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COORDINATION OF CONTINUOUS AND DISCRETE COMPONENTS OF ACTION

STEPHANIE L. KILIAN

Bachelor of Arts in Psychology

Cleveland State University

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We hereby approve this thesis for

Stephanie Kilian

Candidate for the Master of Arts in Psychology degree for the

Department of Psychology

And the CLEVELAND STATE UNIVERSITY

College of Graduate Studies

____

Thesis Chairperson, Andrew B. Slifkin

____

Department & Date

____

Methodologist and Committee Member, Albert F. Smith

____

Department & Date

____

Committee Member, Naohide Yamamoto

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Department & Date

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COORDINATION OF CONTINUOUS AND DISCRETE

COMPONENTS OF ACTION

STEPHANIE L. KILIAN

ABSTRACT

Goal-directed movement may contain discrete and continuous components of action. In this experiment, participants moved back and forth between targets using a computer mouse in a cyclical aiming task. It was of interest to examine the relation between a discrete button press on a computer mouse, indicating an attempt at target capture, and the peak position of the corresponding, continuous movement trajectory of the mouse. How might the spatial and temporal relations between those events vary as a function of variations in task constraints? In particular, this experiment varied the target width (*W*) and amplitude requirement (*A*), where variations of both were quantified by the Index of Difficulty (ID) according to the equation $\log_2(2A/W)$. Previous research by Slifkin et al. (2013) has shown that the spatial and temporal location of the peak position relative to the spatial and temporal location of the button press varied as a function of changes in *W* and *A*. As the ID increased, there was increased coincidence of the peak position of movement and position of the button press with increases in task demand, suggesting serial processing of movement at high indices of difficulty and parallel processing of movement coordination at low IDs. The current study examines whether the effects of *W* or the effects of the *A* have more of an influence on the coordination and timing of button press position and peak movement position. Based on previous research by Adam and Paas (1996), it was predicted that the target width manipulation will have more of an influence on the coordination of peak position and button press. In line with this prediction, results suggest that the *W* manipulation has more of an influence on the coordination of continuous and discrete components of action than the *A* manipulation. These results also suggest that the *W* manipulation has more of an influence on whether movements are produced in serial or parallel. The theoretical and practical implications of these results are also discussed.

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CHAPTER I

INTRODUCTION

Voluntary, goal-directed movement tasks usually require an individual to coordinate a discrete, goal-directed action with a continuous goal-directed action. For example, a tennis player running to hit a ball to the opposite side of the court may require continuous running movement of the legs followed by a swinging movement of the arm in order to hit the ball and complete the action. Research by Hogan and Sternad (2007) suggests that continuous and discrete movements have separate characteristics. A continuous component of action may be characterized as rhythmic, frequent, and considerably periodic, whereas, a discrete component of action may be characterized as distinct, goal-oriented, and containing an identifiable start and stop in space and time (Hogan and Sternad, 2007). Yet how are components of action coordinated and timed in relation with each other? Is there a consistent relationship between the timing and coordination of a continuous and discrete component of action across variation of task constraints? The present study addresses these questions.

Research in ergonomics and movement control have studied goal-directed movement tasks by employing computer mice where the goal is to move to a specified target using the cursor on the screen, with or without the inclusion of a button press to confirm target acquisition. Goal completion in these studies requires an individual to complete the goal under varying task constraints, such as modified target width (*W*) and amplitude (*A*). Research has studied the effects of these task constraints on variables including movement time (MT) and position of the cursor with respect to *W* and *A* requirements. Although ergonomics and motor control research analyze similar facets of movement control, within ergonomics research on human-computer interface, a continuous hand movement and a discrete button press are commonly required for task completion (Visser et al., 2004). For example, when selecting an icon on a video display, participants are required to move to the target and produce a downward press of a mouse button in order to indicate icon selection, and therefore, the end of a movement. Similar to the example of a tennis player running and hitting a ball, the button press may be viewed as a discrete movement of the index finger that must be coordinated with the continuous movement of the mouse by the hand in order to achieve accurate selection of the icon, completing the goal. As shown in Figure 1, the continuous horizontal movement of the mouse by the hand must be coordinated with the vertical movement of the finger administering the button press.

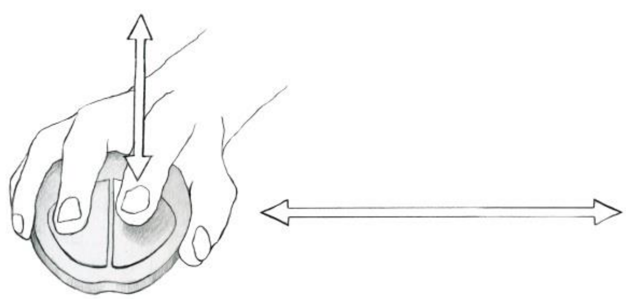

Figure 1. Example of voluntary, discrete, button press coordinated with voluntary, continuous movement of the mouse by the hand.

In contrast, within the movement control literature, what determines goal completion is typically defined by the peak position of a movement's trajectory without any additional response, before reversal of direction to the next target. Within these tasks, the peak position is defined as the maximum amplitude achieved by a movement on the x-axis without the inclusion of a discrete component of movement, and the reversal is defined as the amplitude is which the movement first reversed direction. The underlying movement output regarding the coordination of continuous and discrete components of movement has yet to be considered within the movement control literature.

However, combining aspects of both ergonomics and movement control research, a recent study by Slifkin et al. (2013) examined variations of the spatial and temporal characteristics of a movement peak relative to spatial and temporal characteristics of a button press position, respectively. Movement difficulty in research by Slifkin et al. (2013) and most research pertaining to movement coordination is quantified by the Index of Difficulty (ID), which reflects combined *W* and *A* manipulations, and is quantified by the equation $\log_2(2A/W)$. The experiment by Slifkin et al. (2013) included two levels of ID (2 and 5 bits), and within each there was a small and large scale version of the target display, as shown in Figure 2, with the large scale representing double the *A* and *W* values of the small scale.

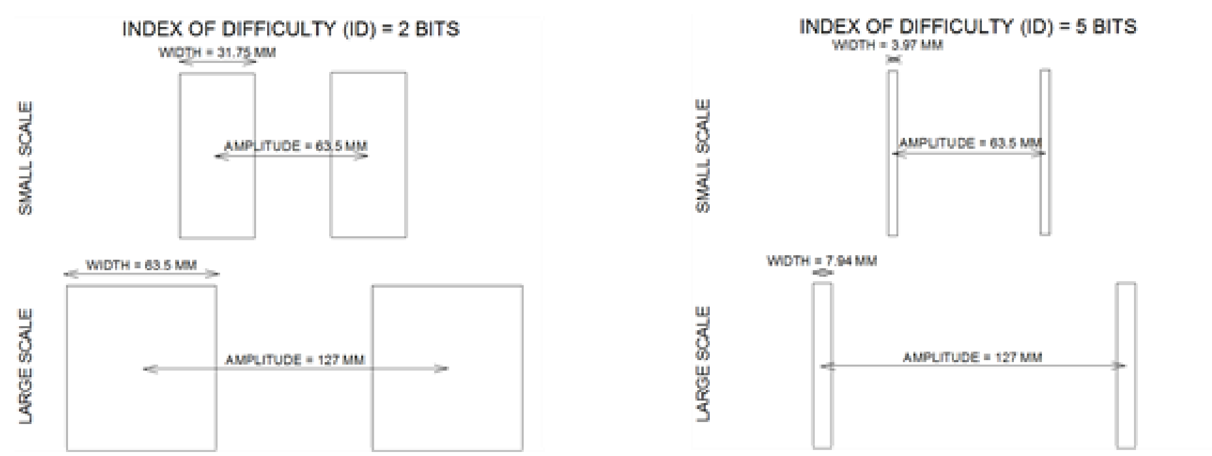

Figure 2. Target display includes small and large scale variations of ID 2 and ID 5 bits (Slifkin and Eder, 2014).

