AN INVESTIGATION OF HUMAN CAPABILITY TO PREDICT THE FUTURE LOCATION OF OBJECTS IN MOTION

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AN INVESTIGATION OF HUMAN CAPABILITY TO PREDICT THE FUTURE LOCATION OF OBJECTS IN MOTION

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[To the students of the Georgia Institute of Technology]

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SUMMARY

Hitting a Major League fastball pitch may be the most difficult task in the sports realm. Anecdotal evidence suggests that certain individuals are able to perform this task reasonably well, perhaps because of superior sensitivity to changes in motion. However, the substantial lack of research investigating detection and assessment of changes in motion renders this conclusion problematic (Kelling, 2008). Two experiments, using expert and novice participants, assessed sensitivity to changes in motion. Experts for these studies were defined as current members of the Georgia Institute of Technology Yellow Jacket softball team. Experimental procedures included assessments of capabilities in batting and motion tracking tasks. Experiment One presented participants with recorded softball pitches thrown from a pitching machine. Experiment Two required participants to predict multiple landing locations for incomplete motion paths resulting from a single main target exploding into additional shrapnel pieces. Results suggest minimal expertise effects in the softball task with high performance by all participants, while distinct expertise effects exist in the shrapnel task. The motion tracking task resulted in fewer errors by experts, while all participants demonstrated a significantly large drop in performance with increasing number of shrapnel pieces. Findings from this work not only have application to the sport of softball, but are critical for identifying the people's capability to detect and assess changes in motion.

CHAPTER 1

INTRODUCTION

Numerous visual challenges are integral to sighted humans' daily lives. These challenges range from avoiding a collision while driving to watching television. Even enjoyment of sports encompasses assorted visual challenges. In the realm of visual motion, Haarmeier and Their (2006) denoted a substantial lack of research designed to address perception of temporal changes in velocity. These changes may be the major challenge for many athletes. To address this general lack of research, Kelling (2008) examined many of the cues related to detecting and assessing changes in visual motion. In this evaluation, two experiments, specifically tasked with motion changes, were proposed. The work described herein was not aimed at testing and supporting these models, but was specifically designed to aid in understanding the capabilities to manage predictions of moving objects' future locations. However, this work should provide the groundwork for further investigation by answering critical questions surrounding perception of changes in visual motion.

Models

Kelling (2008) proposed a dual system for the detection and assessment of changes in motion. Both systems were tasked with different missions. One system's mission was to provide a relatively quick reactive system to collide or avoid an oncoming target. Kelling called this system the primitive collision/avoidance system. The limitation of such a system is the requirement of centralized attention on the target of interest. As proposed, this system records no information on targets not directly approaching the observer. Instead, a global motion system is required for this situation. The second proposed system provides a means through which motion deviations can be determined fairly quickly while also providing the capability to track and maintain multiple targets in our three dimensional environment. The temporal qualities of the global system require greater tracking times than the simple collision/avoidance system.

Haarmeier and Their (2006) depicted a very stark picture for acceleration detection and assessment. They denoted modest difficulty in comparing speeds separated in time, but instantaneous detection of speed changes of an existing stimulus is rather poor. They relate this difficulty to the use of indirect methods to determine acceleration information. Although Corso and Kelling (2007) found contradicting support for speed comparisons separated by time, findings from Haarmeier and Their (2006) were limited to frontoparallel motions, while Corso and Kelling (2007) addressed judgments only in depth. These conflicting data sets presents a supportive opportunity for the divergent systems described above as well as a path for experimental investigations. However, new research must not limit itself to a single plane if a comprehensive understanding is desired.

Differences and changes in object motion are critical to the prediction of future locations. Exactly how these models could be used to predict future locations of objects was a topic of discussion in the original Kelling (2008) work. However, an experimental analysis was still required to understand how effective such model designs could be. Additionally, an analysis of such a capability and the characteristics of the perception of motion characteristics would be beneficial.

Expertise

The first focus for this investigation was to examine different capabilities in the prediction of objects' future locations. The greatest possibility for success in discovering these differences should focus on identifying individual differences in those capabilities. Oudejans, Michaels, and Bakker (1997) compared the ability of experts and novices to catch a tossed ball with trajectories not limited to vertical deviations. In nearly half the trials the novice participants moved forward when the ball was tossed to land behind their starting position. This behavior was almost never observed for participants in the expert group. The experts were observed to err in other directions in six percent of the trials, while this error was recorded two percent less in non-experts. Experts were also found to have slower reaction times. Increases in reaction time may allow for additional time to garner information, thus improving their accuracy. Although Benguigui, Ripoll, and Broderick (2003) suggested no direct ability to sense acceleration, there was clear evidence that experts; basketball players, football players, and marksmen; were able to take acceleration data into account.

For the current investigation, collegiate level softball players were viewed as experts. When examining the actions these athletes must perform, two different types of tasks can be identified; time limited and time rich. How does an outfielder adjust to catch a fly ball that is being affected by wind in the ballpark? Small adjustments may be required as the direction of the ball may vary because of the swirling winds that occur in some parks. The wind effect alters the predictive path of the ball as well as the location at which the player must arrive. This action is an example of a time rich task where corrections can be made the entire time the ball is in flight. An excellent example of a time limited baseball task is batting. Once a baseball pitcher releases a 90 mph fastball, a batter has approximately half a second before the ball crosses home plate. With approximately a quarter second reaction time, only a quarter second remains for the hitter to make multiple adjustments (Paull & Glencross, 1997). Softball pitches, although slower, result in similar time limitations. In either case, the batter must determine the trajectory of the ball as well as its future location. Predicting location is crucial for the task of distinguishing a strike or ball as well as determining when and where to swing the bat to connect with the ball. Difficulty is added to the task when taking multiple pitch types into account. Different pitch types can vary in trajectory and speed. This location variance is compounded with multiple possible targeted locations intended by the pitcher.

Although these tasks are crucial for the games of baseball and softball, they also represent samples of predictive tasks that exist in daily living, such as distinguishing whether a lead vehicle's behavior will result in a collision or whether an object will fall onto one's head. The range of importance of predicting motion may vary from trivial to critical. Unfortunately, very little is known about whether and how humans are able to utilize information based on predictive motion paths. Anecdotally, some capability for such information must exist given that humans are able to play baseball and softball in a successful manner.

Limitations in the Literature on the Detection and Assessment of Changes in Motion

Much of the research on visual perception of motion change has focused on the pure detection of change, and not on describing or assessing the characteristics of that change (Mateeff, Dimitrov, Genova, Likova, Stefanova, & Hohnsbein, 2000) or the effects on future location. Genova, Mateeff, Bonnet, and Hohnsbein (2000) revealed that participants could need up to twice as much time to detect small changes in direction than to discriminate it once detected. These results support Genova's, et al. (2000) theory for two parallel mechanisms, one for change and one for discrimination. It is possible that these mechanisms are not complementary, but instead may be competitive. Although Genova's, et al. dual mechanism theory is directed toward change in direction, mechanisms for velocity may be similar. Mateeff, et al. (2000) recorded large changes in reaction times for stimuli that varied in initial speed, while maintaining final speed and direction. Such differences were not detected for choice reaction times. Additionally, the assessment mechanism may have unique eccentricities. Mateeff, Dimitrov, and Hohnsbein (1995) discovered increases in reaction times for speed decrements when compared to similar speed increments. In terms of direction, small changes, on the orders of 12 and 23 degrees, require longer viewing times, suggesting a deviation bias (Soechting, Mrotek, & Flanders, 2003). The difficulty arises from how these detections and reaction time changes relate to one's capability to predict the future locations of those objects.

The separation of the perception of direction and velocity quickly becomes a difficult discussion. If such characteristics are interdependent, change in either or both characteristics should then affect the other. Hohnsbein and Mateeff (1998) noted that reaction time thresholds for changes in direction could be described in terms of differences in velocity. Interestingly, initial velocity accounted for no real variance except in relation to the new velocity. Later data from Mateeff, Genova, and Hohnsbein (2005) suggested detections of change can be made quickly, but discriminating the direction of change requires an increase in time. Such findings suggest separate mechanisms for assessing speed and direction. However, some combination of direction and speed is required to predict a future location.

Hohnsbein and Mateeff (2002) suggested detection of change in speed was dependent on the lifetime of motion. For many experimental random dot kinematograms, an interaction exists between aperture and base speed. This ratio's effect (aperture/base speed) can be shown through the limited observation time created by the object passing across the aperture. Hohnsbein and Mateeff suggested, based on their findings and the results of others, that motion detectors do not work independently. Instead, they propose velocity tuned detectors signal additional detectors that are sensitive to speed along the line of motion. Different firing patterns in velocity sensors may determine changes in speed along this line. Conversely, when such physical motion in not viewed such predictions of future location is dependent on previous sensory input.

The main difficulty of separating velocity and direction remains in predicting the paths of moving objects. These two variables are critical to successfully predict how a target will move in space as well as its location in time because velocity has a natural directional component. Thus, any experimental analysis seems to require a synergetic approach if investigating the prediction of motion paths.

Examination of Possible Relevant Cues for Detection and Assessment of Motion Change

The complexity involved in the integration of all the cues possibly relevant to the prediction of motion requires a comprehensive overview. Table 1 provides an overview of the conditions where cues provide assistance in motion perception. The details of the

Table 1. Global view of cues that may assist motion detection (Kelling, 2008)

Possible Cues	**Direction**			**Velocity**			**Acceleration**		
	2-D	**3-D**		**2-D**	**3-D**		**2-D**	**3-D**	
		Mono	**Bin**		**Mono**	**Bin**		**Mono**	**Bin**
Direct Direction Sensors	**X**								
Impact Direction	**X**	**X**							
Changing Size / Looming		**X**			**X**				
Relative Retinal Velocity			**X**						
Reference Marks			**X**	**X**					
Direct Velocity Sensors				**X**					
Longer Timed Presentation				**X**		**X**			
Distance				**X**					
Location				**X**					
Continuity				**X**	**X**				
Changing Disparity						**X**			
Tau						**X**			
Change in Direct Velocity Sensors							**X**		
Tau-dot									**X**
Expertise							**X**		

pertinent cues quickly become extensive when examining them thoroughly. A more detailed investigation is provided in Kelling (2008).

One of the first crucial points is the abundance of motion cues attributed to two-dimensional velocity. These cues include reference marks, some form of possible velocity sensors, longer presentation times, observer's distance, location, and continuity. For the purposes of this discussion, three cues are especially pertinent. Presentation times, object location, and continuity provide unique challenges within the motion path prediction paradigm. The effect of these cues goes beyond two-dimensional velocity. Similar effects as a binocular velocity cue in depth have also been shown (see Harris &

Watamaniuk, 1995). When examining the previous baseball/softball examples, different emphases can be placed on the specific cues. Presentation time is the main distinction between the time rich and time limited tasks. A fly ball remains airborne longer than a pitched fastball. This time difference is critical to the type and salience of the information available. It then becomes realistic to derive different functions and actions based on the time difference. Katz, Gizzi, Cohen, and Malach (1990) demonstrated that brief target presentations resulted in higher perceived velocities than the same targets presented for longer durations. The short presentation of the pitch could result in errors in perceived velocity, which in turn may affect detections of deviations in direction or velocity (McKee & Watamaniuk, 1994) resulting in alterations to the predicted motion path.

Object location also differed between the baseball/softball tasks. As a normal pitch will be aimed at the batter's strike zone, the angle of instance for the ball may change as its path is not directly in line with the batter's eyes. This statement should not be misinterpreted to mean the ball could not be maintained in central vision. The batter could rapidly rotate his/her head to maintain the object's location, but the ball's vector components will change. As the batter rotates his/her head depth velocities convert to frontoparallel components. The ball's path, as seen by the outfielder, will have a reverse path. In this scenario, the depth component is the critical variable of interest related to catching the ball. Therefore, the utilization of predictive motion paths may require the capability to rotate the prediction path.

