THE PENNSYLVANIA STATE UNIVERSITY

SCHREYER HONORS COLLEGE

DEPARTMENT OF PSYCHOLOGY

EXAMINING INITIAL IMPULSE CONTROL FOR BALLISTIC AIMING IN THE ABSENCE OF PHYSICAL FEEDBACK

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ABSTRACT

This study was broken into two parts, the first part relating to the current study and second being an exploration of a new application of the cognitive and sport psychology literature. The initial study examined the effect of eliminating feedback in a Fitts' ballistic aiming task on probability of task success. The goal of this study was to clarify the roles that available time and opportunity for feedback play in Fitts' Law by isolating initial impulse by giving no opportunity for feedback. Target width and distance were modified in a 3x3 design, creating 9 conditions randomized in 3 trial blocks. The participant's (n=19) accuracy results were recorded and confirmed our hypothesis that probability of task success decreases as a function of increasing index of difficulty. This line of research, as well as that of the field of sport psychology, led to the second part of our study, an exploratory project on the concept of preparatory hand motion (PHM). Common examples of this motion include throwing a dart, a Frisbee, or a basketball free throw. Our goal was to review literature related to this topic, make predictions about the role that the nature of the target (namely the target size and target distance) plays in this preparatory hand motion, and examine what functionality these movements have to determine if they can be trained.

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Introduction

The field of cognitive psychology has studied the concept of motion planning in a number of domains, and these studies have led to breakthroughs in understanding the way that humans move and what brain processes coincide with motion and motion planning. One key component of this field is the examination of movement in aiming tasks and how the nature of the target influences this movement (Fitts, 1954). Our study utilized research on aiming tasks and altered their typical design in an attempt to better understand and explain the research findings. The process of our research resulted in two main applications of our study, separated into two parts for this paper. The first part of the paper deals with Fitts' Law and ballistic motion aiming, and analyzes several theories for how the target affects hand movement in these tasks. Also in this part I detail the method of our study, our results, and how these can be applied to the cognitive psychology literature and future research. This application led to the second part of the paper, which discusses the novel concept of "Preparatory Hand Motion" (PHM) in the sport psychology concept of "Preperformance Routines" (PPR). In Part 2 we explore the concept of PHM and use the research from aiming, pre-performance routines, and the results from our current study to propose theories for how and why this movement is utilized to better control hand initial impulse movement (Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979) and to maximize probability of optimal performance.

Part 1: Fitts' Law and Ballistic Movement Aiming

Background

Fitt's Law

One core concept in the field of cognitive psychology examines how motion in aiming tasks is related to the nature of the target. This is captured by Fitts' Law (Fitts, 1954), which asserts that the time to move to a target is determined by the distance to the target and the target's size. The equation that Fitts used to define this relationship was as follows: MT= a + b $\log_2$ (2A/W) (MT= movement time; A= amplitude (distance) between center of targets; W=width of target; a and b = empirical constants) (Fitts, 1954). A vital component of this equation is what Fitts referred to as the "index of difficulty." This construct is represented in Fitts' initial equation by the expression: ID= $\log_2$ (2A/W); (ID= Index of difficulty; A= amplitude (distance) between center of targets; W=width of target). The hypothesized relationship here is that movement time increases linearly with index of difficulty, a claim that study of this topic confirms (Meyer, Smith, Kornblum, Abrams, & Wright, 1990).

The crux of Fitts' Law is that movement to a target during an aiming task involves an initial ballistic impulse followed by feedback that allows the participant to home-in on their desired target (Rosenbaum, 2010). This relationship between movement time and the nature of target has been consistently confirmed through research and has allowed for significant application of this law to a multitude of movement concepts. These include movement around obstacles (Jax, Rosenbaum, & Vaughan, 2007), movement through restricted pathways (Accot & Zhai, 2001), and mentally simulated movements (Decety & Jeannerod, 1995). The popularity of this conception has also served as a catalyst for expansions, alterations, and explanations about Fitts' Law and the underlying mechanisms for this relationship.

Iterative Corrections Model

The iterative corrections model (Crossman & Goodeve, 1963/1983, Keele, 1968) hypothesizes that ballistic movement is broken down into a continuous series of discrete "submovements" that are informed by feedback that the target has not yet been reached. Feedback allows the participant to move their hand closer to the target in a fixed proportion until a minimal limit of aiming error is approached. This model postulates that the submovements of the hand decrease in a fixed proportion and terminate when they reach their destination. The iterative corrections model supports Fitts' idea that movement time is directly related to index of difficulty under the assumption that each submovement will have a constant duration (Rosenbaum, 2010). Though the discrete submovements of iterative corrections model have shown up during aiming studies (Annett, Golby, & Kay, 1958; Carlton, 1981; Crossman & Goodeve, 1963/1983; Jagacinski et al., 1980; Langolf, Chaffin, & Foulke, 1976; Woodworth, 1899), the submovements have lacked consistency in duration (Jagacinski et al., 1980; Langolf et al., 1976) and do not move in distances proportionate to the target's location (Jagacinski et al., 1980). The inconsistent findings of this theory have led to further hypotheses attempting to better explain Fitts' Law.

Impulse Variability Model

While iterative corrections model emphasizes the current control phase as a representation of Fitts' Law, impulse variability model turns the focus to initial impulse movement (Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). This model postulates that during ballistic movement there is an initial impulse movement towards the target followed by a coasting movement carried out until the target is reached. Schmidt et al. postulated that the spatial error of the initial impulse is proportional to the distance divided by the time of the movement it produces. If this model is accurate, then virtually all of the variance in hand movement can be accounted for with the initial impulse toward the target. To test for this hypothesis, Schmidt et al. (1979) altered Fitts' design which involved moving to a defined target as quickly as possible, to a task that called for participants to move to targets in a designated period of time while attempting to minimize spatial variability. The results of this study allowed for the establishment of the relationship between time, distance, and effective target which is described in the following equation: $T= k (D/W_e)$ (T=Time; D= Distance; W_e= standard deviation of the endpoints). Simply put, this relationship caused Schmidt et al. to suggest that movement impulse delivers a burst of force to the hand that increases as the distance to target increases and as the response time decreases. The goals of ballistic action, then, should be to optimize the time and force needed to reach a target and to minimize movement variability. The contributions of this theory include the recognition of variability in neuro-motor processes and extending the relationship between time, force, and distance established by Fitts; however, the absence of a feedback component in this model has led to alternative model formation (Rosenbaum, 2010).