Because it was assumed to be most efficient for the timing and placement of the button press to occur when movement velocity is closest to zero, in order to accurately place the button press within a target region, Slifkin et al. (2013) initially predicted that the spatial location and timing of the peak should match the spatial location and timing of the button press. Producing the vertical button press while the mouse is at rest, at zero velocity, might minimize interference between the continuous and discrete movement components, as interference may be associated with the mouse movement and the accurate placement of the button press within the target region. In support of that expectation, research on finger tremor and its coordination with button pressing indicates that the downward button-press response of the finger is timed so it is coordinated with the direction of finger tremor (Goodman and Kelso, 1983). In other words, the initiation of a voluntary button press is timed so as to take advantage of the characteristics of the involuntary characteristics of tremor. However, Slifkin et al. (2013) found that the spatial and temporal coincidence between the coordination of a voluntary continuous movement of the hand (the peak position of movement) and the discrete button press within a goal-oriented task were not entirely synchronous, but varied according to the task constraints.

Considering the probability of the button press occurring after the peak in time and the relationship between the button press position and the peak position, Slifkin et al. (2013) found that the relation between the button press position and peak movement position varied as a function of changes in *W* and *A*. The following illustrations depict examples of the overall relationship of spatial and temporal movement components found at lower and higher ID’s in the study by Slifkin et al. (2013). At lower ID’s, where accuracy demands are minimal, the button press was more likely to occur before the peak position, both temporally and spatially, as shown in Figure 3.

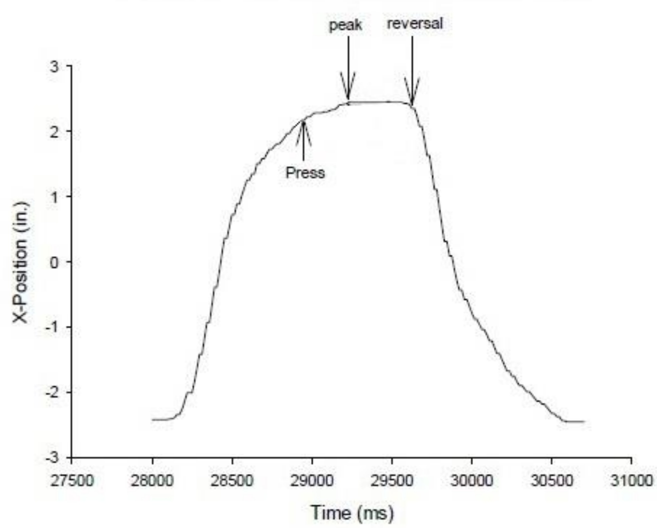

Figure 3. An example of cursor movement from left to right, and back to left at an attempt of right-target capture on the x-axis. The figure depicts a button press occurring before the peak and reversal of movement, spatially and temporally. Zero on the y-axis of the figure represents the midpoint (center) between targets along the movement x-axis, with negative values representing a movement left of center, and positive values representing movement right of center. Time on the x-axis of the figure represents a part of the overall time frame in which the movement occurred within a 1000 movement sequence. Note: The details of the figure have been altered to help illustrate the results of Slifkin et al. (2013).

As illustrated in figure 3, the button press is administered as the mouse is in motion. When the target widths are wide and accuracy demands are minimal, it seems that the button press can be made during movement; there is tolerance for perturbations to button press position introduced by the concurrent mouse movement.

On the other hand, at higher IDs, the button press is more likely to occur at the same point in space as the peak position and after arrival of the peak position in time, as shown in Figure 4.

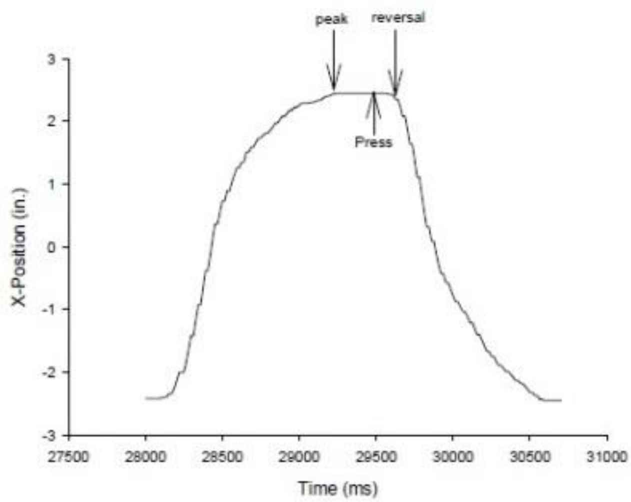

Figure 4. An example of cursor movement from left to right, and back to left at an attempt of right-target capture on the x-axis. The figure depicts a button press occurring spatially at the peak position, temporally after the peak position, and before the reversal of movement to the next target. Zero on the y-axis of the figure represents the midpoint (center) between targets along the movement x-axis, with negative values representing a movement left of center, and positive values representing movement right of center. Time on the x-axis of the figure represents a part of the overall time frame in which the movement occurred within a 1000 movement sequence. Note: The details of the figure have been altered to help illustrate the results of Slifkin et al. (2013).

As represented by the Figure 4, by executing the button press after movement has stopped, the interference that the mouse movement might have on the button press is removed. This would seem to be of particular import when the target widths and accuracy demands are stringent.

As accuracy demands increase at higher indices of difficulty, the probability of the button press position occurring at the peak position and after the peak position in time increases. As shown in figure 5, there is a significant increase of the button press position occurring after the peak position in time from ID 2 (low demand for accuracy) to ID 5 (high demand for accuracy) is displayed. This further indicates that shortly after the peak position is reached in time, a button press occurs coincident to the peak position in space.

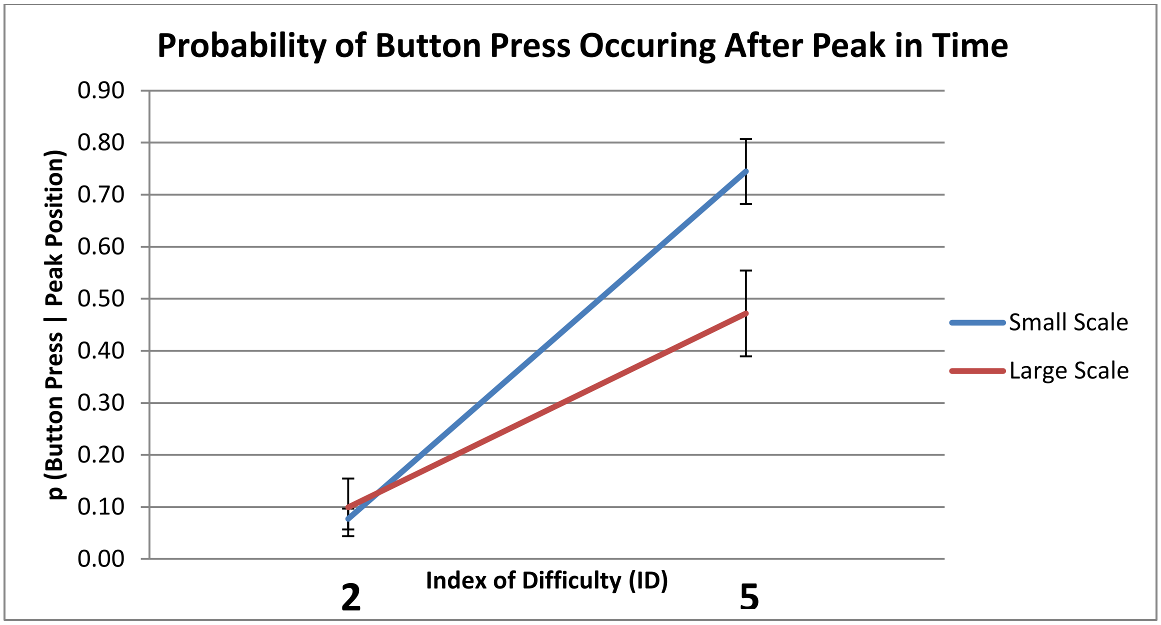

Figure 5. A significant increase in the probability of the button press occurring after the peak in time is displayed between ID 2 and ID 5 for both small and large scale versions of the target display. Values on the y-axis were calculated by assigning individual movements within each condition a 1 (button press occurring after peak in time [subtraction resulting in a positive result]) or 0 (button press occurring before peak in time [subtraction resulting in a negative result]). These assigned values were then averaged. Error bars represent standard error of the mean (Slifkin et al., 2013).