Continuity provides for an additional intriguing discussion. When attempting to catch a fly ball, outfielders may divert their gaze to see how close the outfield wall may be. This diversion of gaze would result in breaking the continuity of the visual motion track. Portfors and Regan (1997) noticed difficulty when motion tracks are disrupted. Targets, which disappeared and reappeared during the trajectory course, disrupted an observer's ability to discriminate rates of change in disparity. These findings would suggest that any stored predictive motion path could be affected by the nature of visual disruptions. Additionally, for the batter, such a deviation would be extremely detrimental because of the very limited duration for assessing the motion path.

Although the aforementioned cues are critical to examining velocity, the focus of this discussion is the understanding of human capability to predict future motion. Further discussion on the critical nature of these velocity cues can be seen in Kelling (2008). The examination of how these cues may affect the capability to predict motion will fill a critical gap. However, velocity is not the only motion information of use in this situation.

Another critical cue of interest is acceleration. Such information could be extremely useful in certain motion prediction tasks. A batter attempting to distinguish between a possible curve ball and fastball could use acceleration data. The consistent velocity change in the ball would allow the batter to determine where the ball will be in the future. Such predictive information would allow the batter to adjust his or her swing to connect with a ball changing its motion. Acceleration supplies a more accurate and adaptable stream information for prediction of future location. Direction and velocity are the minimal requirements for a prediction of a future location. But if the velocity and direction are varying within the motion path, acceleration would provide significant improvements of location prediction.

There are two possible methods for investigating humans' ability to detect and assess acceleration. The first is the direct investigation of cues that may be relevant to such detection. The challenge in applying this method to acceleration is the difficulty of understanding what such a cue would be. For two-dimensional direction, positional displacement can function as a cue for determining direction. The rate of this change is a possible cue for detecting velocity.

Another possibility for velocity detection and assessment is specific sensors tuned to specific temporal pattern. If velocity can be assessed through a temporally sensitive sensor, then there is the possibility that a similar mechanism for acceleration may exist. The dilemma involves the direct measurement of a unique temporal characteristic. Velocity is the change in displacement over time. Acceleration is the change in velocity over time. This view defines acceleration as a second derivative of the original displacement. A simple circuit does not easily accomplish such a mathematical process. Although this technique is not the most elegant solution, it should not be overlooked as a possibility.

The simplest method for handling acceleration is to ignore it. A more straight forward system could adapt to changes in velocity by waiting for velocity signals to stabilize in a new pattern. This technique ignores direct detection of acceleration. Instead, reactions are delayed until a response is generated for the new velocity. This method would hinder adaptive location predictions as minimal real time information is supplied.

The final method involves the single temporal correlate of an existing velocity signal. This method makes the assumption of the existence of a velocity cue and direct access to it. The method also relinquishes acceleration detection to a second order system. The primary concern of such a system would be velocity. The functioning of this system is restricted by its design but also to the limitations of the velocity sensing system. Improper assessment of acceleration data or bad velocity sensor information would both directly lead to errors in prediction.

Unique reactions are seen when comparing velocities in depth. When investigating just noticeable differences of changes in lead vehicle velocity, Corso and Kelling (2007) revealed participant's difficulty in comparing two sequential animations of vehicle speeds. Under these circumstances, observers demonstrated erratic responses regardless of differences in speeds up to 20 mph. Even a methodological change in presentation resulted in little to no change in speed assessments. Another simple alteration of the method resulted in traditional shaped psychophysical relations. Allowing the vehicle to change speeds in one continuous animation greatly improved the ability of the observer to detect changes in a lead vehicle's approaching speed within an 8 to 10 mph JND. Although this experiment was designed for a driving task, these difficulties draw attention to the limitations of a velocity sensitive system.

Previous Softball Related Perception Work

Visual perception in ball related sports has been a topic of interest over many decades (for examples see Regan, 1997). When examining free kicks in soccer, Craig, Berton, Rao, Fernandez, and Bootsma (2006) stated that the

> perceptual effects described find their origin in inherent limitations of the

> human visual system in anticipating the arrival point of an object subjected to an additional accelerative influence resulting from the presence of the Magnus force (pg. 101).

The Magnus force is created by the rotation of an object causing the object to alter its direction. It provides the curve in curveballs or the slide in a slider. The visual difficulty arises from the addition of information that must be integrated with a normal prediction of location. Adding to this problem is the speed at which this calculation must be performed. A 65 mph softball or 90 mph baseball can reach home plate within a half second. Considering that a fair amount of this time must be devoted to the actual swinging of the bat, a sizable amount of the predictive processing must happen quickly.

This limited time frame presents a problem. Van Der Kamp, Rivas, Van Doorn, and Savelsbergh (2008) pose the problem that because of this speed, limitations of the visual and motor systems make information from ball flight spurious and suggests that information prior to flight is critical. To support this claim, Van Der Kamp, et al. (2008) discuss the numerous occlusion studies suggesting an experiential difference in using early visual cues to identifying an opponent's actions. The authors also raise the issue of the limitation in the number of studies not focusing on pre-flight information and suggest that ball flight may be the critical source of required information. When examining previous research, Van Der Kamp, et al. (2008) noted an interesting interaction between some ability to predict landing location based on expertise. Some research has shown experiential differences in landing location based on preflight information. However, the addition of ball flight information in some studies has resulted in differing conclusions and some of these studies dissolved any expertise-based differences. Removing the pre-flight information completely may provide a more interesting examination of the workings of any predictive system.

An additional piece of pre-flight information that may be critical in predicting pitch location is the situation. Experts may have an advantage based on a learned priming scheme that limits pitch types and pitch locations based on probabilities. Such a system could manage number of pitches, previous pitch types thrown, and current number of balls and strikes. Paull and Glencross (1997) presented videos of pitches with or without batting situation information. Although minor reductions in decision time and errors were found, the differences in performance between experts and novices were constant. The evidence still supports a rather sizable gathering of ball flight information in pitch location decisions.

Experts in ball related sports have been shown to require very small time windows for motor activations (Regan, 1997; Gray, 2002). To maximize the power in the swing, contact may need to be achieved within a 70 ms window or less (Gray, 2002). Thus, it may be critical to present information with similar time resolution. The time resolution has varied greatly between studies in combination with how the environment and stimuli were presented. Paull and Glencross (1997) utilized actual video of pitchers but the frame rate of the video was presented at 25 frames per second. This resulted in time points being only 2 frames from each other. Additionally, only the first 10 m of baseball flight were displayed. Although this distance is a little more than half of the pitch trajectory, it assumes that no information will be gathered while swinging the bat. Gray (1999) presented ball flight stimuli using a high frame rate of 120 Hz, which required sacrificing the realism of the stimuli. Computer animations were used and ball rotation rates were altered to 200 rpm from possible real rotations exceeding 1500 rpm (Gray & Regan, 2006). This correction was performed to maximize the utilization of the apparatus available frame rate. Even so, rotational rates have shown to be a useful piece of predictive information for pitch location possibly by creating a visual gradient based on the seams of the ball (Gray, 1999; Gray & Regan, 2006). The complexity arises in whether or not such information is actually present in a field version of the task. It is possible that virtualizations of the task may be over representing the visual effect of ball rotation. Perceiving a high rotational rate on a traveling high-speed object with multiple axes may be beyond human perception.

A second difference among previous studies is the use of various definitions of novice and expert experience. Comparisons between extreme groups may maximize perceptual effects between true novices and experts. Many of the sport related research highlighted has taken a variant approach. Gray (2002) utilized six participants of various levels of competitive baseball play. Similarly, Paull and Glencross (1997) defined experts as those who played professionally and novices as those who had at least three years of club play level. Having distinctively separate groups with a true novice group may better highlight differences in the ability to detect changes in motion. Such an approach should result in a difference between the groups if some performance advantage were to exist for those who have a greater capability.

Goal

The goal for the described work was to provide experimental collaboration for Kelling's (2008) models by focusing the investigation into capabilities to predict future object motion path. A two study framework provides support across various facets of the models. The examination focused on the suggested strengths and weakness of the system as suggested by Kelling (2008). One goal, tuned toward the primitive collision avoidance system, is to assess the capability of performing high speed predictions of location for an approaching object. The second goal was to understand the limitations of a possible global motion system by requiring the system to predict multiple motion paths for non approaching targets. Although such investigation is critical, this work was tuned to the goal of examining capabilities and limitations predicting future locations of moving objects. Continuing with the softball centered motion scenario, many of these studies will focus on the expertise of softball players. The softball players represent a group of individuals who are highly selected and highly trained in a task where motion information would be very helpful for success.

Two experiments were conducted to explore the questions relevant to prediction based on acceleration, velocity, and directional characteristics. Although both experiments were designed to assess differences between novices and experts to predict future locations of high speed objects, Experiment One was designed for oncoming 3-D motion very familiar to experts.   Experiment Two altered this comparison by using a task not as familiar to the experts as the first task and limited the motion to 2-D, frontoparallel presentation. All participants were treated in accordance to the procedures and guidelines established by the ICH/GCP.

CHAPTER 2

EXPERIMENT ONE – XYZ OBJECT VELOCITY TASK

Participants

Nine experts defined as current members of the GT Yellow Jacket Softball Team were participants for this experiment. In addition to the expert group, the novice group was limited to nine individuals who had no high school varsity athletic experience. All participants were required to have normal or corrected to normal visual acuity, which was confirmed using a Snellen Eye Chart. Once visual acuity was assessed, a few simple experience questions were asked and are included in Appendix A. In general, the questions consisted of inquiries about status as a current or former collegiate level softball player (yes/no), high school varsity athletic experience (yes/no), position, and number of years playing softball ($M = 13$, $SD = 2.24$).

Apparatus and Procedure

A projection display system presented videos of pitches taken from behind home plate. The video involved a softball being delivered by a pitching machine situated on the pitching mound in a batting cage. The trajectory of the ball was manipulated via the alteration of vertical and horizontal angles of the machine. The angles were input using the control panel on the machine. Additional trajectory changes were created by changing the pitch type. Three pitch types were used for this experiment. The pitches were right handed fastball (straight pitch with little to no movement), right handed slider (pitch with small downward movement with a larger horizontal movement), and right handed curveball (pitch with relatively large downward movement accompanied by smaller horizontal movement). Videos of the pitches were recorded using a Casio EX-F1 digital camera at 60 pictures per second at a resolution of 2816 x 2112 pixels. The camera was placed behind a wooded shield that had a replaceable Lexan© cover opening in front of the lens. The Lexan© was replaced anytime the ball struck the cover. This shield was placed on home plate in an enclosed batting cage. All pitches were thrown by a pitching machine with an initial speed of 65 mph. The home plate location of the ball was determined when the ball impacted plasticine clay placed on the wooden shield. The true location of the impact could then be measured along a XY coordinate axis. Captured frames were stitched together to make a seamless video at 60 frames per second. Because of presentation limits and a finding described later, the additional resolution of 2816 x 2112 pixels was not deemed advantageous, and so the resolution of the video was reduced to 960 x 720 pixels. Video selection of stimuli resulted in a balance of four in-target and four out-target videos for each pitch type. The target area used was that of an average sized strike zone following NCAA rules. This resulted in an area defined by the dimensions of 44.45 cm (17.5 in) by 64.77 cm (25.5 in). This area was physically drawn on the projection screen at a height of 67.5 cm (26.5 in) and located centrally to simulate the placement of the strike zone from a view behind home plate. Stimulus videos were further broken into presentation times of ¼, ½, and ¾ pitch durations of 125, 250, and 375 ms (approximately 3.28, 6.55, 9.83 m from the pitchers mound).

The participant was seated in an office chair six feet from the projection screen described earlier as the plane of home plate. Participants were instructed to respond on a standard QWERTY keyboard that had all letter keys removed except for two. One key was assigned to responses for pitches that would have crossed home plate within the depicted area, while the second key was for all pitches resulting in crosses outside of the area.