Optimized Initial Impulse Model

Recognizing the strengths and weaknesses of the Iterative Corrections Model and the Impulse Variability Model, the Optimized Initial Impulse Model sought a middle-ground to more fully account for the data on manual aiming in ballistic tasks (Meyer, Abrams, Kornblum, Wright, and Smith, 1988). This model states that a subject begins by making an initial impulse movement towards the target, and if the target is reached, the movement is terminated; however, if the target is not reached, the participant utilizes feedback to make a subsequent movement towards the target. This process is repeated until the target is reached and the task is completed. In the tasks Meyer et al. measured, the participant's goal was to move to the target as quickly as possible, so ideally their desired action should have been optimized through high velocity and minimal spatial error. However, one of the core assumptions of Optimized Initial Impulse Model is that spatial accuracy during ballistic movement is a flawed process. This notion allows for the formulation of the following equation to describe the relationship between the standard deviation of movement, time, and distance travelled: $S_i = k\ (D_i/T_i)$; (S_i=Standard Deviation; D=Distance, T= Time). The equation for optimized initial impulse model leads to the idea that the subject much choose between either making a long movement in a short time period (which would sacrifice spatial accuracy) or making a short movement in a long period of time (which would facilitate spatial accuracy but sacrifice time). Optimized initial impulse model states that to optimize movement efficiency, subjects should balance these two strategies in an attempt to minimize total movement time, an explanation that has been supported by data collected during aiming studies (Rosenbaum, 2010).

Current Study

Fitts' Law has been studied extensively in the field of cognitive psychology and has consistently confirmed Fitts' hypothesized relationship between movement time, the target's width, and the distance to the target. However, because participants in Fitts aiming tasks have performed under time pressure, they may not have prepared their initial impulse as well as they could. Also, ironically, because participants in Fitts aiming tasks have also had the opportunity to correct errors, they also may not have prepared their initial impulse as well as they could.

The task that we designed, on the other hand, involved the participant acting on an object and "launching" towards a target. This design was unique because the participant had no opportunity to utilize feedback when preparing to make their movement towards the target, making it consistent with the theoretical framework of impulse variability model (Schmidt et al., 1979). Figure 1 shows the general characteristics for the variables of "opportunity for feedback" and "available time" (that is allowed to perform the task) in the typical design of Fitts' Aiming tasks, compared with the design of the current study.

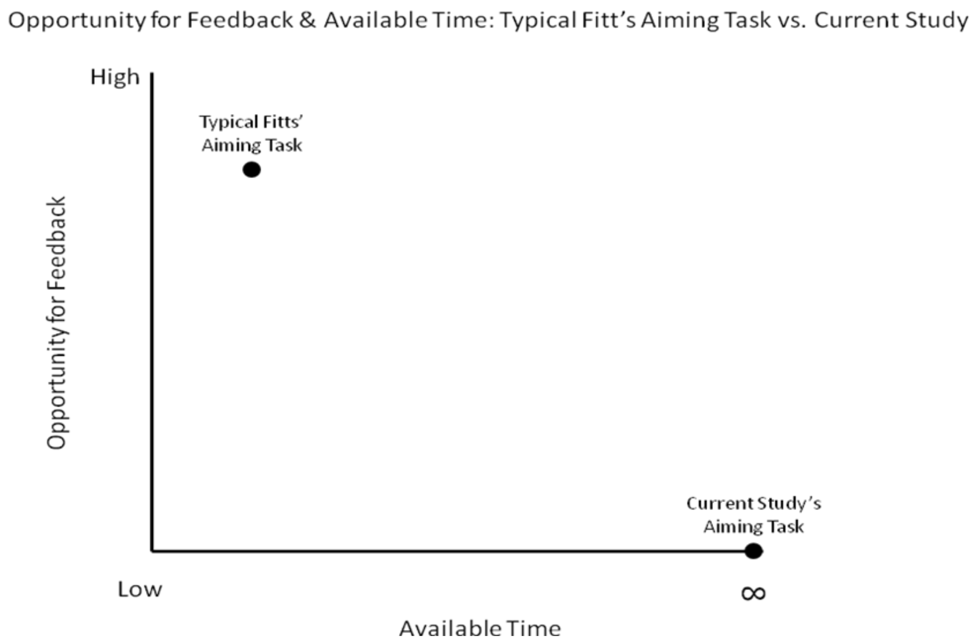

Figure 1

An advantage of this study is that even without the opportunity for feedback, our study still varied the amplitude and width of the two targets, allowing us to form a relationship between the index of difficulty ($ID = \log_2 2A/W$) and trial accuracy. This setup allowed to us to apply Fitts' concept to our design and form the following hypothesis that the probability of trial success (henceforth referred to as "probability of hit") decreases as a function of increasing index of difficulty:

H_0: If Fitts' Law is mainly due to feedback correction, as proposed by Crossman and Goodeve (Crossman & Goodeve, 1963/1983) and Keele (1968) there should be no relation between the index of difficulty and the probability of success on the ballistic aiming task.

H_1: If Fitts' Law is mainly due to initial impulse control, as proposed by Schmidt et al. (1979) and Meyer et al. (1988, 1990), there should be a strong relation between the index of difficulty and the probability of success on the ballistic aiming task.