It can be assumed that the increased spatial alignment between the button press and the peak position in difficult tasks illustrates that continuous and discrete components of movement were produced in series. That is, if the continuous component of the mouse movement by the hand is ceased, the discrete component of the button press is produced when the continuous component of the action has been completed. For example, the observation that mouse-movement ends and then the button press occurs may reflect associated information that are separate and produced in series. Similar to single-channel hypotheses of information processing, it may be assumed that the continuous component of movement must be completely processed before the discrete component of movement is processed during difficult tasks (Schmidt, 1982). For example, when the target width is narrow, or in other words, when accuracy demands are high, movements are more likely to be processed separately, or in serial. Conversely, in simple tasks where demand for accuracy is low and the button press occurs during movement of the mouse, the peak position occurs after the button press, such decreased spatial alignment of the peak position and button press position might reflect parallel (or simultaneous) planning and sequencing of the components of action. The button press is depressed as the trajectory of the mouse movement by the hand continues in space, indicating that the movements are produced and perhaps planned simultaneously in less demanding tasks. As shown in figure 6, as ID decreases from ID 5 to ID 2, the button press position tends to occur before the peak, suggesting that the spatial alignment of the button press to the spatial position of the peak decreases as demand for accuracy decreases.

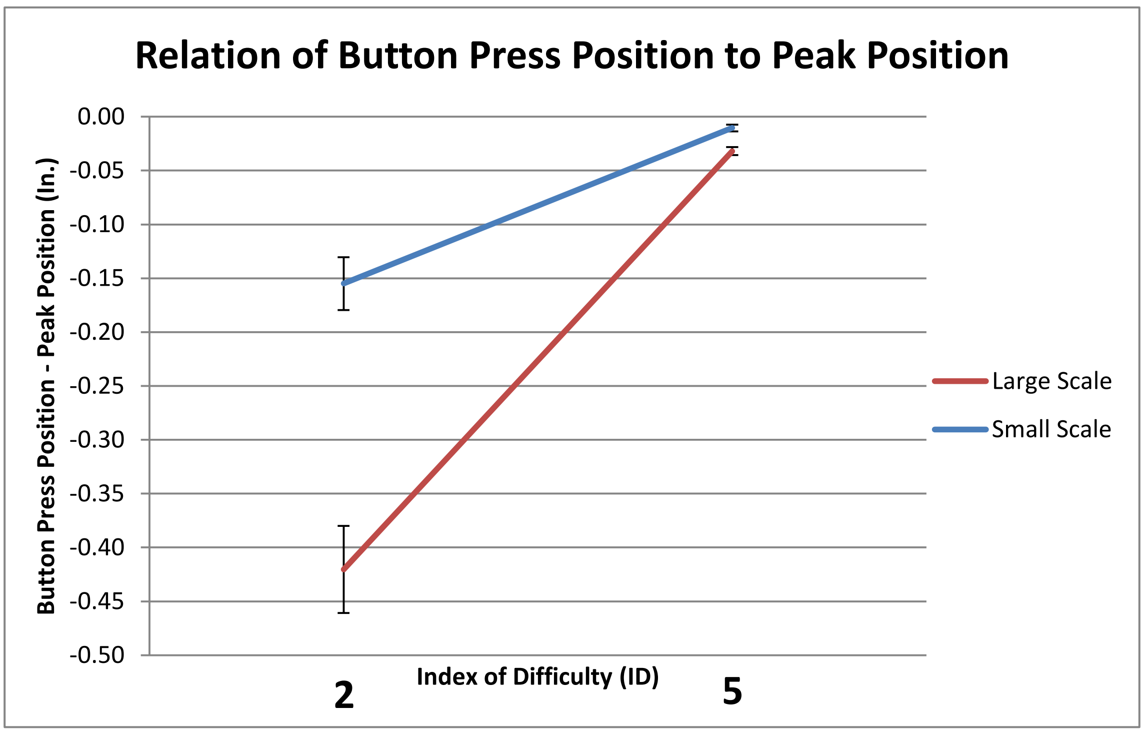

Figure 6. A significant increase in the coincidence of button press and peak position from ID 2 to ID 5 is displayed. The position of the button press occurs before the peak position at ID 2. That effect is stronger at the large scale target display where there is a much greater small-to-large scale increase in the absolute size of *W*. At ID 5 the button press and peak position occur, on average, at the same point in space. In that case,

between-scale changes in the absolute size of *W* are small (see figure 2). Error bars represent the standard error of the mean (Slifkin et al., 2013).

Research indicating that increased precision demands require reductions in physiological disturbances may also support findings by Slifkin et al. For example, studies by Kuznetsov et al., (2011), on the effect of movement on respiration have shown that during difficult aiming tasks, respiration becomes more regular and periods of breath holding increase. The theory of reactive tuning also postulates that the body must adjust to a more stable state when introduced to a movement task with increased accuracy demands (Kuznetsov et al., 2011). As reflected in the research of Slifkin et al. (2013), it may also be assumed that the resulting synchronization and serial planning of button press position and peak movement position at high indices of difficulty may be due to the increased demand of end point accuracy and precision, which may only be achieved through the reduction of movement disturbances, specifically, the reduction of perturbations from the hand.

While prior research by Slifkin et al. (2013) seems to provide support for the influence of *W* on the results, the design did not allow for the determination if and how much *A* has an influence. In a study in which a button press was not required, results indicated that the manipulation of *W* affects the temporal attributes of goal directed movements more than the manipulation of *A* (Adam and Paas, 1996). It was found that as *W* decreases and *A* increases it becomes more difficult to accurately terminate movement within the target region, and that reduced *W* carries a stronger effect on this difficulty (Adam and Paas, 1996). That may result in increased dwelling at movement end points (dwell time) within the target region. It may then be assumed that the *W* manipulation will have more of an impact on the spatial and temporal coordination of button press position and peak position than the manipulation of movement amplitude.

The present study investigated whether the size of target width or the distance between targets (*A*) in a movement task has more of an effect on the location and timing of the button press in relation to the peak position, and therefore, the occurrence of serial versus parallel planning of movement. Following the concept of reactive tuning, which postulates that disturbances in movement must be diminished to facilitate increased movement performance (Kuznetsov et al., 2011), it was hypothesized that reductions in *W* will create an increased demand for reductions of perturbations by the hand, also increasing the likelihood of serial arrangement between continuous and discrete components of action at smaller target widths. The present study also explores the possibility that the structural output of movement components in tasks of varying difficulties may illustrate the production of serial or parallel movement processes. By gradually increasing the difficulty of the task by altering the combination of *A* and *W* values according to the equation $\log_2(2A/W)$ in order to maintain consistency with research by Slifkin et al. (2013) and previous movement control literature, there may bean explanation as to when the transition to one form of processing to another may occur.