Stimulus presentations were handled using Inquisit (2006). The pitch types (slider and fastball) were randomized. There were eight pitches by three pitch durations resulting in 24 different videos. The videos for one specific pitch type were then presented twice in each experimental block. The selected pitch type experimental block was repeated until a consistent level of accuracy was achieved. This consistent level was defined by the accuracy being within 5 correct answers (approximately 10%) over four trial blocks. Once this level was reached, the same procedure was repeated with the other pitch type. When both pitch types (slider and fastball) were complete a final block consisting of a combination of slider, fastball, and curveball stimuli was presented using the same procedure. The curveball stimuli were not used in a single pitch type block because of the nature of the pitch. When the pitch was released from the machine, a large majority of pitches exiting toward the left resulted in pitches inside the target area. The inverse was true of a large majority of pitches exiting right. For this reason, the curveball was limited to the combination block only, where the random mixed pitch presentation would make the use of initial direction unreliable for prediction. Latency and accuracy were recorded for each response and accuracy feedback was provided after each experimental block. No notice was given when the pitch type was changed.

Design

A 2 (expertise) x 2 (pitch type) x 3 (pitch duration) x 2 (slider/fastball order) x 2 (presentation type) mixed model design was used with expertise and slider/fastball order being between subject. Fastball and slider were the two types of pitches and these were presented for three pitch durations of 125 ms, 250 ms and 375 ms. The slider or fastball order was defined as which pitch type was presented first to the participant. The final variable was the type of presentation; either one pitch type alone or in combination with other types of pitches. Latency and accuracy data for each pitch and participant were collected and subjected to separate ANOVAs. Additionally C and a' measures (MacMillan & Creelman, 2005) were calculated for each participant within each combination of variables. These measures were based on the metric of a presented in-target or "strike" stimulus combined with an in-target response were recorded as a hit. Likewise, an out-target or "ball" presentation with an in-target response was a false alarm. All trials were used in the analysis.

Results

An interesting result was observed during the stimulus creation phase of this experiment. Originally, images were taken at a high resolution. It was expected that high resolution would be required given that anecdotal reports suggested the seams of the ball may provide a critical cue for predicting future location. Additionally, research (Gray & Regan, 2006) suggested the gradients caused by the rotation of the seams in travel may be a valuable aid to the experts. Interestingly, the seams were not visible as the ball traveled when recorded at a resolution of 2816 by 2112 pixels. Figure 1 shows two 1/60th image frames. One is from the full resolution (2816 x 2112 pixels) recording while the second is from the video presented at a lower resolution of 960 by 720. Secondly, no distinct gradient was evident to the author in the presented lower resolution. A similar examination was completed with the high resolution video. The original video was cropped to the same total resolution size of the lower resolution video. The video could

Full Resolution

Presented Resolution

Figure 1. Full and Presented Resolution Images of the Target

then be displayed using a standard projector, as there was no method to display the higher resolution at its full size. Still no gradient pattern was observed. As such the interpretation of this result will be that only the trajectory of the softball is the cue for future location rather than a sense of ball rotation. Additional archival results can be seen Appendix B.

Non-Steady State

This analysis included all trials the participant completed including the four blocks within 10% main target accuracy (steady state). In the non-steady state statistical analysis, four statistically significant effects were found.

Latency

Pitch duration was the only significant main effect ($F(1.97, 25.55) = 5.70$, $p < .01$). Further paired t-tests determined that all three time points had statistically significantly different mean latency times. The shortest pitch duration, 125 ms, resulted in the longest latency followed by a decrease in latency (M = 169.29, SD = 48.2) for the 250 ms duration ($t(17) = 14.901$, $p < .01$, two tailed). A further shortening of latencies is evident from the 250 ms to 375 ms duration (M = 128.60, SD = 46.5) ($t(17) = 11.734$, $p < .01$, two tailed). The total deviation from 125 ms duration and 375 ms duration was 297.89 ms with a standard deviation of 75.02 ($t(17) = 16.85$, $p < .01$, two tailed). Latency time for pitch duration was also significant when interacting with pitch order ($F(1.89, 24.566) = 3.491$, $p = .049$). This finding was not further analyzed as a graphical representation denoted a small effect. Additionally, presentation order x pitch type x presentation type (single or combo presentation) was significant ($F(1, 13) = 6.52$, $p = .024$). A graphical analysis suggested that a single pitch combination created this result; the slider presented as a single pitch. A single post-hoc test was run to further analyze this single comparison, but it was not significant.

A-prime

The only significant result for a' in the non-steady state phase was presentation type, single pitch versus combo presentation ($F(1, 13) = 8.47$, $p = .012$). The single pitch presentation resulted in a higher mean for a', however, this difference was only 0.0158.

Criterion C

The last analysis performed in the non-steady state phase was for the criterion measure C. No statistically significant effects were found. No transformations were attempted.

Steady State

Steady state analyses were performed only on the four trial blocks that maintained a 10% or less difference in main target accuracy. The analyses from the non-steady state phase were repeated for the steady state phase data.

Latency

Similar effects described in the non-steady state phase for latency were observed during this phase. Pitch type x slider/fastball order ($F(1, 13) = 6.08$, $p = .028$) and presentation type (single vs. combo) x pitch type x slider/fastball order ($F(1, 13) = 4.78$, $p = .048$) depicted similar effects to the non-steady state results. Additionally, pitch duration was statistically significant ($F(2, 26) = 10.85$, $p < .01$). The Bonferroni corrected paired t-test analysis resulted in the same findings as the non-steady state results; 125 ms – 250 ms (M= 162.51 SD= 45.2; $t(17) = 15.18$, $p < .01$, two-tailed), 250 ms - 375 ms (M= 130.21 SD= 38.28; $t(17) = 14.43$, $p < .01$, two-tailed), 125 ms - 375 ms (M= 292.72 SD= 60.38; $t(17) = 20.57$, $p < .01$, two-tailed).

A-prime

A' results include presentation type ($F(1, 13) = 9.16$, $p = .01$) but two additional statistically significant interactions were observed: presentation type x slider/fastball order x expertise ($F(1, 13) = 5.71$, $p = .03$) and a between-subjects effect of pitch order x expertise ($F(1, 13) = 5.02$, $p < .01$). The difference between means in the single versus combo presentation was a little larger relative to non-steady state, 0.0242. When examining the graphical representation of the three way interaction of presentation type x slider/fastball order x expertise, an intriguing result was observed. Differences exist between experts and novices for single presentation (M= .073 SD= .024, $t(7) = 3.085$, $p = .018$, two tailed) and for combo presentation (M= .122 SD= .042, $t(7) = 2.916$, $p = .022$, two tailed) in post hoc Bonferroni correction t-tests for participants who received the slider as the second pitch type. In addition, it was the novices that demonstrate the higher a's. The between-subject effect of expertise x slider/fastball order can be separated into a more detailed analysis. Separated by slider/fastball order, an expertise effect was found for mean a' values, but only for those individuals who received the slider second (M= .097 SD= .028, $t(7) = 3.45$, $p = .011$, two tailed, Bonferroni corrected).

Criterion C

No statistically significant findings were reported for the criterion measure of C.

Percent Correct

The final analysis for Experiment One was based on percent correct at steady state. In this analysis, a single main effect of presentation type (single vs. combo) was found ($F(1, 13) = 7.033$, $p = .02$) and one interaction; presentation type x expertise ($F(1, 13) = 6.13$, $p = .028$). The mean difference between single and combo presentation was

2.08% in favor of single presentation. Further analysis of the expertise interaction with presentation type did not yield significant results when corrected for family-wise error corrections, but a trend is evident for experts to demonstrate a difference between single and combo presentation percent correct (Appendix B).

Discussion

The first surprising result of this study is the high performance of both groups without ball rotation information from the seams of the ball. Mean percent correct for fastball (73%), slider (73%), and curve (55%) pitches, were all above chance performance, which was 50%. The information the participants were utilizing was limited to xyz velocities. These findings suggest that in a task in which an object is directed toward an individual such as softball, the ability to predict general locations may not be different for distinctive levels of expertise. This significance of expertise carries over into the general analysis of Experiment One. Expertise effects were limited to interactions in the steady state condition. Experts exhibited poorer performance than novices (as shown by a' and percent correct) in presentations involving multiple pitches over single pitches. This finding is interesting considering that pitch presentations during a game would be combined. One would expect experts to demonstrate superior performance relative to novices especially in a combined presentation, as repeated exposure would promote a learned scheme. Even though moving the viewpoint to that of the umpire might have altered the visual processing of the experts, this cause is unlikely. The X,Y, and Z velocities would not differ significantly between the two viewpoints until the ball was well into flight. Another possibility for the poor performance of the experts is the change in response type; denying the experts the ability to perform their natural swinging action. This change might have altered their processing of the situation by removing a portion of what may be an automatic process. Ranganathan and Carlton (2007) suggest that such an explanation is unrealistic. When examining expert players and novice players with no high school or better baseball experience uncoupled, non swinging, responses were significantly more accurate in predicting pitch type then when able to swing. This effect is further exaggerated by the experimental design of the current study. As the combination presentation was always presented last, training effects or repeated exposure should allow for better performance. At the very least, these findings present evidence that participants were unable to simply learn the stimuli. More abstractly, the findings raise the possibility that current training techniques or strategies employed by the experts in the combination presentation may not be optimal. Further investigation is highly warranted and should include situational factors as utilized by Paull and Glencross (1997).

Pitch order effects, either in steady state or not, suggest a detrimental effect of having the slider presented after the fastball. This finding is not too surprising because participants may acclimate to the fastball and have a difficult time changing when presented a similar pitch. In the steady state trials, the trend suggests that the experts are more vulnerable to such an effect possibly affecting prediction schemes.

Finally, the significant findings of pitch duration suggest an attempt by the participants to maximize accuracy. The decrease in latency coupled with no significant time related effects in percent correct (Figure 2), C, or a' show that the visual system can accurately pursue the problem with limited information. The lack of findings for C suggests that no criterion shift was evident based on expertise. The decrease in latency implies that additional time may be required to complete the process if provided