Method

Participants

19 participants ages 18-33 (*M* =19.74, *SD* = 3.41) who were enrolled in introductory psychology courses at The Pennsylvania State University were recruited through the undergraduate psychology subject pool. There were 9 male participants and 10 female; 57.89% were Caucasian, 21.1% were Asian, 15.79% were Hispanic/Latino, & 5.26% were African American. All 19 participants responded that they had no vision, hearing, or other notable physical impairments. The participants of this study received course credit for their participation. Participants signed an informed consent form and were also had the option to give consent to be videotaped, which 17 or the 19 participants did. This experiment was conducted in Room 443C Moore Building of Penn State University and done in conjunction with Dr. David Rosenbaum's lab for cognition and action.

Equipment

This experiment was conducted with the use of a three-meter linear PASCO low-friction track and cart. The cart was approximately 2.2 m long, 3.5 cm high, weighed approximately 500 grams, and had four wheels that allowed the cart to roll along the track with low resistance. This track was positioned on an incline of five degrees so that the cart could be launched by a participant up the inclined track and it would naturally reverse, returning to the participant's initial position. The degree of incline was determined through pilot testing and an incline of five degrees was chosen because it was most sufficient in showing the desired variability in trial outcomes. Next, a “target zone” was added which marked a specific area on the track in which the cart was meant to reverse after being launched, creating a ballistic aiming task. Though the specific details of the experiment were altered throughout pilot testing, this core aiming task of launching the cart up the track to a desired point of reversal remained the same. This basic design allowed us to formulate our hypothesis that the index of difficulty is negatively related to rate of trial success.

Procedure

To test our hypothesis the experiment was prepared using the previously described PASCO low-friction track and rolling cart, placed on a table and tilted on a five degree incline. A motion sensor was attached at the track’s end nearest to the starting point to provide readings of the cart’s displacement, velocity, and acceleration, as well as time elapsed in each trial. A wooden stopper was attached at both ends of the track to maintain that the cart would remain on the track. There were 9 conditions based on a 3x3 design of target width and mean target distance. For width, the target zone was 20, 40, or 60 cm wide, and the mean target distance was 80, 110, or 140 cm from the starting point. These 9 conditions were randomized and put into three trial blocks, resulting in 27 trials that took approximately 30 minutes for each of the 19 participants. The participant was notified that their 27 trials were being recorded for accuracy, but that time was not a factor. After each trial, the experimenter verbally indicated to the participant on whether the trial was a “hit” or “miss.” The trial set-up is shown below in Figure 2.

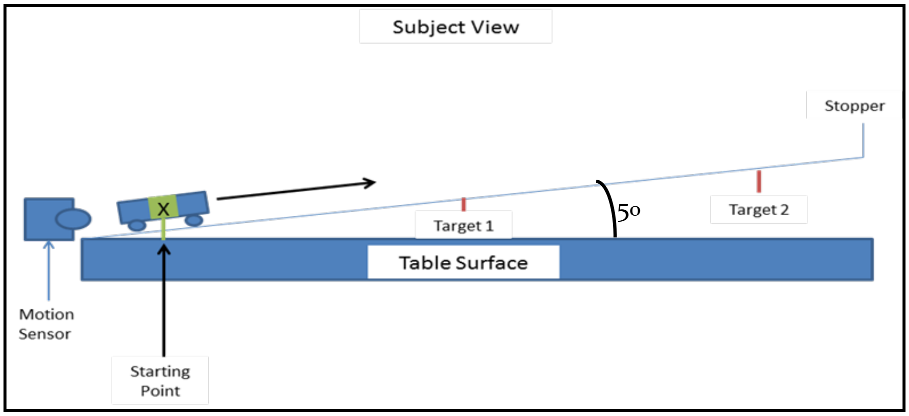

Figure 2: Subject View of Study Design

To prepare for the experiment, the participant was first asked to remove any rings, jewelry, or watches from their right arm. The participant was then prompted to stand parallel to the track and place their right hand on the center point of the cart which was marked by an "X" on a piece of blue tape. Next the participant was asked to position the cart so that this center point of the cart was aligned with the task's starting point, also marked by a blue strip of tape on the track itself. Before the experiment began the participant was allowed unlimited and untimed practice so that they could familiarize themselves with the feel of the cart and the nature of the experiment. When the participant felt prepared they verbally indicated that they were ready to begin the study.

Each trial began with the participant closing their eyes and holding the cart at the start position while I adjusted the width and distance of the target zone, whose beginning and ends were marked by two pieces of orange tape that were attached to the linear track. At this point I would initiate the motion sensor, cuing the participants to open their eyes, assess the target and begin the trial. The goal of each trial was to launch the cart up the inclined track so that it would stop and reverse within the marked target zone. Trials that accomplished this goal were deemed successful "hits", and those that failed to do this or ran off the edge of the track were considered "misses." The data that was collected using PASCO's Capstone software and allowed us to graphically represent the path of the cart during each trial. An example of a resulting graph from one of the participant's trials is shown below in Figure 3.