1.1 Initial Prediction

W was predicted to have a significant effect on the coincidence of button press position and peak position in movement tasks with a high index of difficulty. As shown in Figure 7, the predicted results of the two-way *A* by *W* ANOVA on the probability of the button press occurring after the peak position would reveal a significant effect of the

W manipulation compared to the amplitude manipulation as the index of difficulty increases.

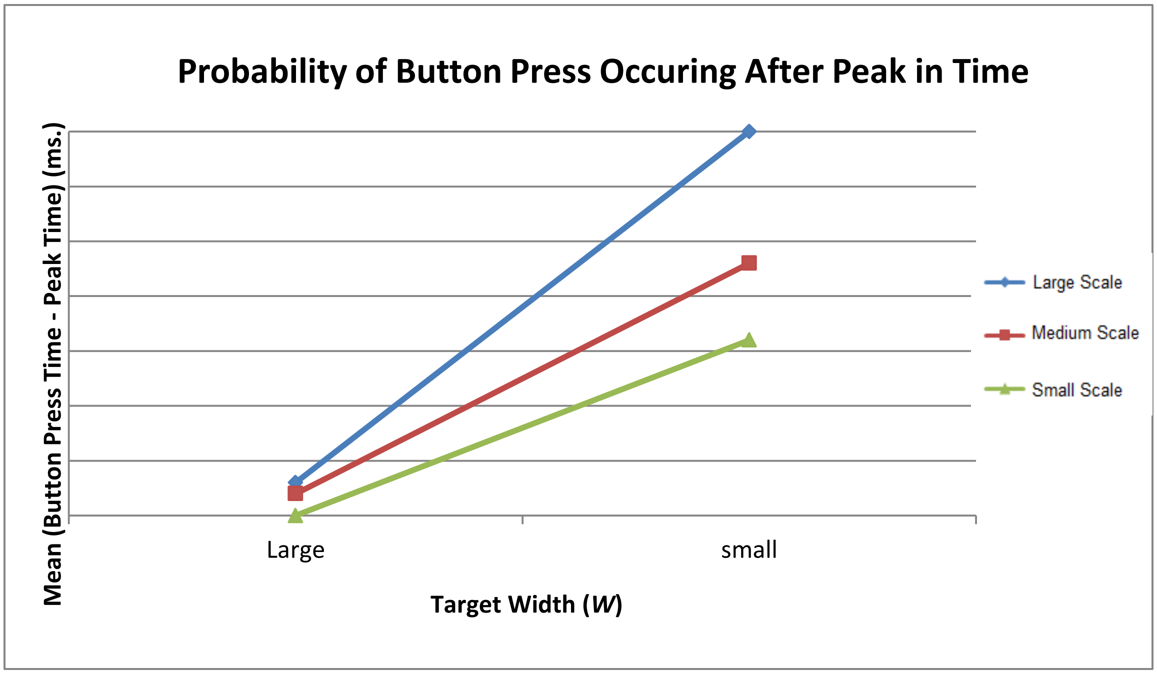

Figure 7. The probability of the button press occurring after the peak in time is predicted to be significantly greater as ID increases for target width in comparison to amplitude, where amplitude has little influence at large values of *W*, but increases in *A* have an increasing effect at smaller values of *W*.

The *W* manipulation is predicted to show the strongest effects due to increased demands for accuracy, and this effect should occur gradually as *W* decreases in size. In order to reduce chances of error at smaller target widths, it is hypothesized that hand and finger perturbations must be reduced in order to maintain accuracy (Kuznetsov et al., 2011). Overall, the above results would further support the hypothesis that divergent spatial and temporal processing may occur more strongly within tasks that contain smaller and more constrained end points or targets. However, an effect of *A* would also be displayed as *A* increases, but the effect would not occur as strongly as compared to *W*.

CHAPTER II

METHOD

2.1 Participants

Twenty right-hand dominant individuals from Cleveland State University with no known prior history of neurological disease or damage, and normal or corrected-to-normal vision served as participants. Participants self-reported hand-dominance and prior history. Participants not meeting these criteria were excluded from participating. All participants received compensation by receiving course credit. The last thirteen participants of the participant pool were used in the current data analysis (N=13).

2.2 Materials

Target displays were viewed on a 469.90 mm flat screen LCD video monitor (Acer X183H) with viewable dimensions of 230 mm in height by 430 mm in width. The LCD video monitor had a height of 977.90 mm and was fixed to a stand resting on a tabletop so that the center of the monitor was at eye level for the typical participant. Movements were made on 304.80 by 457.20 mm graphics tablet (Wacom Intuos2) using its cordless mouse (Wacom Intuos2 4D Mouse) stationed on a tabletop with a height of 742.95 mm. The graphics tablet was placed directly in front of the video monitor, and participants were seated in an adjustable chair in front of the table so that their body midline was aligned with the midline of the tablet and monitor. Participants were allowed to adjust the chair to a comfortable height and distance from the table, making the distance, on average, from participants' eyes to the video monitor 660.40 mm.

2.3 Design

Customized software ran the experimental contingencies and randomly presented the target displays. Each target display consisted of two targets set equidistantly from the center of the monitor. The targets appeared as thin, white rectangular outlines overlaying a black background. The heights of the targets were always set at 139.70 mm. As shown in Table 1, there were three levels of *A* (80, 160, 320 mm) and at each level of *A* there were five levels of *W* (5, 10, 20, 40, 80 mm). Thus, there were 15 unique and randomly presented target display conditions. Each display was associated with an ID level ranging from 1-7 bits (1, 2, 3, 4, 5, 6, or 7 bits). Further, within ID levels 3, 4 and 5 bits there were three levels of scale, within ID levels 2 and 6 bits there were two levels of scale, and there was a single scale level at ID levels 1 and 7 bits. Thus, this design allowed an examination of the influence of a wide range of *A* values, *W* values, and their potential interaction on relations of the button press and the peak.

Amplitude (mm)	**Width (mm)**				
	80	**40**	**20**	**10**	**5**
80	ID 1	ID 2	ID 3	ID 4	ID 5
160	ID 2	ID 3	ID 4	ID 5	ID 6
320	ID 3	ID 4	ID 5	ID 6	ID 7

Table 1. *A* by *W* manipulations according to level of ID.

For each display, participants completed 100 consecutive movements. During that time, a white cursor in the shape of a cross-hair was continuously displayed on the video monitor. The x-dimension control-to-display mapping was a 1:1 ratio, such that a unit of mouse movement along the x-dimension of the graphics tablet translated to a unit of cursor movement along the x-dimension of the video display. The y-dimension control-to-display gain was 1:1.33.

2.4 Procedure

Upon arrival to the laboratory, participants were provided an informed consent form (Appendix A) and asked to fill-out a questionnaire regarding handedness, demographic information, and health history (Appendix B). The experimenter then demonstrated the procedure of the movement task at the start of the experimental session. Participants were instructed that the unfixed crosshairs on the video monitor would serve as a cursor that corresponded to the position of the mouse on the graphics tablet. At the start of each movement condition, a stationary white marker, also in the shape of a crosshairs, appeared in the center of the left target. Participants were told that the stationary marker in the center of a target identified the currently active target; however it was emphasized that a target hit would register if the mouse button is pressed while the unfixed cursor is within any interior region of the target area. In contrast, any button press occurring when the cursor crosshair were outside of the active target area was classified as a target miss and was accompanied by a "beep" sounded by the computer. At the time of either a target hit or miss, the marker crosshairs would change location and therefore activate the opposite target. Participants were instructed that they should move to the active target and produce a button press when the cursor was in that target region. Participants were told to continue the sequence of back and forth movements until the target display disappeared from the screen. This event signaled the end of the 100 movement sequence. Participants were told to be as fast and accurate as possible in making their movements, and that it was equally important to maintain attention throughout the task.

