to attend one single testing session that will last approximately one and a half hours. In this one session you will be asked to complete movements on a touch screen using a pen/stylus to move from a starting position to a sequential target(s) as quickly and accurately as possible. You will be timed and the movement of the pen/stylus will be documented by using the NDI 3D Investigator (Optotrak).

#### **POTENTIAL RISKS AND DISCOMFORTS**

There will be minimal amount of risk in this study. Possible risk could include your arm or hand getting tired from hold/moving the pen/stylus.

#### **POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY**

Some potential direct benefits from participating in this project would be to see how studies are conducted within the Faculty of Human Kinetics and to gain further knowledge of Kinesiology Research. They will be exposed to innovative technology in the NDI 3D Investigator (Optotrak).

#### **COMPENSATION FOR PARTICIPATION**

There will be no compensation for this study.

#### **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

All participants will be given a numerical code and the code will be used in all analyses. Data will also be held in a locked cabinet and will be held for 3 years. All files will be digitally encrypted.

#### **PARTICIPATION AND WITHDRAWAL**



You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

## FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

Results will be put up in a reader friendly summary report on the REB website [www.uwindsor.ca/reb/](http://www.uwindsor.ca/reb/) by July 2014.

## SUBSEQUENT USE OF DATA

These data may be used in subsequent studies in publications and in presentations.

## RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: [ethics@uwindsor.ca](mailto:ethics@uwindsor.ca)

## SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I understand the information provided for the study **Preparation of an Extension Movement in a One and Two-Target Aiming Movement** as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

\_\_\_\_\_  
Name of Participant

\_\_\_\_\_  
Signature of Participant

\_\_\_\_\_  
Date

## SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

\_\_\_\_\_  
Signature of Investigator

\_\_\_\_\_  
Date



## **LETTER OF INFORMATION FOR CONSENT TO PARTICIPATE IN RESEARCH**

### **Title of Study: Preparation of an Extension Movement in a One and Two-Target Aiming Movement**

You are asked to participate in a research study conducted by Dr. Michael Khan and Mr. Stephen Bested, from the Kinesiology Department at the University of Windsor. The results from this study will be used for an independent study for Stephen Bested as a course credit. If you have any questions or concerns about the research, please feel to contact Stephen Bested: (519) 300-2369, and Dr. Michael Khan: (519) 253-3000 ext.2432.

### **PURPOSE OF THE STUDY**

The purpose of this study is to investigate the preparatory and control processes underlying the one-target advantage by adding or removing a target prior to movement initiation and during movement execution.

### **PROCEDURES**

If you volunteer to participate in this study, you will be asked to attend one single testing session that will last approximately one and a half hours. In this one session you will be asked to complete movements on a touch screen using a pen/stylus to move from a starting position to a sequential target(s) as quickly and accurately as possible. You will be timed and the movement of the pen/stylus will be documented by using the NDI 3D Investigator (Optotrak).

### **POTENTIAL RISKS AND DISCOMFORTS**

There will be minimal amount of risk in this study. Possible risk could include your arm or hand getting tired from hold/moving the pen/stylus.

### **POTENTIAL BENEFITS TO PARTICIPANTS AND/OR TO SOCIETY**

Some potential direct benefits from participating in this project would be to see how studies are conducted within the Faculty of Human Kinetics and to gain further knowledge of Kinesiology Research. They will be exposed to innovative technology in the NDI 3D Investigator (Optotrak).

### **COMPENSATION FOR PARTICIPATION**

There will be no compensation for this study.

### **CONFIDENTIALITY**

Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission.

All participants will be given a numerical code and the code will be used in all analyses. Data will also be held in a locked cabinet and will be held for 3 years. All files will be digitally encrypted.

## PARTICIPATION AND WITHDRAWAL

You can choose whether to be in this study or not. If you volunteer to be in this study, you may withdraw at any time without consequences of any kind. You may also refuse to answer any questions you don't want to answer and still remain in the study. The investigator may withdraw you from this research if circumstances arise which warrant doing so.

## FEEDBACK OF THE RESULTS OF THIS STUDY TO THE PARTICIPANTS

Results will be put up in a reader friendly summary report on the REB website [www.uwindsor.ca/reb/](http://www.uwindsor.ca/reb/) by July 2014.

## SUBSEQUENT USE OF DATA

These data may be used in subsequent studies in publications and in presentations.