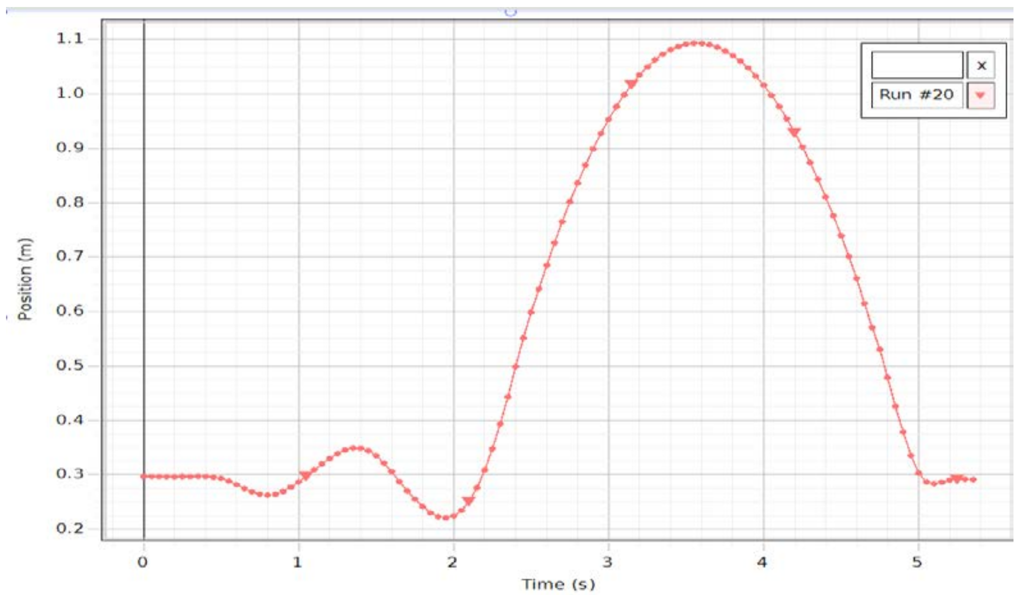

Figure 3: Participant 15, Trial 20

Results

19 subjects participated in this study that used a 3x3 design (target width x target distance) in 3 trial blocks (each condition was performed once per block), resulting in 27 trials for each subject. The summary data (see **Appendix A**) of the 19 participants was analyzed to examine the relationship between the mean distance to the target zone and the probability of hit with respect to the target width. The results showed higher probability of hit for wider targets (60 cm: M=.94; 40 cm: M=.85, 20 cm: M=.67) and for shorter distances to the target (80 cm: M=.89; 110 cm: M=.83; 140 cm: M=.74). This data is represented below in Figure 4.

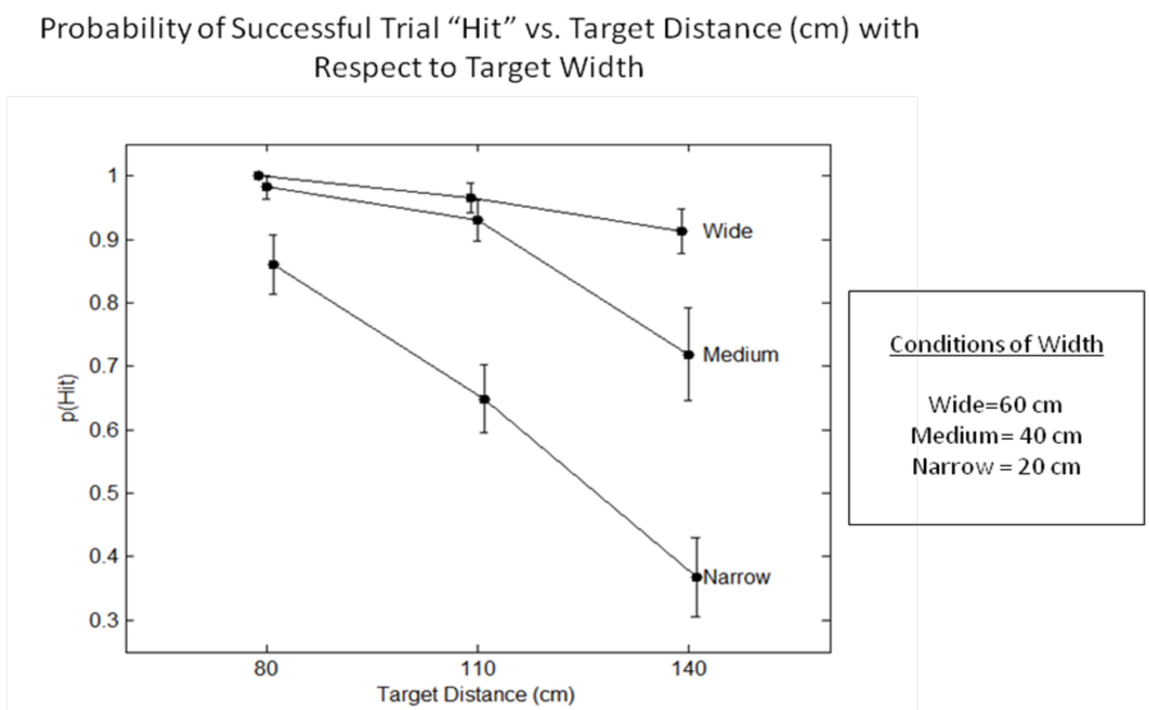

Figure 4

Our findings represented in Figure 4 support Fitts' assignment of target width and target distance as main effects of movement accuracy, and are consistent with our assumption that probability of "hit" is directly related to the mean target distance and inversely related to the target width. Applying these results, and remembering Fitts' equation for index of difficulty (ID= $\log_2$ (2A/W), we were able to construct a plot of the relationship between the index of difficulty for each condition and the probability of "hit," shown below in Figure 5.