After the experimenter demonstrated the procedure, each participant completed 10 practice movements for 5 randomly selected *W* and *A* conditions. Participants were asked to take a brief rest before continuing to the next experimental target width and amplitude conditions in order to reduce any potential effects of fatigue. Participants were also able to rest after each experimental condition, if needed. The room lights were extinguished while the experimental task was performed, making only task-related visual information, such as the target displays on the video monitor, available to the participants. In addition, participants wore sound attenuating ear muffs during the experimental trials to minimize the potential influence of sound extraneous to the experiment. The total duration of the session was approximately 1 hour and all participants were tested individually. Upon completion of the task, participants were handed a debriefing form (Appendix C), thanked and given participation credit.

2.5 Data Analysis

2.5.1 General Data Processing.

- Movement time (*MT)* was defined as the time of the mouse click that terminated movement at the previous target to the mouse click that terminated movement at the current target.
- Peak position was defined as the location of the maximum amplitude achieved by the cursor on the x-axis, independent of the button press. Peak position always occurred before the reversal in time, and after the reversal in space, as peak position always occurs at a larger amplitude value than reversal. It was often found that the peak position was reached and then followed by more than one

sample of the same positional value paired with increasing time values, in such a case, the first value in the sample was recorded. Peak time was associated with the value of the peak position.

- Button press position was defined as the position of the button press that terminates movement at or around each target area, and was identified as either a target hit or target miss. An accurate movement was defined as a target hit. Button press time was defined as the time during the session in which the button press occurs.
- Reversal position was identified as the position where the trajectory first reversed direction, always occurring after the time of the peak position but at a lower peak position in space. The reversal position may occur before or after the button press position. Reversal time was defined as the time in which the reversal first takes place, associated with the reversal position.

Maintaining consistency with previous research by Slifkin et al. (2013), a total of twenty-five movements, movements 74 through 98, were subject to analysis. Movements that were inaccurate, for example, movements that did not result in the button press occurring within the target region, remained in the analysis. Dependent variables included the probability of the button press given the peak, button press position minus peak position, reversal time minus peak time (dwell time) and movement time (MT). Variations in those dependent variables were examined as a function of target width (*W*), and amplitude (*A*).

Each dependent variable was analyzed using 2-way amplitude by target width ANOVAs with repeated measures on *A* and *W* conditions. *A* included three levels and *W* included five levels, resulting in a total of fifteen conditions. By applying the *A* by *W* ANOVA with repeated measures, the effects of *A* and *W* manipulations on the spatial and temporal coordination of movement output was tested. Because it was initially predicted that the main influence of increased spatial and temporal coordination is *W*, the initial *A* by *W* ANOVA on probability of the button press position given the peak position was proposed to reveal that *W* will be the main determinant of variations in the coordination of spatial and temporal qualities of movement.

CHAPTER III

RESULTS

The main 2-way *A* by *W* ANOVA with repeated measures on the probability of the button press given the peak position indicated a main effect for target width *W* $F(4,52) = 75.726$, $p < .01$, partial $\eta^2 = .853$ and a main effect for Amplitude *A* $F(2,26) = 3.607$, $p<.05$, partial $\eta^2 = .217$, with *W* having a more pronounced effect on the coincidence of button press and peak. In particular, as *W* was reduced below 40 mm, there were strong and systematic increases in the likelihood that the button press would occur after the peak. As shown in Figure 8, the effect of *W* is large, increasing nearly by p = .7 as *W* decreases to 5 mm. The overall *A* by *W* interaction was also significant, $F(8,104)=2.258$, $p<.05$, partial $\eta^2 = .148$.

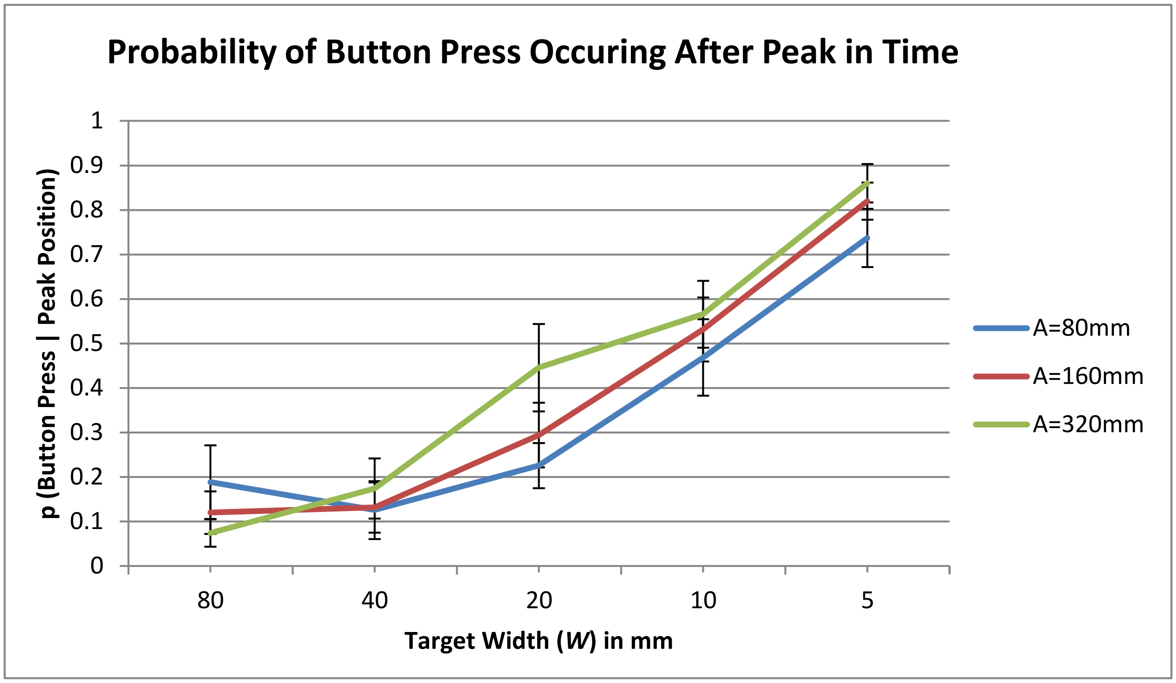

Figure 8. The probability of the button press position occurring after the peak position in time increases as *W* becomes smaller and as *A* becomes greater, with *W* having a more profound effect on this relationship. Values on the y-axis were calculated by assigning individual movements within each condition a 1 (button press occurring after peak in time [subtraction resulting in a positive result]) or 0 (button press occurring before peak in time [subtraction resulting in a negative result]). These assigned values were then averaged. Error bars represent standard error of the mean.

By looking more closely at Figure 8, it can be suggested that *W*'s of 80mm and 40mm do not display a probability effect, unlike what is displayed between *W*'s of 10mm and 5mm. It may be suggested that, because *W*'s at 80mm and 40mm remain wide enough to accommodate higher levels of movement variability, the relationship between button press and peak is affected more strongly over a certain range of reduced *W*'s. It is also important to note that the results of this variable do not adequately demonstrate that the peak position is more coincident with the button press if the button press occurs after the peak in time. Because reversal position may occur in time before the button press occurs (e.g. – a participant is in reversal to the next target and administers a button press), an analysis on button press position minus peak position was conducted.

A 2-way *A* by target *W* ANOVA with repeated measures on the additional variable of button press position relative to peak position was considered. The analysis revealed a main effect for *W* $F(4,52) = 20.233$, $p < .01$, partial $\eta^2 = .608$, and a main effect for *A* $F(2,26) = 5.619$, $p < .01$, partial $\eta^2 = .301$. The *A* by *W* interaction was also significant, $F(8,104) = 2.946$, $p < .01$, partial $\eta^2 = .185$. See figure 9.