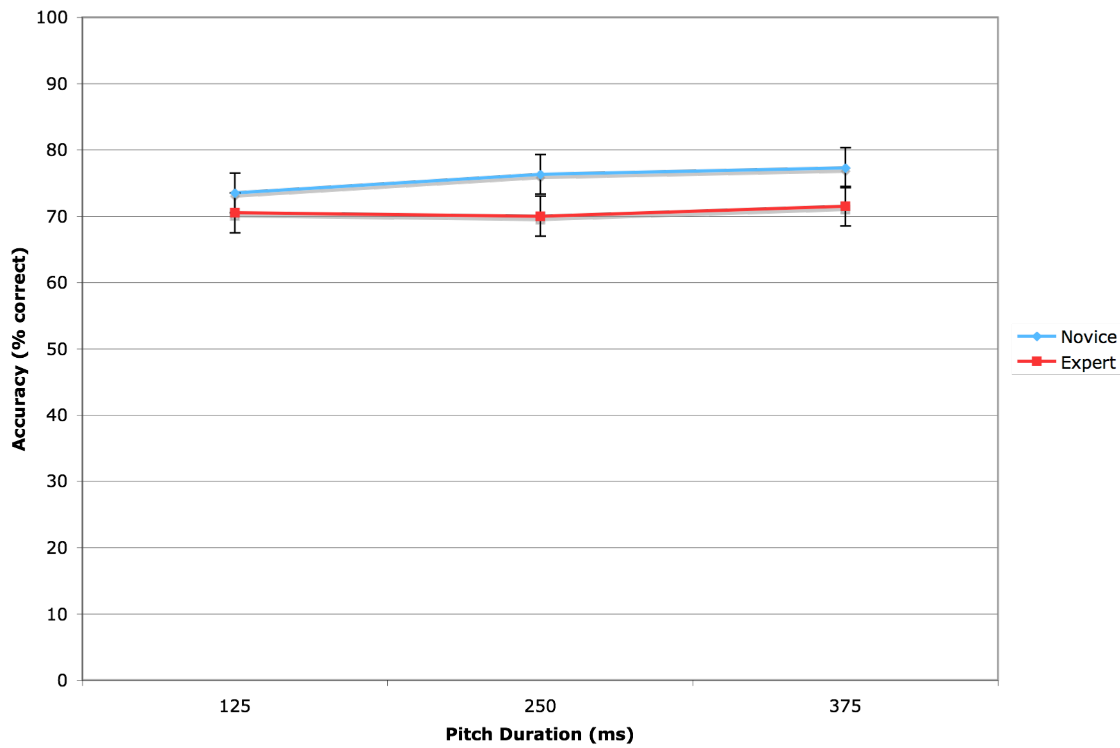


Figure 2. Accuracy in the Softball Task for Expert and Novice Groups

limited information. Such a fact would suggest that an optimal time might exist for motion prediction to provide the optimal timed reaction while gathering the maximum visual information. Such information could be critical for training of athletes as an optimal time to perform a batting task that maximizes the trade-off between percent of ball flight and decision making. As latency did not vary by expertise, it is reasonable to assume the differences found in decision time from Paul and Glencross (1997) is reliant on processing strategic information. There were small improvements in accuracy error after 80 ms of ball flight (Paul & Glencross, 1997). While no such accuracy differences were found in this study, the likely culprit of Paul and Glencross' result may be the processing of complex situational information. These differences seem less reliant on ball flight information, as evident from the results of this study, than time to process. This conclusion would support research suggesting an experts' ability to utilize early information of an opponent's action (Van Der Kamp, et al, 2008). These findings lead to the conclusion that expected expert differences relative to novices were not found. Information that would have been utilized by the players given their expertise was missing. Because the task did not highlight the reaction and timing of the motor function for the bat swing, the situational cues or the pitcher cues that provide an edge to the experienced batters may not have been activated resulting in a null effect for expertise.

In entirety, these findings imply a possible change to current training techniques. As the two levels of expertise could determine general ball location equally well, it may be warranted to assume that such a capability is a characteristic of the human visual system. As such, attempting to train this capability directly or indirectly may be unhelpful. Instead, training of timing and situational factors may yield better results. Further analysis of individual differences for the experts would be very beneficial to the discussion of what aspects may be the most efficient to train.

CHAPTER 3

EXPERIMENT TWO – EXPLODING OBJECT TASK

Participants

The same individuals from Experiment One participated in this experiment.

Apparatus and Videos

A 19" touchscreen LCD monitor was used for stimulus presentation and for recording participant responses. Videos were comprised of a 2-D view of a main target object traveling along a 45-degree ballistic path. At some point in this trajectory, the main target exploded resulting in a number of possible shrapnel pieces. The possible shrapnel conditions were 0, 2, 4, or 6 pieces. Velocities were delineated based on initial XY object velocities. Velocities were 10, 12.5, and 15 cm/s. Each combination of velocity and shrapnel were presented with the exploding time points, ¼, ½, and ¾ path. Videos were created using the Carrara® 4 software package and were generated at a resolution of 960 x 720.

Procedure

The participant was shown a 2-D view of a main target object traveling along a 45-degree ballistic path. At some point in this trajectory, the main target exploded resulting in a number of shrapnel pieces, either 0, 2, 4 or 6 pieces. The participant's task was to predict the landing location of the main target and the individual pieces of shrapnel. Landing positions were measured via the touch screen monitor and responses were limited to 50 possible selection blocks located beneath the horizontal representation of the ground. Latency, main target accuracy, absolute main target error, and absolute mean shrapnel error were recorded. When the performance of predicting the landing location of the main target was stable within 10% averaged over four trial blocks, a new phase began until all shrapnel conditions were used. Main target accuracy for the landing location was based on a bucket of five selection blocks centered in the actual landing location. Error for the main target or shrapnel pieces was calculated based on the number of selection blocks between the actual single block landing location and the participant selected box.

Design

A 2 (expertise) x 3 (velocity) x 3 (exploding time point) x 4 (number of shrapnel) mixed model design was used. The definition of expertise was carried over from Experiment One. Velocities consisted of 10, 12.5, and 15 cm/s and exploding time points included ¼, ½, and ¾ paths. Shrapnel possibilities included 0, 2, 4, and 6 pieces. An additional covariate of the number of blocks to reach steady state for the zero shrapnel condition was also used. The analysis performed included multiple mixed model ANOVAs with expertise as the only between group variable for the dependent measures of latency, main target accuracy, mean absolute main target error, mean absolute shrapnel error.

Results

Only a steady state analysis was performed for Experiment Two because the participants reached steady state very quickly. The vast majority of participants, 94%, required only four phases, the minimum, for the different shrapnel conditions. Participant means were calculated for main target accuracy, absolute main target error, and absolute mean shrapnel error. Absolute mean shrapnel error was calculated by the combined mean of all pieces of shrapnel for a particular trial. This calculation resulted in a single absolute mean shrapnel error for a particular participant's trial. These values could then be further combined to a final absolute mean shrapnel error for each independent measure combination for each participant. Additional archival results can be seen Appendix B.

<u>Main Target Accuracy</u>

Main target accuracy was found to be statistically significant based on shrapnel condition ($\underline{F}(3, 48) = 64.5$, $\underline{p} < .01$). The associated graph can be seen in Figure 3. Further Bonferroni corrected paired t-tests reveal that the four shrapnel conditions were significantly different from each other (statistical values can be seen in Table 2).

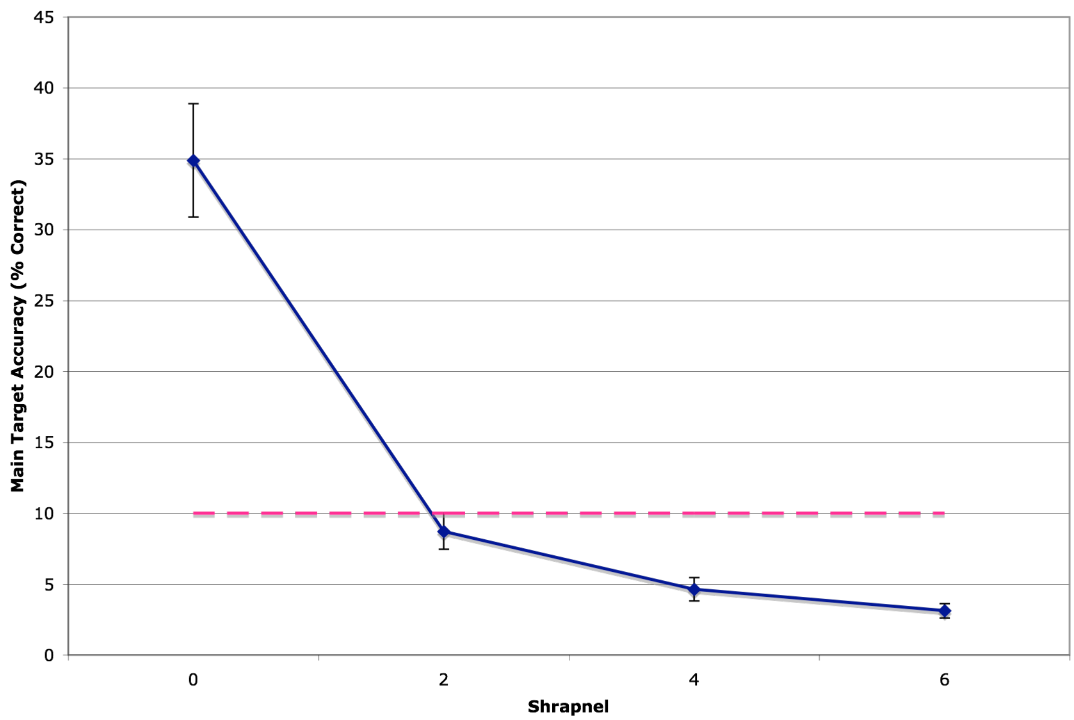


Figure 3. Main Target Accuracy as a Function of Number of Shrapnel Pieces Displayed (chance performance denoted by dashed line)

Table 2. Bonferroni Corrected Comparisons for Main Target Accuracy (all comparisons significant).

Piece Comparisons	Mean Difference	Std. Deviation	t	df	Sig. (2-tailed)
s0 - s2	26.17222	14.05074	7.903	17	0
s0 - s4	30.25556	15.18475	8.453	17	0
s0 - s6	31.7833	15.9619	8.448	17	0
s2 - s4	4.08333	2.80231	6.182	17	0
s2 - s6	5.61111	3.7605	6.331	17	0
s4 - s6	1.52778	2.06848	3.134	17	0.006

Absolute Main Target Error

Four significant effects were found for main target error. Two main effects were found; velocity ($F(1.41, 19.75)= 6.53$, $p= .012$) and exploding time point ($F(1.35, 18.92)= 4.18$, $p= .045$). Two significant two-way interactions were observed: velocity x exploding time point ($F(3.14, 43.91)= 2.85$, $p= .046$) and shrapnel x expertise ($F(3, 42)= 2.92$, $p= .045$). The general effect of velocity based on a statistically significant linear contrast ($F(1, 14)= 6.76$, $p= .02$) is an increase in error with an increase in initial main target speed. Exploding time points, ¼, ½, or ¾ paths, resulted in a trend with the ¼ point having the highest mean error compared to the ½ and ¾ points (M= 77.2 SD=24.79 and M= 111.98 and SD= 36.52). Additional separation is evident between the two final points with the ½ resulting in a higher mean (M= 34.79 SD= 14.87). These comparisons were completed with Bonferroni corrected paired t-tests ($t(17) = 13.21$, $p< .01$, two tailed; $t(17) = 13.01$, $p< .01$, two tailed; and $t(17) = 9.92$, $p< .01$, two tailed) respectively. The interaction between velocity and time results in a logical conclusion that higher speeds coupled with earlier exploding time points resulted in greater error. Thus, a further analysis was not performed. Figure 4 depicts the relationship between main target error and the interaction between shrapnel number and expertise. Experts demonstrated less of an impact of main target error based on number of shrapnel pieces presented.

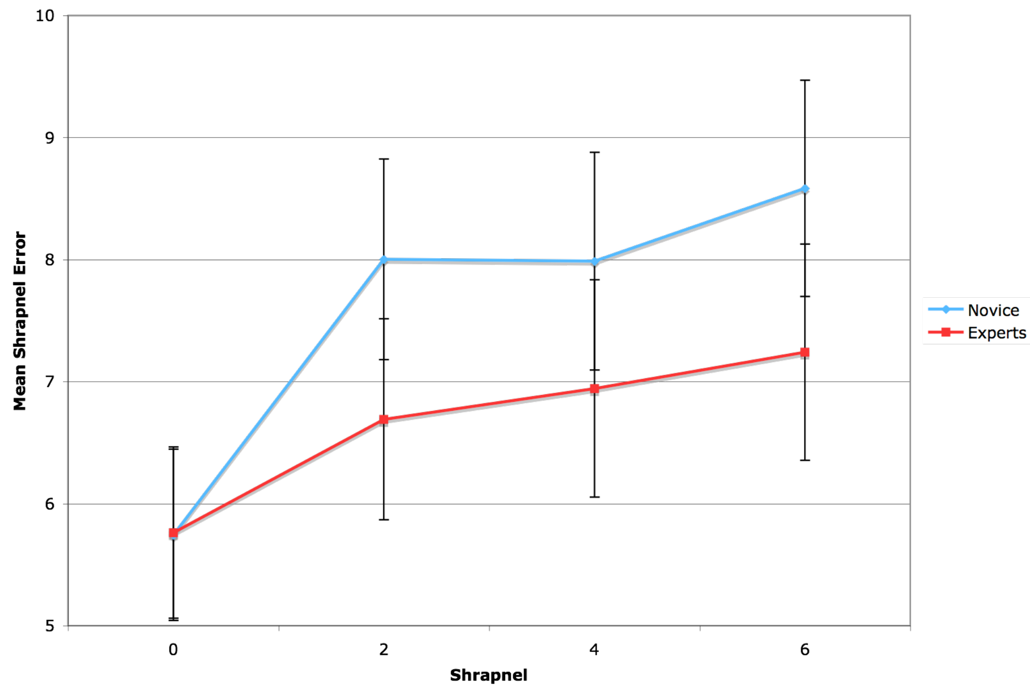


Figure 4. Mean Absolute Main Target Error as a Function of Number of Shrapnel Pieces and Expertise.