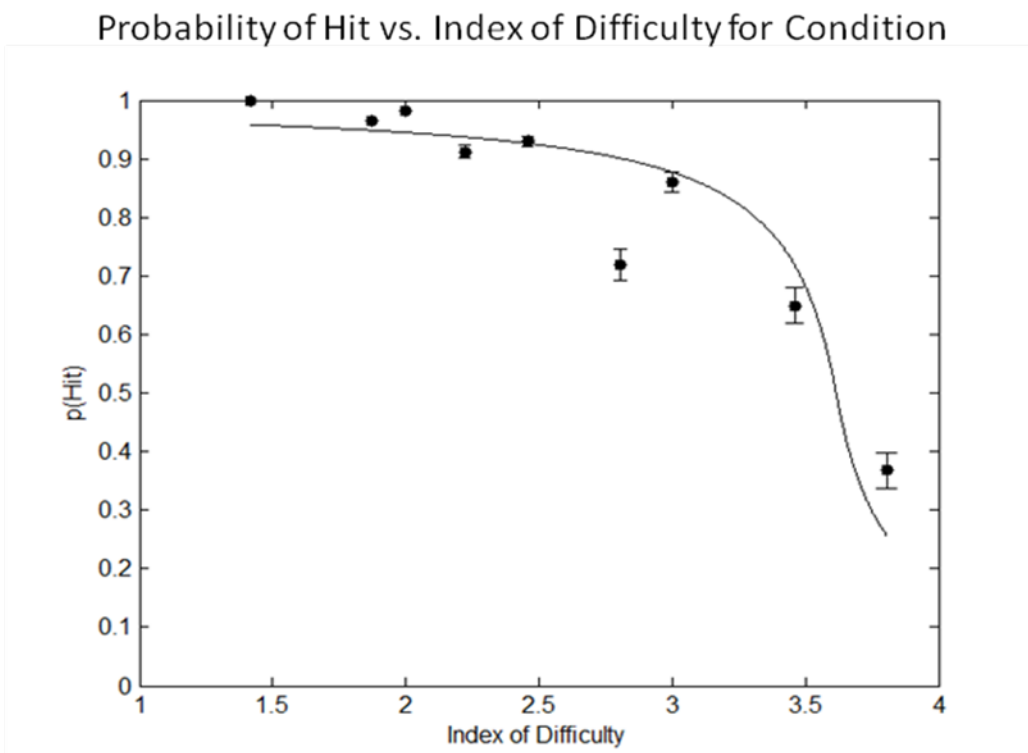

Figure 5

This logistic function confirms our prediction that the probability of "hit" decreases as the index of difficulty increases. We also fitted a curve to the data points to better demonstrate the shape of this relationship. The curve accounts for 90% of the variance in the data points and shows that a subject's probability of success is .5 when the Index of Difficulty is equal to 3.6150.

To clarify, when ID < 3.6150, the participant is more likely to “miss” than “hit” the target; when ID > 3.6150, the participant is more likely to “hit” than “miss.” The shape of this curve applies logically to the task at hand, because probability of success is bound at 1 in a trivially easy condition (i.e. very short target distance, very large target width) and 0 for conditions that approach the lower limit of possibility (i.e. target is very far away, only a few millimeters wide). An extension of the logistic function in Figure 5 is shown in the theoretical curve of Figure 6 as the probability of hit as it reaches its upper and lower limits.

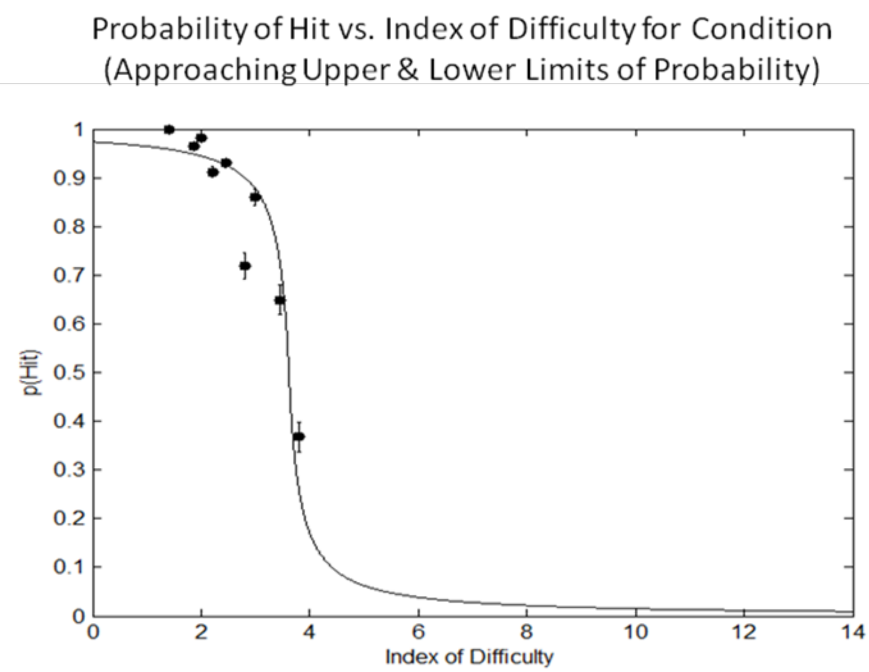

Figure 6

Discussion

Fitts' Law has been shown to consistently inform us about the nature of movement in aiming tasks by establishing a relationship between movement time, target distance, and target width (Fitts, 1954). This concept has spawned several models to explain the underlying mechanisms at work in ballistic aiming tasks, such as Iterative Corrections Model (Crossman & Goodeve, 1963/1983; Keele, 1968), Impulse Variability Model (Schmidt et al., 1979), and Optimized Initial Impulse Model (Meyer et al., 1988). One of the key limitations of study within this literature has been that the tasks involve both speed pressure and the opportunity for feedback, which may have led to an underestimate of the degree to which initial movement impulses can lead to successful aiming. By creating an untimed task that involved launching an object to a target rather than manually moving the hand to the target, we eliminated both time pressure and the feedback component, isolating the initial impulse movement. Once the subject launched the cart via their initial impulse, the results were literally and figuratively out of their hands. By varying the mean distance to the target and the target width, we were able to examine the relationship between the probability of "hit" and index of difficulty. We hypothesized that p(hit) would decrease as a function of increasing index of difficulty, and the strong negative relation of our results confirmed this hypothesis (See **Figure 5**).

The results of this study suggest that even in the absence of movement feedback, Fitts' negative relationship between movement accuracy and index of difficulty is still present. This finding is consistent with the Impulse Variability Model and has called into question the degree of importance of movement feedback in the relationship between these two variables. It is important to note another characteristic of feedback in this study, the organization of the trials.

Each condition was present only once per condition, and the conditions were randomized within the block so that the subject would never perform the same condition consecutively. Therefore, this study not only eliminated intra-trial feedback, but inter-trial feedback as well, increasing the power of our results.

Future research could return to the traditional method and, for participants who also do the ballistic unspeeded task, movement time could be plotted both as a function of ID and as a function of probability of hit in the ballistic, unspeeded task. The question then would be, how would the terms a and b in Fitts' Law correlate, over participants, with ID and with probability of hit. This method could be applied to other groups to better understand how subject demographics and characteristics affect the skill of initial impulse control. These groups of interest could include children, the elderly, and those with cognitive or physical disabilities. By pursuing this line of research in future studies, we hope enhance the already rich literature about aiming tasks and better understand the underlying explanation behind Fitts' Law.