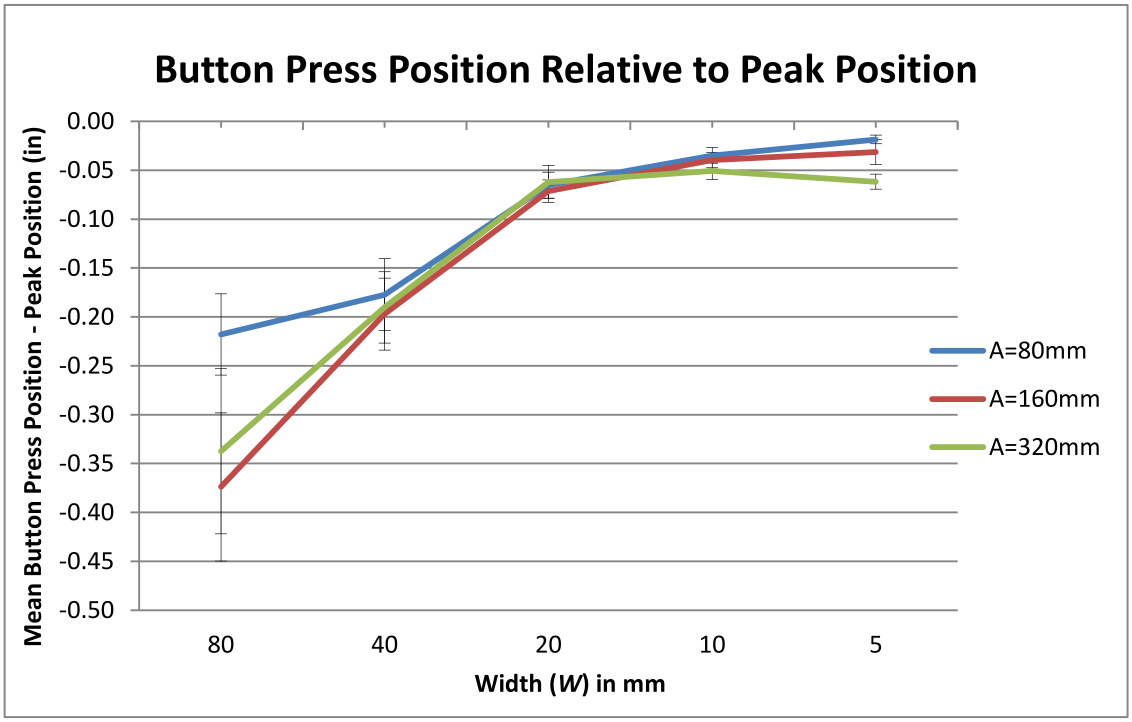

Figure 9. Results regarding position further support the trend that the coincidence of the button press and the peak increases as target width decreases. Error bars represent the standard error of the mean.

By looking at Figure 9, it appears that there is no significant effect for *A* values when paired with *W*'s of 40, 20, or 10mm. It can be suggested that the overall *A* x *W* effect accommodate for a large amount of movement variability that will continue to provide accurate movement output at a movement's end. Therefore, according to the figure, the difference between button press position and peak position when paired with larger *W*'s displays more of an effect. Supporting these results, a study by Walker et al. (1997)

concluded that reductions in W and increases in distance result in increases in corrective submovements, or adjustments in cursor location, at target endpoints. Corrective submovements may also reflect a lack of coincidence between peak position and button press variables in the current study. However, the SEM is large within *W* = 80, which may indicate that there is no effect between the three levels of *A* in this figure.

A two-way A by W ANOVA with repeated measures was also applied to the analysis of the difference between button press time and peak time. Results of this analysis yielded significant results for W $F(4,52) = 47.785$, $p < .01$, partial $\eta2 = .786$, and A $F(2,26) = 9.862$, $p < .01$, partial $\eta2 = .431$. The overall interaction was also significant, $F(8,104) = 4.600$, $p < .01$, partial $\eta2 = .261$. See figure 11.

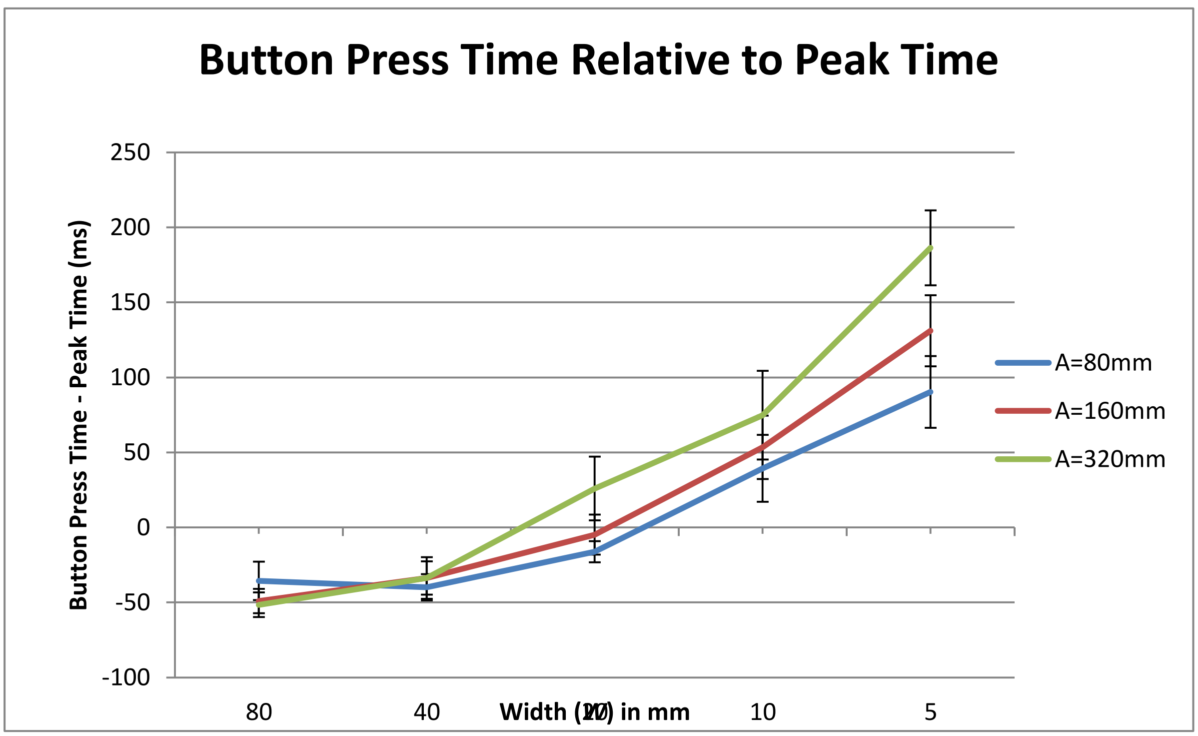

Figure 10. As values of W decrease, results suggest that the time between when the peak is reached and when the button press is administered increases. Error bars represent the standard error of the mean.

Taking a closer look at Figure 11, results suggest that larger A's and smaller W's increase the span between the administration of the button press and the time that the peak is reached in space. This result does not suggest there is a separation of button press position and peak position, but rather, in most cases, movements are more likely to cease for a short period of time at smaller W's and larger A's, suggesting that when the peak is reached, button press is administered when movement velocity is closest to zero.

Also extending the results of the main 2-way amplitude by target width ANOVA, the analysis of dwell time, or the difference between the reversal time and peak time was also considered. Applying a 2-way *A* by *W* ANOVA with repeated measures, the analysis yielded a main effect for *W* $F(4,52) = 73.854$, $p < .01$, partial $\eta^2 = .850$, but did not yield a significant main effect for *A* $F(2,26) = 2.546$, $p > .05$, partial $\eta^2 = .163$. The overall interaction was significant $F(8,104) = 3.721$, $p < .01$, partial $\eta^2 = .223$. See figure 10.