## RIGHTS OF RESEARCH PARTICIPANTS

If you have questions regarding your rights as a research participant, contact: Research Ethics Coordinator, University of Windsor, Windsor, Ontario, N9B 3P4; Telephone: 519-253-3000, ext. 3948; e-mail: [ethics@uwindsor.ca](mailto:ethics@uwindsor.ca)

## SIGNATURE OF RESEARCH PARTICIPANT/LEGAL REPRESENTATIVE

I understand the information provided for the study **Preparation of an Extension Movement in a One and Two-Target Aiming Movement** as described herein. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

\_\_\_\_\_  
Name of Participant

\_\_\_\_\_  
Signature of Participant

\_\_\_\_\_  
Date

## SIGNATURE OF INVESTIGATOR

These are the terms under which I will conduct research.

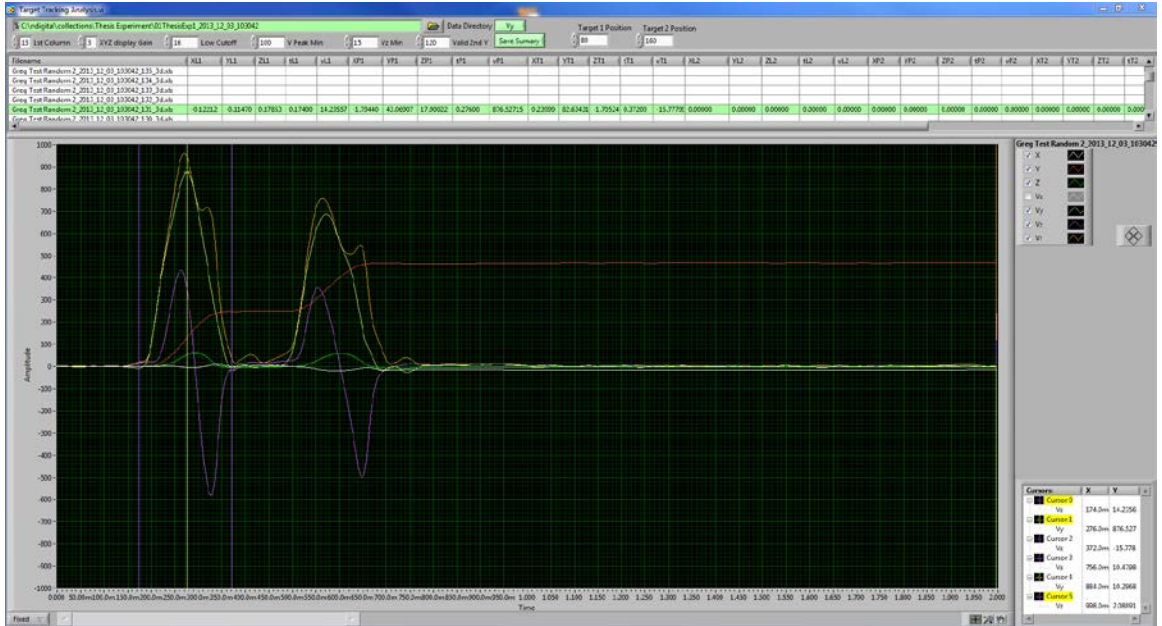
\_\_\_\_\_  
Signature of Investigator

\_\_\_\_\_  
Date

## Appendix D – Script for Data Collection

1. Thank participant for taking part in research
2. Get participant to sign consent forms
3. **General** ~ “You will be taking part in a manual target aiming task. There will be either one target appearing or two targets appearing. (**Show participant**). There will be two total sets of data being collected the first consisting of 40 trials and the second consisting of 160/180 testing trials. For each trial we want you to always hit the target but to move as quickly and accurately as possible while doing so.
4. **Testing part 1** ~ “The first set of testing trials will be in a blocked format. This means that you will have 20 of the one target appearing in a row and then following 20 of the 2 target condition in a row. You will know every time how many targets will be appearing”.
5. **Testing part 2 (Explaining target reduction for experiment 2)** ~ “For the second part of the study you will now be getting random trials between 1 and 2 targets. The second target will be appearing at different times. This could be during movement onset, both targets may appear at the same time, or the second target may appear after a short delay. For each trial we want you to always prepare for the one target. The one target condition will be appearing more frequently than the two target condition. For each trial we want you to always hit the target, but to move as quickly and accurately as possible.”
6. **End** ~ “Thank you for participating in our research.”

### Appendix E – Labview Data Analysis Software



VITA AUCTORIS

NAME: Stephen Ryan Bested  
PLACE OF BIRTH: North York, ON  
YEAR OF BIRTH: 1990  
EDUCATION: University of Windsor, B.H.K., Windsor, ON, 2012  
University of Windsor, M.H.K., Windsor, ON, 2014