Part 2: Preparatory Hand Motion in Pre-Performance Routines

During observation of the study procedure, a phenomenon present in some of the subject's aiming movement was noted. This motion involved oscillating the hand in small movements forward and backwards on the track in cyclical fashion before launching, and actually prefaced the initial impulse movement towards the target. Though participants lacked consistency in the presence of this hand preparation, it is interesting to note that the participant who showed the most consistent and significant PHM had the highest number of successful trials during the study (26 hits on 27 attempts). Applying this fact to the design of our study, we were interested in how and why this motion could be utilized to optimize initial impulse movement. Other examples in which PHM was present were generated and were used to inform our exploration of the potential underlying mechanisms, variables, and future application of research for this new concept.

Background

As someone whose future career interests lie in the field of sport psychology, a key topic of interest for me is the study of how athletes are able to maximize their chances for success. More specifically, how can sport psychologists prepare an athlete's physiological and cognitive states to optimize their actions? There is a considerable amount of research in the sport psychology and kinesiology fields that deal with preparation and "pre-performance routines" that help athletes to optimize their performance (Cohn, 1990). Though the literature concerning these topics continues to grow, there has been little connection made between the fine motor movements detailed in cognitive psychology and the psychological and physical planning of athletic action. An integration of these two lines of research would help examine the understudied phenomenon of preparatory hand motion in pre-performance routines.

Preparation routines and rituals have been a prevalent and enduring part of athletes' performances across generations, but the systematic study of this concept did not come about until Cohn coined the term "pre-performance routines" (or PPR) to describe this type of psychological and physical preparation (1990). Studies have shown that the best PPRs are consistent and rehearsed (Anderson, 1997), can occur at a deliberate or subconscious level (Weinberg & Gould, 1999), and create a sense of optimality for the participant's motor, emotional, and cognitive state (Lonsdale & Tam, 2008). However, despite the prevalent inclusion of PPRs in sport psychology training techniques, empirical evidence has not universally confirmed the effectiveness of these techniques, and there is still little understanding of the underlying mechanisms that may allow these routines to be utilized effectively (Jackson, 2003).

Preparatory hand motion, or PHM, is the term we use referring to the cyclical, preparatory motor rehearsal of the hand before a planned aiming task. PHM is a type of pre-performance routine, but rather than the gross body preparation normally described in PPR literature, the physical rehearsal of interest in PHM is the movement of the hand and forearm. Examples of this phenomenon include prior to throwing a dart or Frisbee, shooting a basketball free throw, or putting in golf. These examples of PHM demonstrate that before executing these planned actions, there is often a significant and unprompted hand "warm-up" motion in which the hand oscillates back and forth in preparation of carrying out the action. Hypotheses for the rationale of PHMs mirror those of PPR research in that they may install a state of optimal arousal, confidence, and focus before carrying out the desired action (Lidor & Singer, 2000). Studies in the PPR domain have ranged across a broad spectrum of settings and activities and often focus on macro body processes (i.e. Cotterill, Sanders, & Collins, 2010; Jackson & Baker, 2001), psychological skills training (i.e. Boutcher & Zinsser, 1990; Mesagno & Mullane-Grant, 2010), or superstition (i.e. Foster, Weigand, & Baines, 2006). However, little has been done to apply this research to planned action on a micro-scale, more specifically the movement of one's hand.

One potential reason for the lack of connectivity between the cognitive and sport psychology literature may be the tendency for the cognitive experiments to be less competitive and physically taxing than studies of sport psychology. Though this difference is acknowledged, these two fields also clearly overlap. With these dissimilarities in mind, literature in both fields can be utilized to gain a better understanding of the utility and underlying mechanisms of preparatory hand motion in pre-performance routines.

Theory

Proprioception

To construct the optimal experimental setup to determine the effectiveness and basis of PHM in pre-performance routines, several potential theories for the presence of PHM should be considered. The first of these theories is that this behavior is a way of increasing proprioception in the absence of visual feedback. For example, when a person throws a dart their eyes tend to be focused on the dartboard, not their hand. PHM may be occurring in this case in order to elevate the thrower's spatial awareness of their hand without interrupting their gaze and focus on their target. Research supports this hypothesis by showing that "spatial accuracy" becomes a higher priority in the absence of visual feedback, and that this effect reduces as practice increases, suggesting that people are able to utilize kinesthetic feedback to overcome the presence of visual uncertainty (Cohen, Biddle, & Rosenbaum, 2010). This theory may also support the results of our

Fitts' aiming task described in Part 1, because a better sense of the hand's position may be used as a substitute to physical feedback of the action. To test this theory, PHM studies should be designed so that the participant is performing an action that requires their gaze to be fixed on the target rather than their hand.

Priming

The next theory for why people engage in PHM is that it serves as priming tool before action. This is to say that though the PHM does not demonstrate motion directly representative of the task being carried out (the physical exertion in the preparatory movements is much lower than in the actual task), this motion is somehow priming the hand to act. Research shows that smooth, rhythmic motion is easier to control than discrete motion (Zelaznik et al., 2005), which would support this theory since PHM is present in tasks that require precise aiming. Using the cart-launching task from our study, the PHM would mediate the hand from a state of rest to a state of fluid movement in which the participant was primed to launch the dart towards their target, and the fluid oscillatory motion of the hand would allow for greater precision in the initial impulse movement of the hand.

Timing

Another conjecture for why people engage in PHM is that it serves as a timing mechanism. The literature on this topic diverges into two categories: Event timing and emergent timing. Event timing takes place when salient events (i.e. clapping one's hands) are temporally representative of the desired time between each of these events. Emergent timing, on the other hand, occurs during fluid, continuous movement (i.e. drawing a circle) and has been shown to be a way of maintaining trajectory, rather than representing interval duration (Zelaznik et al., 2005). It is also important to note that research has shown no relation between "temporal precision" in salient tasks and that in continuous tasks (Robertson et al., 1999), reaffirming the idea that an individual's performance is dependent on the task (Henry, 1960). The sport psychology literature supports this idea as well, showing that pre-performance routines are normally individualized, transient, and task-specific (Cotterill, Sanders, & Collins, 2010). An aim for future PHM research should be to design studies that explore PHM using event timing (i.e. prompt the participant to move their hand between two targets during their PHM), and studies that explore PHM using emergent timing (i.e. use fluid, continuous motion during PHM).