Absolute Mean Shrapnel Error

The mixed model ANOVA performed on mean shrapnel error highlighted three significant interactions; shrapnel x number of trials to reach zero shrapnel steady state ($F(2, 28)= 4.54$, $p= .02$), velocity x exploding time point x number of trials to reach zero shrapnel steady state ($F(4, 56)= 3.12$, $p= .022$), and velocity x exploding time point x expertise ($F(4, 56)= 4.34$, $p< .01$). A graphical analysis of the two-way interaction of number of shrapnel pieces x number of trial required to reach steady state suggests a trend for the six shrapnel condition to result in marginally higher error rates as a function of increases in number of trials required for steady state. In the three-way interaction between velocity, exploding time points, and number of trials required for steady state, the velocities of 10 cm/s and 15 cm/s resulted in rather flat slopes relating the time points across number of required phases. The velocity of 12.5 cm/s resulted in a separation between the time points (figure 5). The most interesting of the three significant results is the velocity x time x expertise ($F(4, 56) = 4.34$, $p < .01$). Figure 6 depicts the patterns evident in this interaction. The novices and experts demonstrated similar patterns except for the ¼ path exploding time point at 10 cm/s and 12.5 cm/s velocities. The figure further suggests a grouping difference between expertise at the ¼ exploding time point. Experts demonstrated similar levels of mean absolute shrapnel error for velocities of 12.5 cm/s and 15 cm/s, while the error for the velocity of 10 cm/s was smaller. The novices inversely group 10 cm/s and 15 cm/s, while a velocity of 12.5 cm/s results in higher errors.

Discussion

Figure 3 shows main target accuracy as a function of number of presented shrapnel pieces along with chance performance. The stark finding of below chance performance for all conditions except the zero shrapnel condition relates to an interesting characteristic of the visual system. There are multiple possible reasons for such an effect. It is possible that the shrapnel is functioning purely as noise. The increases in noise level lead to decreases in accuracy. Another probable explanation relies on a similar but distinct distraction. The noise argument is based on the fact that the anticipated target track is interfered by additional target tracks of the shrapnel. As the number of motion path tracks increase, the probability of track interference, motion path overlaps, rises.

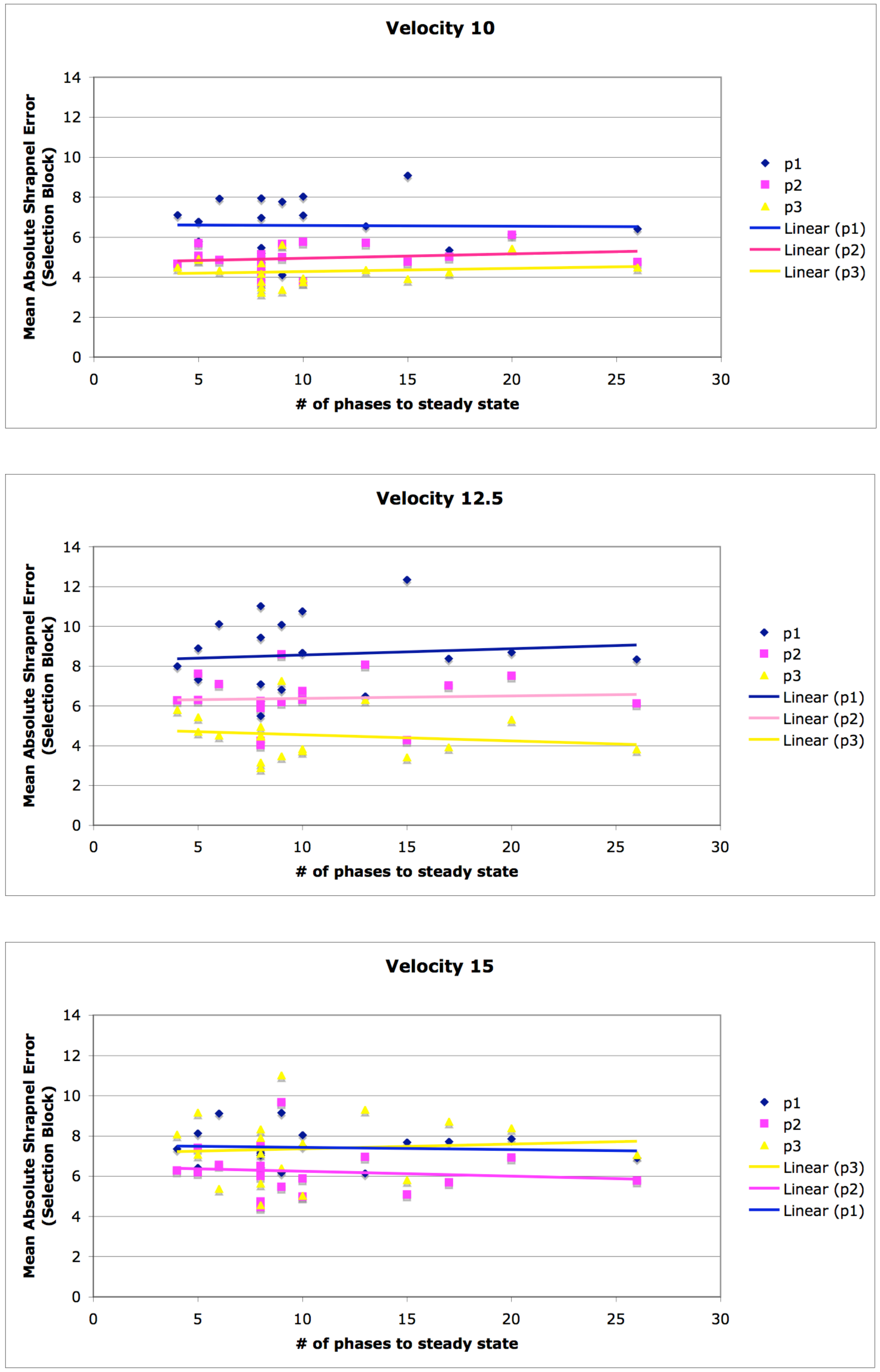


Figure 5. Mean Absolute Shrapnel Error as a Function of Velocity, Exploding Point Time, and Number of Trials to Steady State

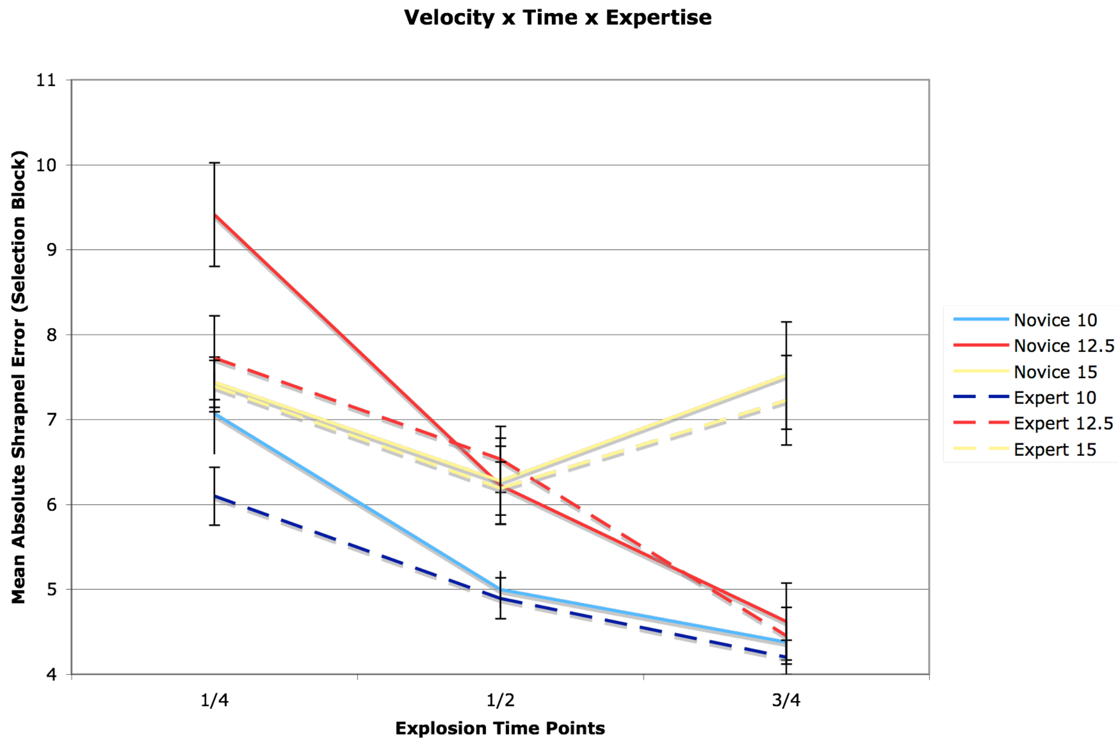


Figure 6. Mean Absolute Shrapnel Error as a Function of Velocity, Exploding Time Point, and Expertise

The distraction explanation relates more to an inability to maintain the main target track in memory when attempting to create a new track which may overwhelm resources. This reasoning would lead to a conclusion that the number of possible motion tracks available in memory is limited. The final possibility is a limitation in the speed of processing. As the number of pieces increases, the speed at which all processing must be completed increases. In order for correct perception to be achieved, processing shortcuts may be used to maximize total performance to offset processing limitations. An example of a possible shortcut would be utilizing a smaller percentage of the motion path to make a prediction. These shortcuts could affect main target accuracy by balancing performance between main target and shrapnel pieces.

The main effects of velocity and exploding time point coupled with the interaction of the two for main target absolute error lead to expected results. As velocity increases, the difficulty of predicting the future path increases, resulting in higher errors. Exploding time point results in a similar effect. When the target explodes earlier, the possible landing locations are larger than when the target explodes at a later point. The interaction between the two illustrates an additive effect of the two main effects. The lowest speed and the latest exploding time point produce the easiest combination while the highest speed coupled with the earliest exploding time point produces the most difficult in a logical progression. These three effects could be used to support all three proposed explanations. Velocity could hypothetically increase variance in probability of landing location, expediency of distraction, or reduction in available processing time. Exploding time point similarly could affect variance in probable landing locations, increase interaction between possible motion paths, or reduce processing information or processing time.

The analysis of the mean absolute shrapnel error did not result in the same effects as absolute main target error. The interaction between number of shrapnel pieces and number of blocks to reach steady state seemed limited to the six shrapnel condition and resulted in a minor effect. A similar minor effect was shown in the three way interaction between velocity, exploding time point, and number of blocks to reach steady state. Because the presentation order for the shrapnel was randomized and only the steady state responses were used, it is probable that some level of frustration was being generated in the participants who utilized more blocks to achieve steady state.

The rather startling results of Experiment Two were the repeated effect of expertise. These effects were more distinct and cleaner than resulted from expertise in the softball pitch task. The exploding object task was designed to be more abstract than the more realistic and valid task of the XYZ object, softball task. The intriguing findings of the three way interaction between velocity, exploding time point, and expertise with mean absolute shrapnel error was the difference in performance at the ¼ exploding time point. While the experts demonstrated a logical progression of error at this point with the slowest velocity showing better performance, the mid velocity illustrates the worst performance for the novices. An explanation for this effect is not evident. The other effect of expertise, shrapnel by expertise with mean absolute main target error did result in more apparent effects. The experts exhibited a greater level of resistance to the number of shrapnel pieces affecting their main target accuracy. The greater susceptibility of the novices to number of shrapnel pieces may be caused by a lower capability to focus on multiple objects simultaneously. Utilizing the explanation of noise, it is probable that training has conditioned the athletes to better focus on an individualized task. The difficulty with this argument is that the reciprocal effect that should result. If the experts were simply focusing more on the main target, shrapnel accuracy should be reduced. An additional possibility is a capability of the experts to be less distracted by multiple motions overall.