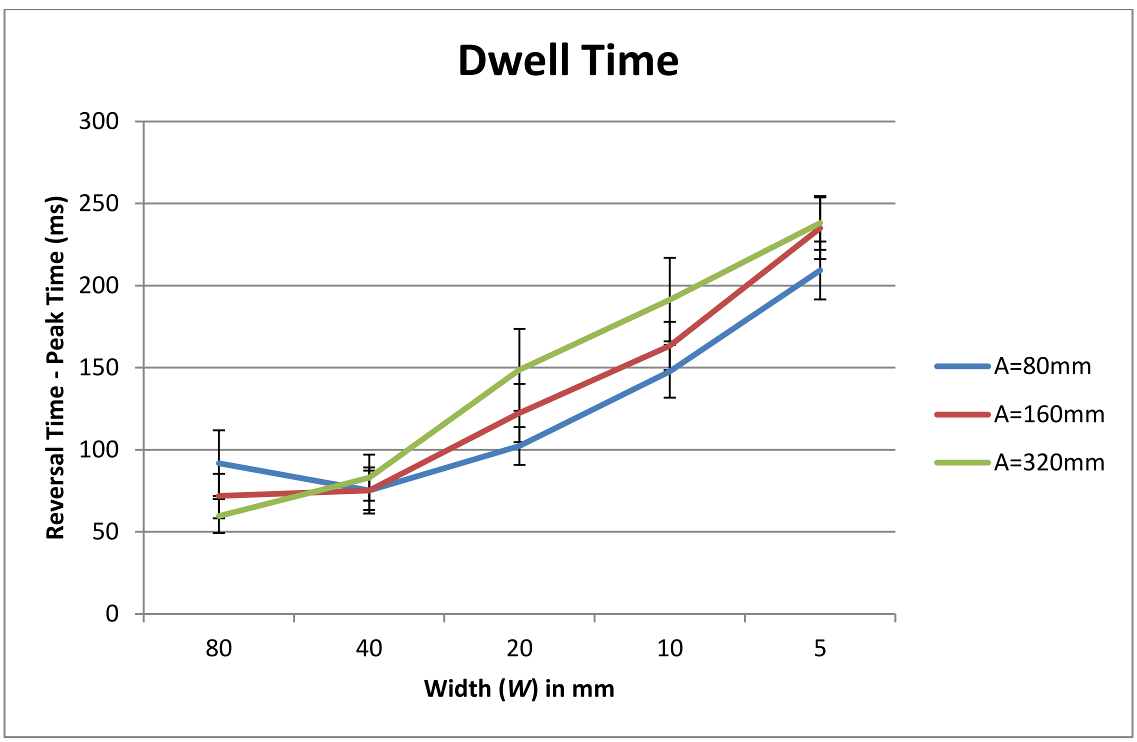

Figure 11. Results regarding dwell time suggest that as *W* decreases, the amount of time spent within target regions increases. Error bars represent the standard error of the mean.

Again, closer analysis of Figure 10 suggests that *W*'s of 80mm and 40mm do not display an effect of dwell time due to these targets being wide enough to reduce the cost of making an error prone or erratic movement.

Finally, movement time was also analyzed via a two-way *A* by *W* ANOVA with repeated measures. Overall analysis yielded significant results, with *W* achieving significance $F(4,52) = 376.309$, $p < .01$, partial $\eta^2 = .967$, and *A* achieving significance $F(2,26) = 194.642$, $p < .01$, partial $\eta^2 = .937$. The interaction was also significant $F(8,104) = 4.778$, $p < .01$, partial $\eta^2 = .269$. See figure 12.

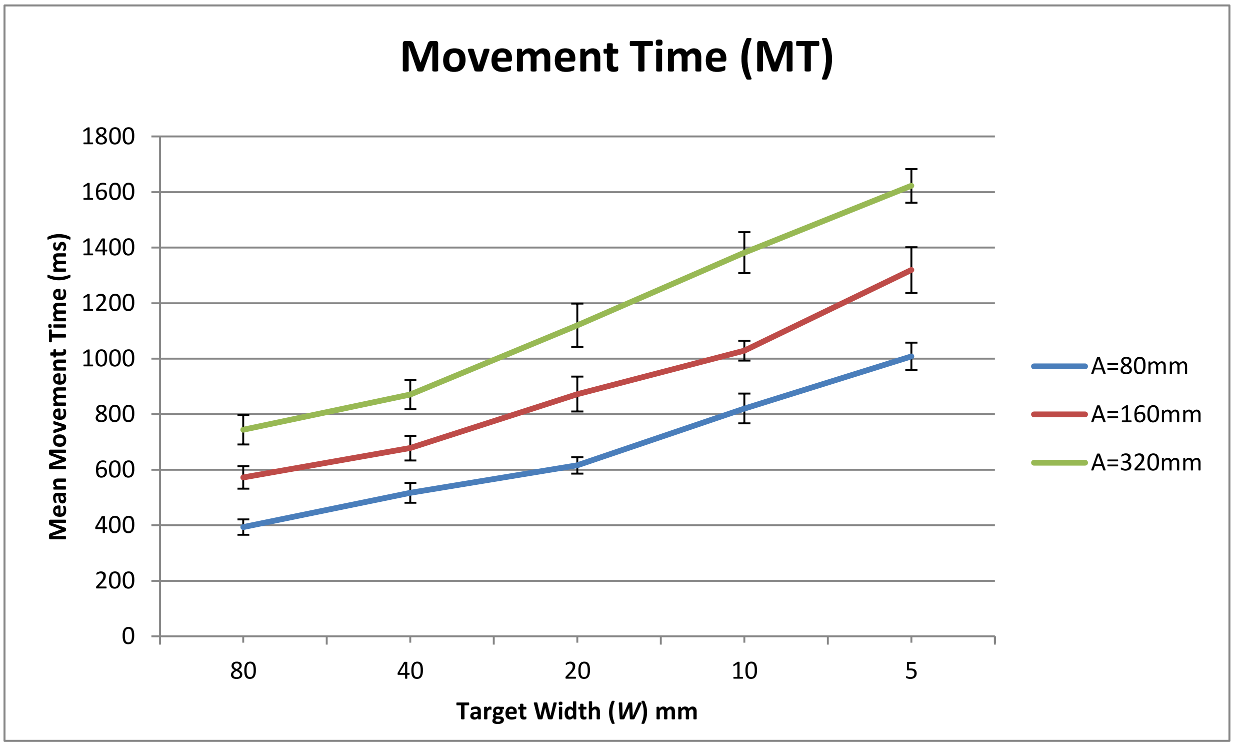

Figure 12. Results regarding movement time (MT) indicate that as *W* decreases and *A* increases, the overall movement time (MT) increases, this effect is more pronounced with reduced values of *W*. Error bars represent the standard error of the mean.

The results of Figure 12 indicate that smaller values of *W* and larger values of *A* increase MT. These results align with results of research by Adam and Paas (1994), with an absence of a button press, reduced values of W and increases in A produce increases in MT.

CHAPTER IV

DISCUSSION

The purpose of the present study was to examine the relation between continuous and discrete components of action, and to further extend the findings of Slifkin et al. (2013). In addition, the present study also contributes to literature regarding amplitude and target width manipulations found within previous research on movement control and ergonomics. Based on predictions by Slifkin et al.'s (2013) previous research, and research conducted using variations of *W* by Adam and Paas (1996), it was predicted that the *W* manipulation would have a more pronounced effect on the location and timing of the button press in relation to the peak position. Results of the present study suggest that *W* carries a more pronounced effect on the spatial and temporal coordination of discrete and continuous movement components. These results may also suggest that movements are processed and produced serially at smaller target widths, and in parallel at larger target widths. In addition, these results may also indicate that these processes are more profoundly affected by *W* as opposed to *A*.