There is also a considerable amount of literature in the field of sport psychology about the utilization of timing in PPRs. One aspect of interest here is how the duration of a PPR will affect the task outcome, a topic that has shown conflicting evidence. For example, one study showed that preparation time was negatively correlated with performance, (Wrisberg & Pein, 1992), suggesting that performance decreases the longer the preparation time; other studies have found these two variables to be unrelated (Jackson, 2003; Southard & Miracle, 1993). The research is equally ambiguous in regards to the role that temporal consistency plays in performance, though there has been a positive correlation found between *behavioral* consistency and performance (Lonsdale & Tam, 2008). Another important temporal feature in the study of PHM is whether to the trials are self-paced by the participant. Self-paced activities are stable, predictable, and un-timed, leaving the pacing of action to the participant's discretion (Singer, 1988). When researching the usefulness of PPRs in sport, athletes who implemented a systematic routine before performing an activity showed greater gains in performance in self-paced activities than in activities in which time was a factor (Cohn, 1990).

Blocking External Distraction

Many self-paced tasks require very little in terms of decision-making strategies, which can lead to the participant's attention being diverted to external distractions (Jackson & Baker, 2001). Research has shown that one of the functions of PPRs is to block out external distractions (Moran, 1996), and this leads to the postulation that PHM could also serve to block out distractions. To test this notion, PHM research could present the subject with a choice component to minimize external distractions and create subject focus on the task. A theoretical study to test this theory would be provide the subject the opportunity to choose whether they wished to attempt each trial, so that they would be positively rewarded for successfully completing a trial, penalized for a failed attempt, and receive no positive or negative feedback from abstaining from a trial. The decision-making process associated with each trial would downplay the role of external distractions and allow the subject to focus solely on the task at hand.

Stress/Anxiety

The next potential explanation for the presence of PHM was to minimize stress and anxiety. This concept is one of great interest to the field of sport psychology because of the high amount of pressure that athletes are often under when performing action. Movement under stressful conditions tends to require a high degree of precision and motor control (Jackson, 2003), which we predict would affect the nature of PHM depending on task difficulty. In our task that required precise control of the initial impulse movement of the hand, decreasing stress could allow for less variability and lead to higher probability of trial success. Support for this theory has shown that athletes who employ PPRs have greater control of their physiological arousal (Boutcher & Zinsser, 1990) and decreases the likelihood of "choking" under pressure (Mesagno & Mullane-Grant, 2010). Accounting for this literature, PHM studies should strive to design a study atmosphere that breeds competition between participants and presents varying degrees of task difficulty.

Experience

The nature of the task is also an important consideration for constructing this study. Sport psychology research has shown that experience is vital in the development of an effective PPR (McPherson, 1993) and that experts in their domain utilize PPRs (both physical and cognitive) more so than beginners (Boutcher & Zinsser, 1990). Lidor & Zinsser (2000) explained this finding by stating that the "cognitive load" of using PPRs posed a challenge in novel challenges because most of the subject's cognitive attention is devoted to physical skill development. Future studies on PHM should utilize both rehearsed and novel tasks to that are representative of real-world situations in which this phenomenon occurs, which would increase clarity about the relationship between experience and nature of PHM.

After reviewing the literature on to gain background information on the physical and cognitive processes associated with the new concept of PHM, hypothesis can be formulated to better understand what underlying mechanisms prompt people to engage in this unique and understudied field of motion.

Hypotheses

The cornerstone of our hypotheses about PHM is the notion that there is a relationship between PHM and where the cart was launched. This assumption allows us to generate ideas as to what variables and mechanisms are affecting the way that a subject prepares for each trial. The independent variables we predict will affect the nature of EI are the target width and distance to the target, mirroring the factors accounted for in Fitts' Law of Aiming (1954). The dependent variable would then be "nature of PHM" which we break down into were "magnitude" of PHM, "frequency" of PHM, and "duration" of PHM. Magnitude of PHM refers to the total distance travelled by the hand prior to action (regardless of direction, speed, or any other variable), the frequency of PHM refers to the number of reversals of hand movement the participant enacts before performing a task, and duration of PHM refers simply to how much time the participant takes between the beginning and end of the PHM. To clarify, a person with PHM expressing high magnitude, high frequency, and high duration would be someone who moved their hand a greater total distance, back-and-forth more times, and took a longer amount of time to complete their PHM. The first hypothesis of this study is that the magnitude of PHM was directly related to the size of the target. This was generated because we feel that conditions in which the target is smaller would prompt more refined, minute hand movements corresponding to the greater precision required to successfully launch the cart into the smaller target zone. On the contrary, larger targets require less amount of precision in the cart launch trajectory, which would be reflected through less precise and greater magnitude of PHM. An alternative hypothesis is that the magnitude of PHM is *inversely* related to target size. This notion corresponds with our theory that PHM primes the hand to successfully carry out a desired action. By increasing the magnitude of PHM, the participant may be increasing the fluidity of motion in the hand so that they are primed to launch the cart in a more precise fashion, while larger targets require less hand priming because they require less precision.

The second hypothesis dealing with magnitude is that magnitude of PHM is directly related to the target distance. The basis for this idea is that acting towards a target set at a shorter target requires less physical exertion, and that this would be reflected through less physical hand movement during preparation, with the opposite being true for targets at a greater distance. This hypothesis also supports the theory that PHM occurs to increase proprioception in absence of visual feedback, since the participant's vision would be diverted further and further from the hand as the target's distance increased, creating a greater need for proprioception. An alternative hypothesis is that these two variables are inversely related, as it can be postulated that targets at a greater distance possess a higher degree of difficulty and would prompt more focused, precise hand movements in attempting the trial. This idea coincides with our theory that PHM helps to mediate stress and anxiety prior to carrying out an action.