Evidence from a follow-up experiment seems to disconfirm a simple distraction explanation. The same procedure was replicated with ten undergraduate students and steady state reduced to three sequential blocks, but with the addition of a new shrapnel condition. In this condition the zero shrapnel condition was repeated with exposure to a

250 ms visual mask before a response was permitted. The mask was comprised of visual snow much like that of television static. The results suggest above chance performance for the masked condition that is similar to the zero shrapnel condition than the 2, 4, or 6 shrapnel conditions, as shown Figure 7. No statistically significant differences were found between the zero shrapnel and the zero shrapnel with mask condition while both conditions were significantly different than the 2, 4, and 6 conditions (Table 3). This result suggests that the shrapnel is not simply acting as a pure visual distracter.

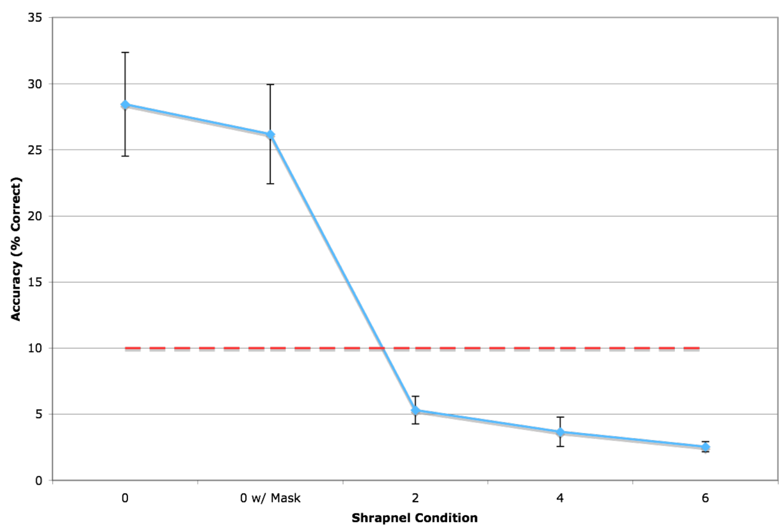


Figure 7. Accuracy in the Follow-up Exploding Object Task Including the Visual Mask Condition

Table 3. Bonferroni Corrected Comparisons for Main Target Accuracy for Follow-up Visual Mask Experiment

	Mean	Std. Deviation	t	df	Sig. (2-tailed)
s0 - s0mask	2.266	7.02489	1.02	9	0.334
s0 - s2	23.134	12.42994	5.885	9	0*
s0 - s4	24.767	10.94369	7.157	9	0*
s0 - s6	25.902	12.75813	6.42	9	0*
s0mask - s2	20.868	11.74899	5.617	9	0*
s0mask - s4	22.501	9.94435	7.155	9	0*
s0mask - s6	23.636	11.95886	6.25	9	0*
s2 - s4	1.633	4.08837	1.263	9	0.238
s2 - s6	2.768	2.65176	3.301	9	0.009
s4 - s6	1.135	3.45493	1.039	9	0.326

* denotes significance

Whether innate or trained, it is probable that experts were able to complete the processing required to complete a full predictive motion path before moving to the shrapnel. This increase in processing speed does not guarantee better accuracy, but may relate to smaller error. The experts could be processing more of the main target path, compared to the novices, before switching to track the shrapnel. As the processing for the shrapnel must be performed more in parallel compared to the single main target, the same effect would not be shown in the shrapnel error. Increasing motion path prediction speed would be advantageous in situations where longer prediction paths would need to be calculated quickly. This effect is evident in the three way interaction of velocity, exploding time point, and expertise with shrapnel. In this interaction, the ¼ exploding time point requires the longest motion track for the main target, increasing prediction speed would allow the switch to shrapnel to be more efficient providing more time to process shrapnel information. Such advantages are not shown during later exploding times. This finding is most likely caused by this speed advantage being rather small and eliminated with increases in main target path lengths.

CHAPTER 4

GENERAL DISCUSSION OF MODEL IMPACT

Both studies provide useful information to the further development of the Kelling (2008) models. The softball task was designed to assess the limits of the proposed primitive collision avoidance system. The collision avoidance system is tasked with the simple mission of maintaining an object within or outside a centralized focus area. By doing so, with a stabilized head, motor corrections can be made to avoid the object by acting to move the target outside the area or collide with the object by acting to move the target inside the area. The simplicity of the system allows for quick reactions.

The overall high success of all participants appears to support the primitive mechanism outlined by Kelling. The target area was positioned egocentrically and signal trials would travel in the direction of a collision. Gray and Regan (2006) denote that motion in depth shows a detrimental effect if motion paths are not traveling along a head collision trajectory. As the position used in the task was designed to highlight such trajectories, a simple collision/avoidance system would result in high success at fast latencies. Such an effect was found in experiment one. The lack of expertise effects further supports a simplistic system. A primitive system would already be streamlined over the evolution of the system. As the system lacks great complexity, there should be little difference between groups or individuals. This prediction also seems well supported by the data.

The vastly different effects of the second experiment suggest a quantitatively and qualitatively different mechanisms being used. Whereas rather high success rates were achieved in the softball task, the exploding object task resulted in far worse performance. This finding would support Kelling's (2008) proposal of a second distinctly different system. The global motion system simulates the motion of all objects in a representational form. Following the guidelines suggested by Kelling, the exploding object task should be impinging onto the global motion system. The primary limitation of the system is the restriction on the number of possible predictive paths that an individual is capable of managing simultaneously. This suggestion seems readily evident in the results of Experiment Two. Simply raising the number of objects from one to three pieces results in large performance deficits.

As the design of the system is much more complex than the collision/avoidance system, room should exist for larger individual differences. When the complexity of a system increases, the possibility of individualized components becoming honed increases. More complex systems are inherently less efficient. Differences based on alterations of individualized components become probable with this inefficiency. As experiential effects were found, the proposed model seems more probable. This work provides a limit to the simultaneous processing of a global motion system. While the system seems fully capable of handling many motions simultaneously, the capability to focus on more than one motion simultaneously while predicting where objects will land is limited. Additional attempts to predict multiple object landing locations may only function at a very high cost.

Because the capability to predict future motion paths is limited to one, it seems evident that the capability to detect changes in motion would be limited to the same magnitude. If changes in velocity are to be calculated using a comparison tactic to a further location in time and only one object track can be predicted into the future, then detecting changes in velocity or acceleration of objects is severely restricted to one as well. Although further research is required to make a true assessment of the proposed model and model implications, this work does provide empirical support for such models.

General Conclusion

This work has made it evident that there still exists a great deal unknown about the visual system's capabilities in motion. Gaps still exist in our knowledge of how velocity information is processed and utilized. The Kelling (2008) models provide a starting point to further delve into a topic that has implications far beyond sports. Such experimental testing should continue as impact would extend not only our general understanding of vision, but human's daily life.

APPENDIX A

EXPERTISE QUESTIONAIRRE

Experiment 497

Subject # _____________

Are you currently or have you been a collegiate level softball player? YES NO

If NO, did you participate in any high school varsity athletics? YES NO

If YES, How many years have you participated in softball ____________

What is / was your position at the collegiate level ____________

BtA ___________ SP ______________ GrPA ___________________

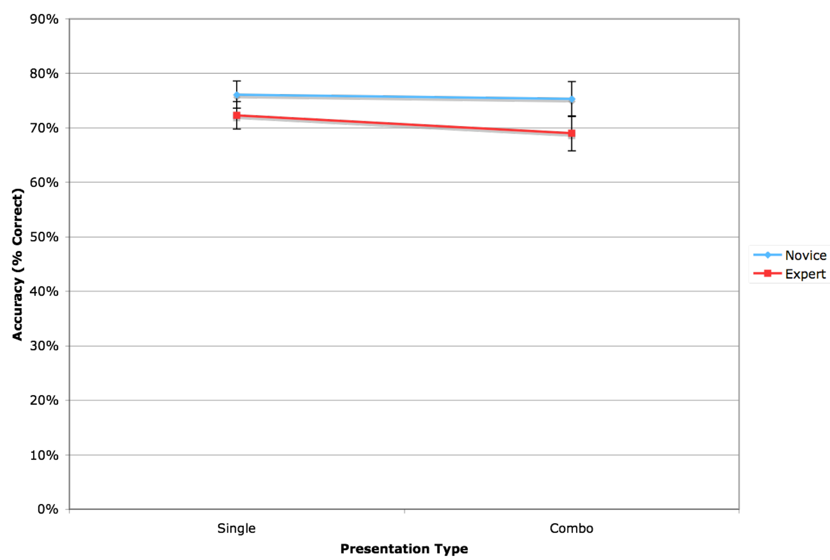
VISUAL ACUITY CHECK PASS FAIL

APPENDIX B

ARCHIVAL RESULTS

SOFTBALL TASK

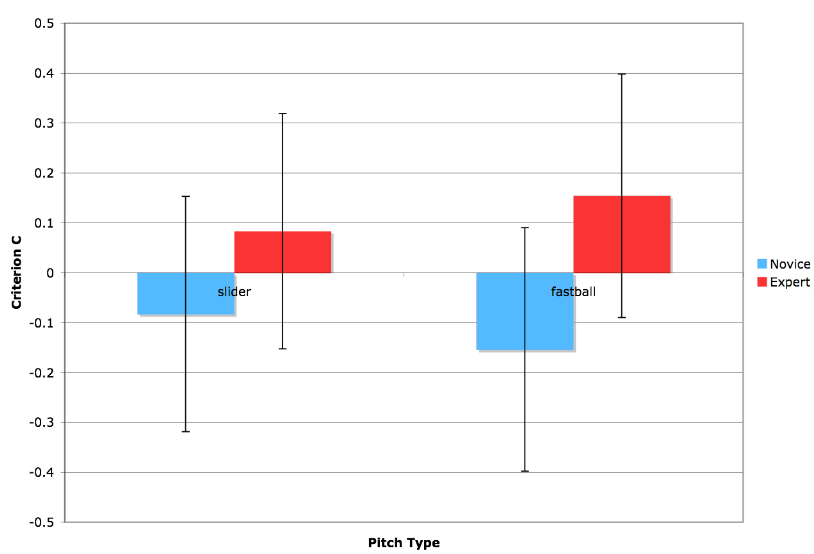
Accuracy Differences by Presentation Type for Novice and Expert Groups