Predictions regarding the underlying processes of movement output at smaller target widths within the present study are supported by the single-channel hypothesis of information processing. It can be assumed that, at smaller target widths where accuracy demands are high, the temporal window must be increased in order to verify movement accuracy. Research by Welford (1967) on the review of the single-channel hypothesis of information processing indicates that the delay between the presentation of a signal and the reaction of a response suggests that one signal must be processed before the next can be processed. These temporal delays between signal and response may reflect the increasing temporal delays between button press and peak position at reduced target widths found in the present study. It may also be suggested that movements are processed according to the single-channel hypothesis, where one movement is processed before the next movement is processed (i.e. – peak position is reached, and then button press is administered), but this effect is more profound as the targets become reduced or when accuracy demands increase (i.e. – at reduced target widths).

The results of the present study may also suggest that increased accuracy demands due to smaller target regions have a profound effect on the physical control of movement coordination. Supported by research on movement precision by Kuznetsov et al. (2011) and Rabler (2000), movement perturbations and motor noise must be reduced in order to maintain accuracy in movement output. For example, in a study by Rabler (2000), movement flexion in a precision task became less accurate if performed within the expiration stage of breathing as opposed to the inhalation stage. Rabler (2000) concludes that certain physiological functions, such as the exhalation stage of breathing, may be the cause of the increase in movement perturbations. Future research may more closely consider the role of physiological effects on the coordination of continuous and discrete components of movement as related to the present study.

Also, unlike initial predictions, the results suggest that the spatial coincidence of button press position and peak position do not occur coincident in a gradual and perfectly linear progression as difficulty of the task increases. For example, it may be concluded that target widths of 80mm and 40mm are similar in size and continue to contain enough space for accuracy maintenance, enough to not produce a significant effect on the spatial coincidence of button press position and peak position. These results may provide evidence that there is a certain threshold where components of movement output shift from one pattern of output to another. It can also be concluded that in a rhythmic task, such as within the present study, the pattern of movement output (i.e. - dwell time, coincidence of peak position and button press position) is due to the planning of the movement as one reaches the target goal, as opposed to the planning of the movement to the next goal while one continues to remain at a current target. In research by Walker et al. (1997), the term 'verification time' is used to characterize the time between the end of the last submovement and the release of a mouse button. Suggesting that there is increased verification of movements at reduced values of *W*, and in order to attempt to produce an accurate movement, one must plan, program and then implement the desired movement. This may reflect the acquisition of the peak position and the administration of the button press within the current study. The time that is required to plan, program, and then implement a movement increases at reduced values of *W*. It may also be concluded that the planning, programming, and implementation of movement processes are occurring as one approaches the target area. Future research may consider more closely these effects on the structural output of movement.

The results of the present study may also have implications towards the study of ergonomics, such as within the design of user-friendly graphical interface systems. Previous research on interface-design set forth by Whisenand and Emurian (1996), considers the role of icon size (target width) and distance between icons (amplitude) on movement time, but does not exclusively determine that target width has a more profound effect on the location of the button press by the mouse, or on accurate icon selection. Applying the results of the present study may aid in the design of user-friendly graphical interface systems that require accurate icon selection by a mouse.

Although the present study was able to demonstrate that *W* in a movement task has a more profound effect on the location and timing of variables regarding movement output, there are some potential limitations that should be addressed. Participants were only required to self-report handedness, which may not reflect an accurate representation of hand dominance. In addition, further studies may not only consider the attempt of target capture, but also further consider the role of accuracy on target capture for the present results of this study, in addition to modified values of *A* and *W*. The present study reflects *A* and *W* values that are similar to values used in current movement control literature, however, future research may consider much larger values of *A* and *W* on movement output. Also, future research on this task may analyze individual differences between participants and explore how certain neurological, psychological, and physiological limitations may play a role in the output of movement structure.

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APPENDICES

APPENDIX A

(Participant Information and Informed Consent Form)

Participant Information and Informed Consent

Thank you for volunteering to participate in our study. We are hoping to learn more about various aspects of the information processes involved in the control of movement. The principle investigator in this study is Dr. Andrew Slifkin, Associate Professor of Psychology, Cleveland State University. Dr. Slifkin may be contacted at 216-875-9752.

There will be a maximum of one experimental session in this study and it will last no more than two hours. After this consent form is signed, but before the experiment begins, we will ask you to complete a brief health questionnaire including questions concerning vision, physical health, medications, and psychiatric disorders. This questionnaire will be used to determine eligibility for participation. You may be excluded from the study if you have physical, neurologic, or psychiatric impairments that impede your upper extremity function or comprehension of the task instructions. If it is determined that you will not be able to participate due to questionnaire responses, then you will receive credit in proportion to the time that you spent in the laboratory.

During the experiment you will be required to make long sequences of hand movements over differing distances toward target areas of differing widths, i.e., under different conditions of visual feedback. We will be interested in examining how changes in those conditions influence your performance. The direct benefit to you for your participation in the study will be the receipt of credit for satisfying your course requirement or possible extra credit opportunity provided by your instructor. In addition, your participation may have benefit to others: The data collected in this study—on healthy individuals—may eventually be used to improve diagnoses and therapies for those with deficits in motor function. Once the experiment is complete you will be given an educational summary of the purpose of the experiment.

There is the possibility that you may experience minor physical fatigue associated with making repetitive hand movements in the task. To help alleviate any fatigue that you may experience, we encourage you to take a break—for as long as you feel you need—between conditions of the experiment. Between conditions, the experimenter will ask you about your feelings of fatigue and if you feel you need to take a break. In addition, between conditions, please alert the experimenter to your fatigue level.

As a volunteer you have the right to discontinue your participation at any point for any reason.

All experimental data will be collected in a way that ensures confidentiality and will in no way be traceable back to you. Should you consent to this research, your data may be used in the future for educational and scientific purposes.

Should you feel the need to seek psychological help due to your experience with participating in this experiment please contact the CSU Counseling Center at 216-687-2277.

Consent

I consent to participate in this research. I have read and understood the information that has been provided regarding this procedure, my task, the purpose of this research, any risks that may be involved and the safeguards that have been taken, benefits that may result from the research, and the educational feedback I will receive when my participation is complete. I understand that my participation is voluntary, and that I may terminate my involvement at any time, without penalty.

I further understand that if I have any questions about my rights as a research subject, I can contact Cleveland State University's Institutional Review Board at 216-687-3630.

Please now complete the first 4 of the following items:

1. Signed____
2. Printed Name____
3. CSU ID Number____
4. Psychology Course Instructor____________________________________
5. Time in Experiment____
6. Experimenter____
7. Experiment Complete?   Y / N

APPENDIX B

(Basic Demographic Information and Health Questionnaire)

Participation Code______________________
Date__________________

Basic Demographic Information and Health Questionnaire

Age______________________ Date of

Birth_______________________

Weight____________________

Height___________________________

Hand Dominance____________

Sex______________________________

Do you wear corrective lenses? Yes No Are you

wearing them today Yes No

Do you have any neurological or psychological disorders

Yes No

If yes, please explain:

____

____

____

Are you taking any medication? Yes No

If yes, please explain:

____

____

Do you have any difficulties using either of your two hands? Yes No

If yes, please explain:

APPENDIX C

(Debriefing Summary)

Debriefing Summary

Thank you for participating in our study. Its main purpose is to examine how movement-related visual feedback influences the way in which you control your movements.

In particular, in this experiment, we are interested in assessing the influence of task requirements (for example, amplitude requirement and target width) and how they influence the control of movement amplitude. That is, how do participants adjust/change the scaling of the amplitude of their movements when faced with different task requirements?

Do you have any questions that I might answer?