Our next variable of interest is the frequency of PHM, referring to the total amount of hand reversals that occur during PHM. We hypothesize that frequency of PHM is inversely related to the width of target zone. The basis for this hypothesis is that trials with narrower target zones are more difficult and require more frequent PHM to affectively prime the hand, block out distractions, and mediate stress and anxiety, with the reverse being true for wider target zones. This increased difficulty could also lead to the participant's desire for greater sense of proprioception, and the more they engage in PHM, the greater their awareness of the hand's position becomes, allowing them to feel more confident in attempting the trial. In accounting for target distance, our hypothesis is that the frequency of PHM is directly related. Shorter targets require less precision and focus for the participant, so they would be less likely to engage in frequent PHM to increase proprioception, prime the hand, and decrease stress.

Finally, a proposed relationship between duration of PHM and nature of the target is part of our hypotheses. Our first notion here is that duration of PHM is inversely related to width of the target zone. The rationale for this prediction is consistent with the hypothesis for frequency of PHM, in that narrower targets present a higher degree of difficulty, require a longer preparation time to prime the hand, block out distractions, decrease stress, and increase proprioception. For wider targets, the duration would be shorter because there would be less need for these same factors. Next, we hypothesize that duration of PHM is directly related to target distance. This reasoning also mirrors that of our frequency predictions, in that targets at a greater distance are more difficult and require a longer period of preparation time for increased proprioception, hand priming, and managing task stress.

In dealing with these hypotheses it is important to re-iterate the findings of PPR literature that argues that these routines are individualized and lack consistent evidence for effectiveness (Cotterill, Sanders, & Collins, 2010; Jackson, 2003; Lonsdale & Tam, 2008). These ideas would provide some support for the null hypothesis that there is no relation between the variables of magnitude, frequency, and time of PHM and the nature of the target.

To Summarize:

H_1: Magnitude of PHM is directly related to width of target zone; magnitude of PHM is directly related to target distance

$H_{2:}$ Frequency of PHM is inversely related to width of target zone; frequency of PHM is directly related to target distance

H_3: Duration of PHM is inversely related to width of target zone; duration of PHM is directly related to target distance

$H_{0:}$ There is no relation between magnitude, frequency, and time of PHM and the target width or distance

Conclusion

The phenomenon of preparatory hand motion is a novel concept that has much potential for growth and can benefit the fields of cognitive and sport psychology. We hypothesize that this motion can be used to optimize initial impulse movement of the hand when the subject is not allowed the opportunity for physical feedback. The exploration of this concept in this paper has created a new area of research and shaped a theoretical basis for ensuing studies. At this point we are unable to determine the underlying mechanisms for PHM, but we have generated several potential explanations, implications, and questions that can serve as the impetus for future experiments within this line of research. These include asking why people engage in PHM, what sorts of tasks are benefitted by PHM, can PHM be trained/optimized, at what level of consciousness does it occur, and what other variables play a role?

We have hypothesized that PHM magnitude, frequency, and duration are affected to the target's size and target distance. If these hypotheses are correct, future research could systematically determine if and how PHM can be optimized to maximize probability of successful performance. Other characteristics that could be of interest in future study include the effect of hand dominance on PHM and the amount and type of athletic experience (since PPRs are generally associated with sports). Several other potentially useful factors to PHM research have been contemplated and could lead to application of this concept in the future. One of these is the potential utilization of PHM to assist those with neurological disabilities. The cerebellum has been shown to play a crucial role in temporal processing, and those with cerebellar lesions have been shown to demonstrate temporal deficits. However, it has been discovered that these disruptions to timing are mostly present in action requiring discontinuous motion, and much less so in fluid, continuous motion (Spencer, Zelaznik, Diedrichsen, & Ivry, 2003). With greater support for the utility of PHM, people with these deficits may be able to use PHM as a systematic tool to improve their timing.

As research of the phenomenon of PHM continues to develop, our hope is that the findings can be applied to better understand the underlying mechanisms of PHM and how this idea can be positively utilized. We believe that our exploration of PHM has served as a great introduction into understanding this motion in the future, and has provided sufficient discussion to lead to fruitful and enduring research of this topic.

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Appendix A:
Summary Data for Participant Accuracy Based on Condition & Block

Condition #	Target Width (cm)	Target Length* (cm)	Total Number of Trials	Block 1 Success Rate	Block 2 Success Rate	Block 3 Success Rate	Overall Success Rate
1	60	80	57	1.0	.95	.95	.96
2	40	80	57	.79	.95	1.0	.91
3	20	80	57	.68	.79	.89	.79
4	60	110	57	.94	1.0	1.0	.98
5	40	110	57	.74	.84	.94	.84
6	20	110	57	.47	.74	.79	.67
7	60	140	57	.79	.95	.95	.89
8	40	140	57	.79	.79	.79	.79
9	20	140	57	.42	.63	.57	.54

*Signifies the mean length of the target zone from the starting point; Note: Success rates were rounded to the nearest one-hundredth

Appendix B: Sample Participant Data Sheet

Trial #	Condition #	Target Length	Target Width	Target Point 1 (cm)	Target Point 2 (cm)	Hit/Miss
1	1	S	W	140	80	Hit
2	7	L	W	80	20	Hit
3	5	M	M	100	60	Hit
4	3	S	N	120	100	Miss
5	6	M	N	90	70	Miss
6	8	L	M	70	30	Hit
7	9	L	N	60	40	Hit
8	2	S	M	130	90	Hit
9	4	M	W	110	50	Hit

ACADEMIC VITA

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Education

B.A., Psychology, 2013, The Pennsylvania State University, University Park, PA

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Research Interests

I have a broad interest in cognitive psychology and have some experience with motor planning, but my specific interests focus in the field of sport psychology, in which I plan to pursue my career. My interests here lie in the fields of mental imagery, motivation, and youth sport. I am specifically interested in how mental preparation strategies are affected by characteristics of both the individual and the sport.

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