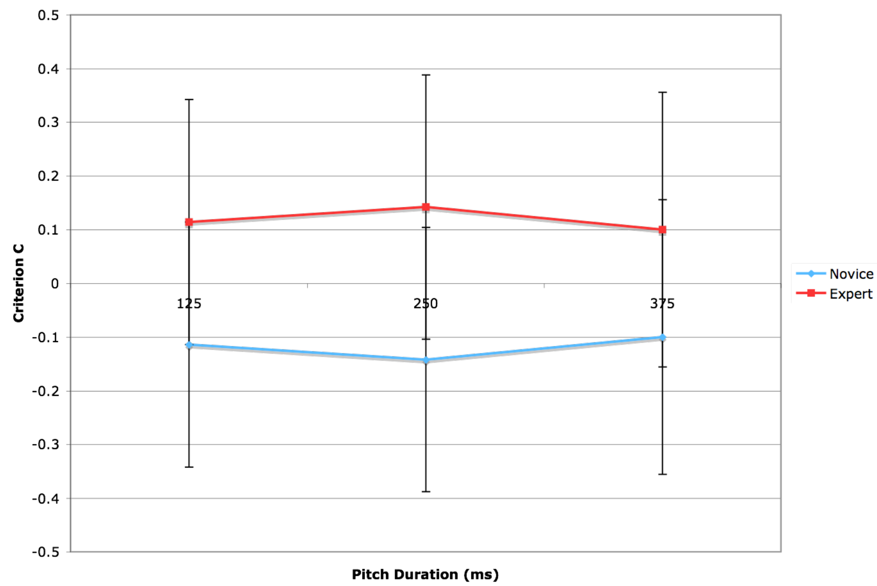
Non-Steady State

<u>Criterion C</u>

Differences of Criterion C by Pitch Type for Novice and Expert Groups

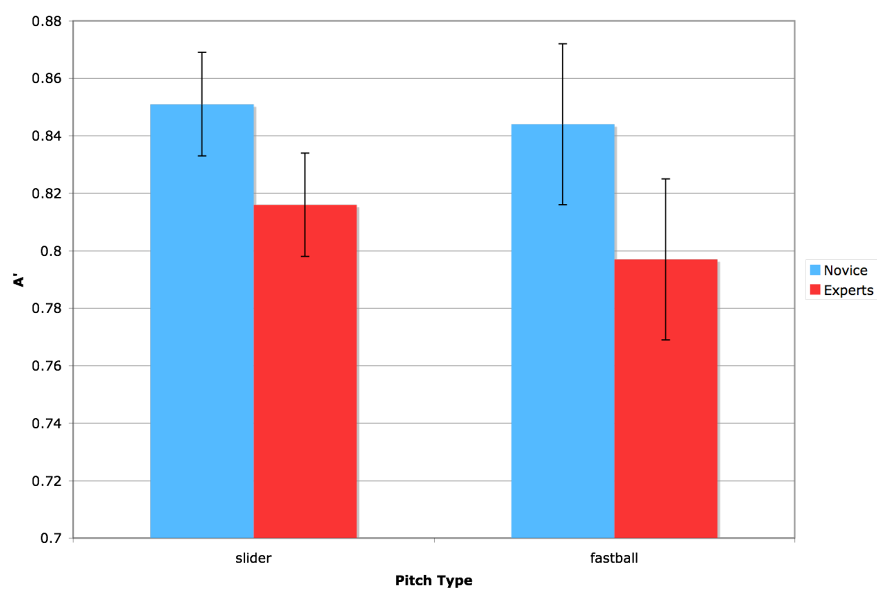


Differences in Criterion C by Pitch Duration for Novice and Expert Groups

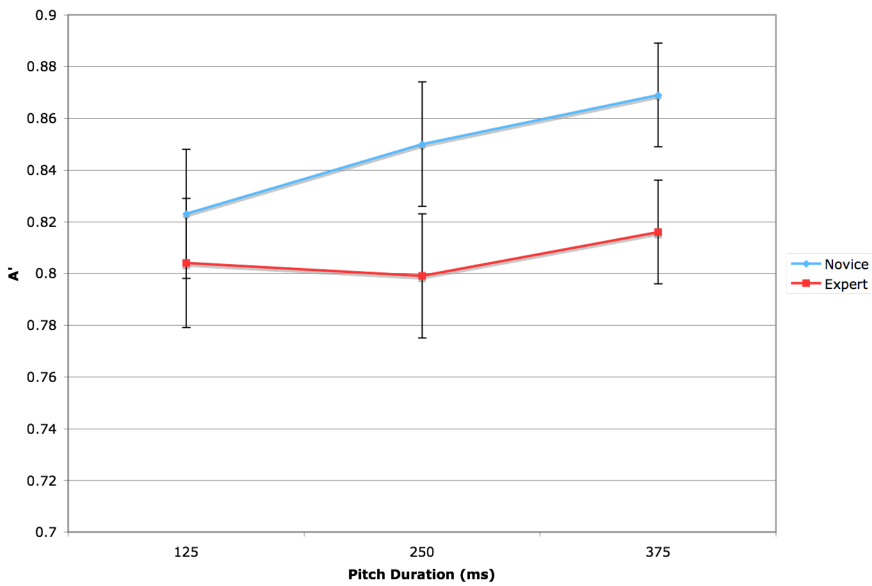


A’

Differences in A’ by Pitch Type for Novice and Expert Groups

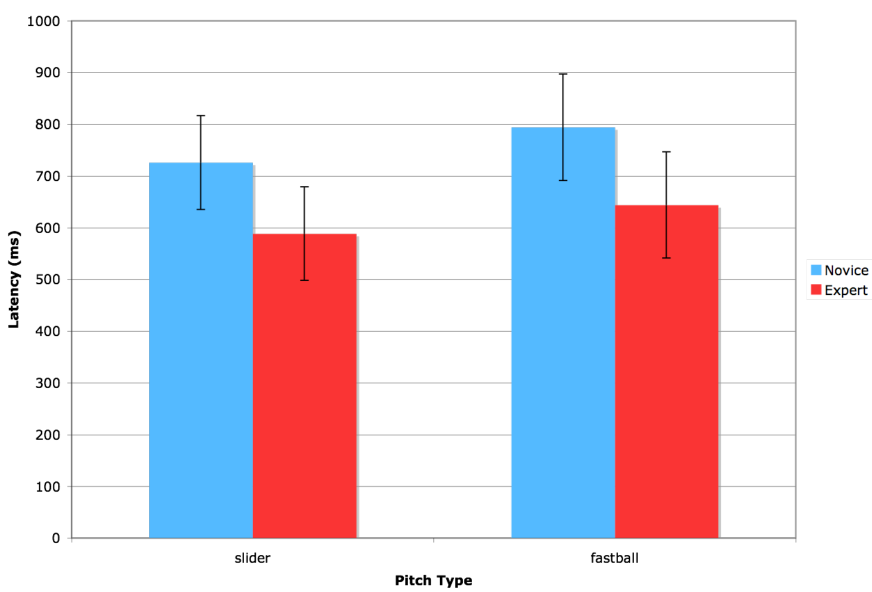


Differences in A' by Pitch Duration for Novice and Expert Groups

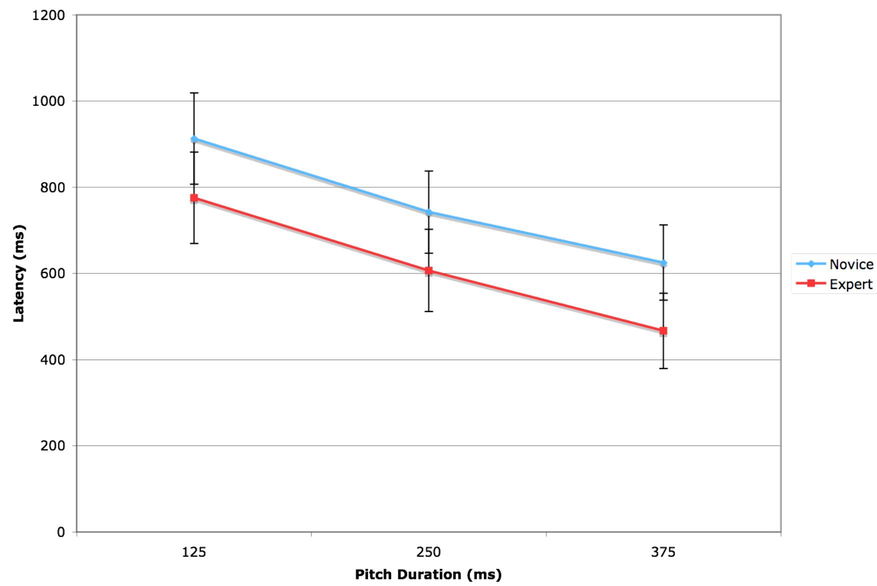


<u>Latencies</u>

Differences in Latencies by Pitch Type for Novice and Expert Groups



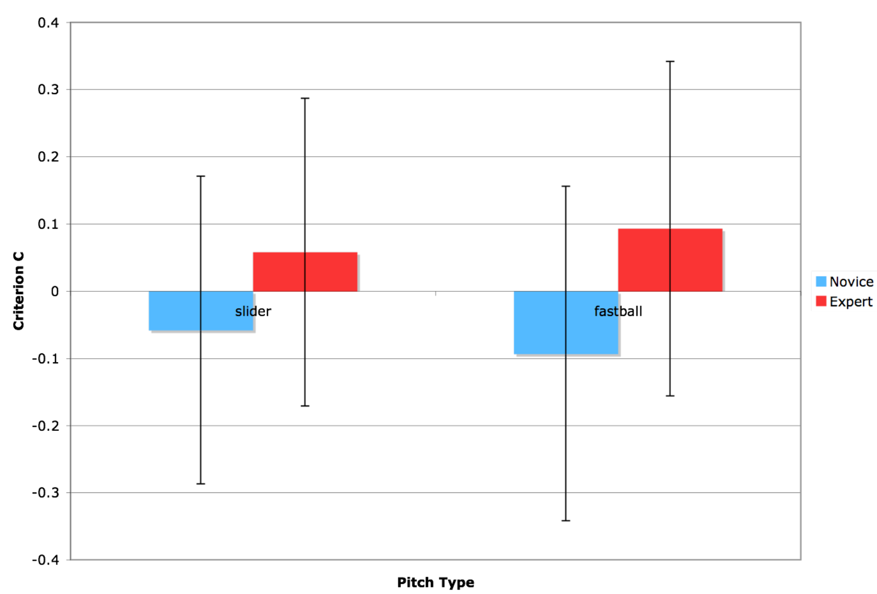
Differences in Latencies by Pitch Duration for Novice and Expert Groups



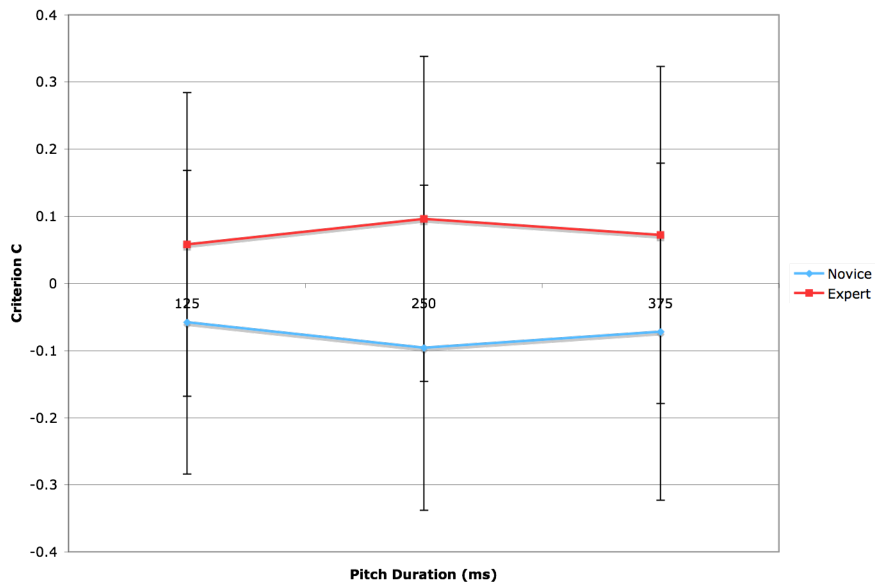
Steady State

<u>Criterion C</u>

Differences in Criterion C by Pitch Type for Novice and Expert Groups

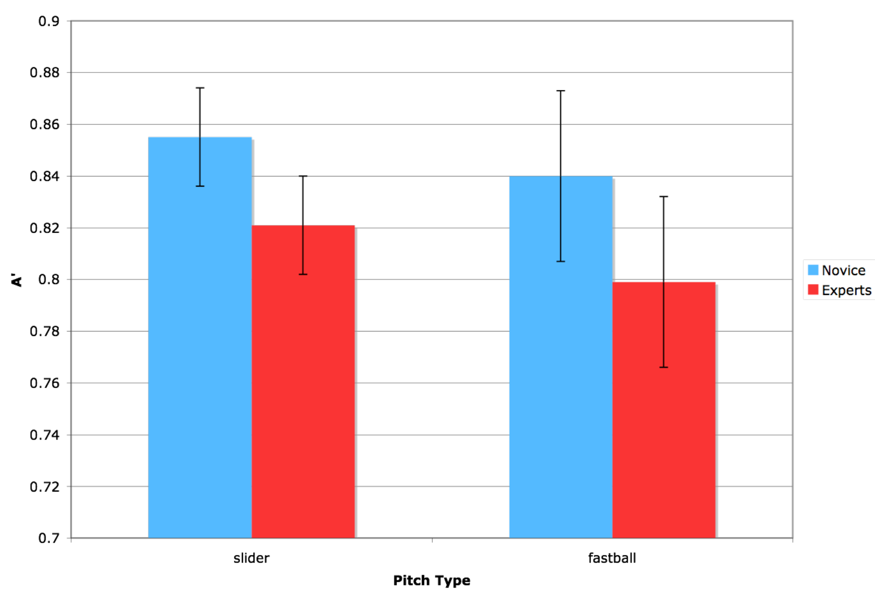


Differences in Criterion C by Pitch Duration for Novice and Expert Groups

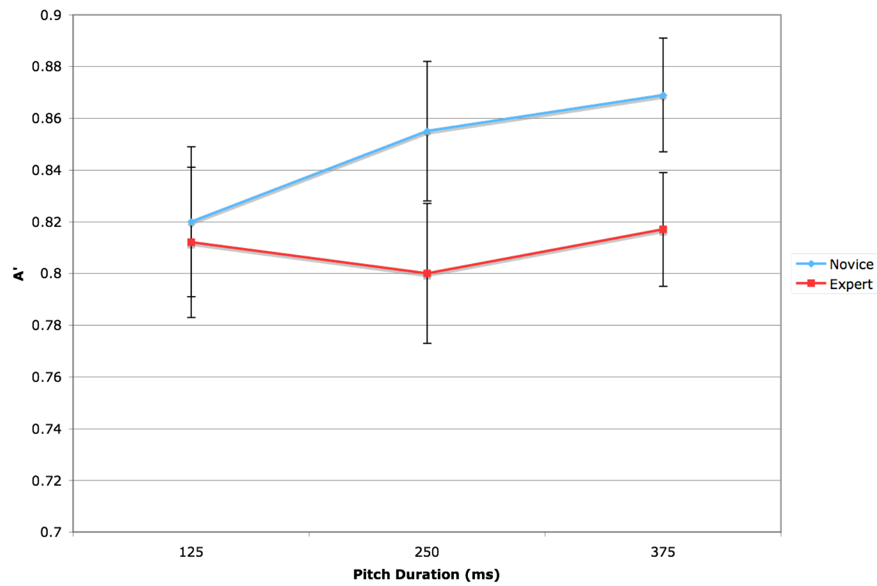


A'

Differences in A' by Pitch Type for Novice and Expert Groups

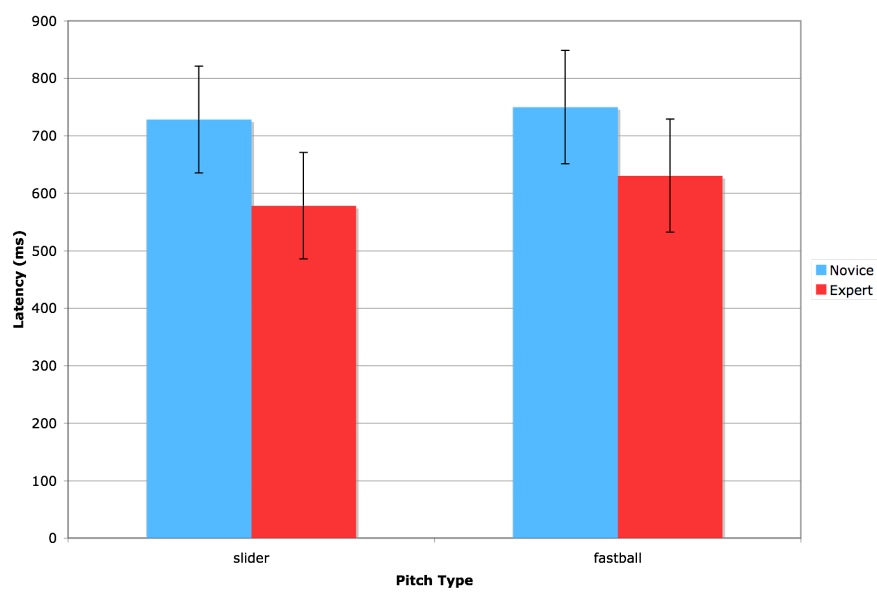


Differences in A’ by Pitch Duration for Novice and Expert Groups

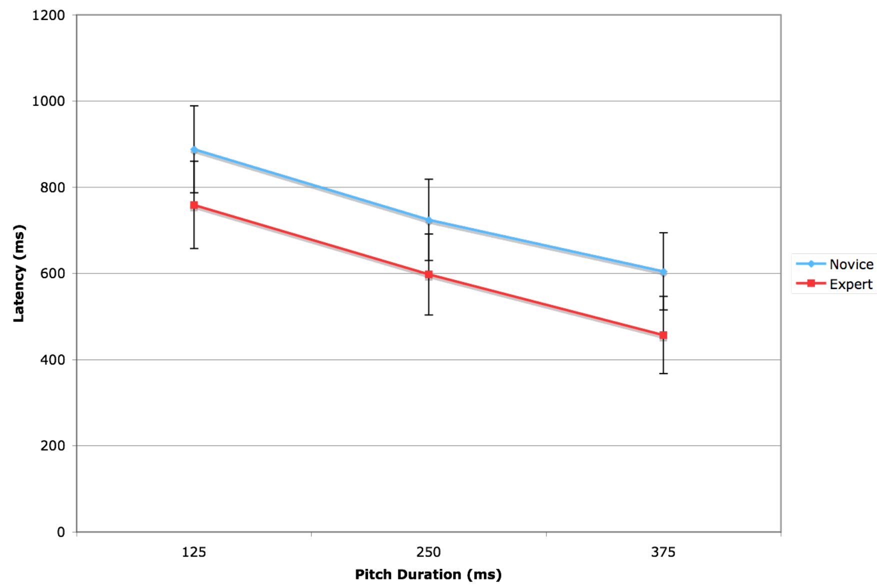


Latency

Differences in Latencies by Pitch Type for Novice and Expert Groups

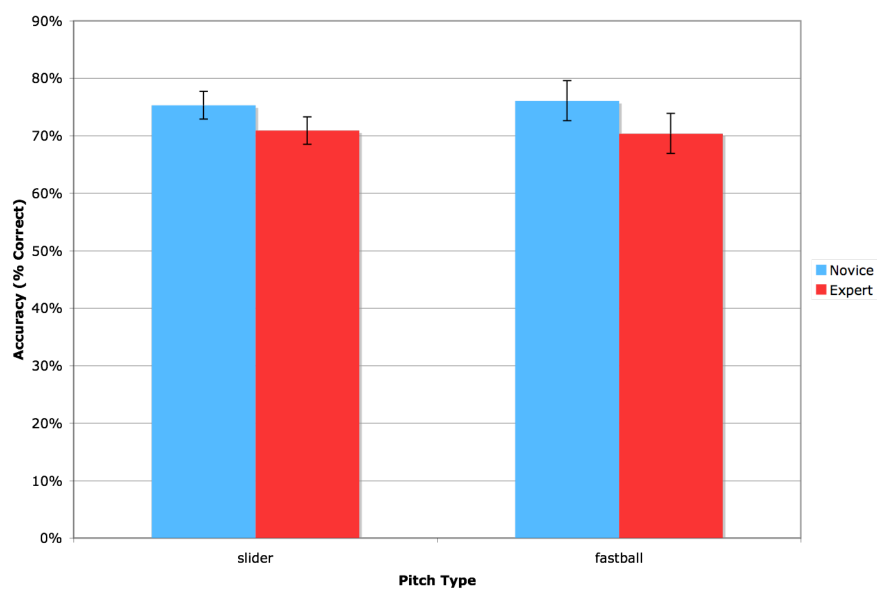


Differences in Latencies by Pitch Duration for Novice and Expert Groups

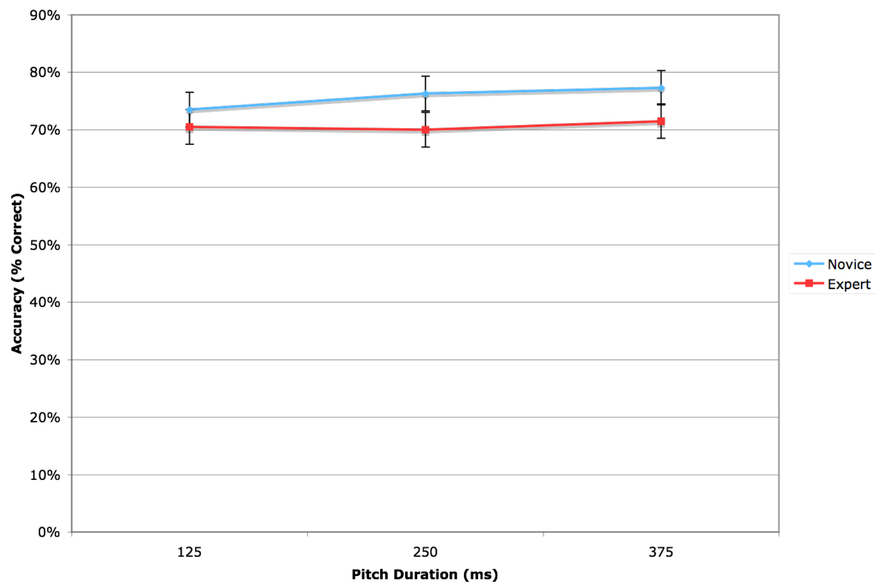


<u>Accuracy</u>

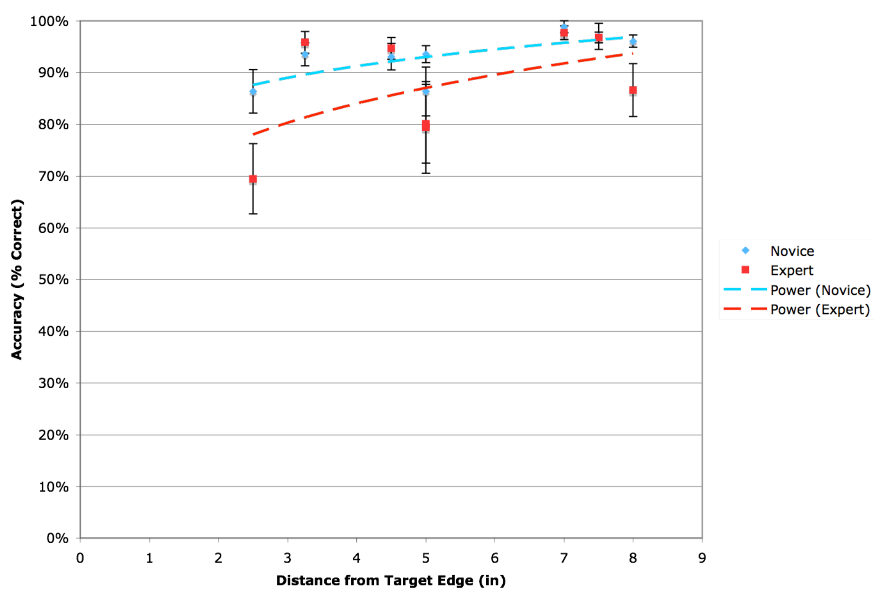
Differences in Accuracy by Pitch Type for Novice and Expert Groups



Differences in Accuracy by Pitch Duration for Novice and Expert Groups

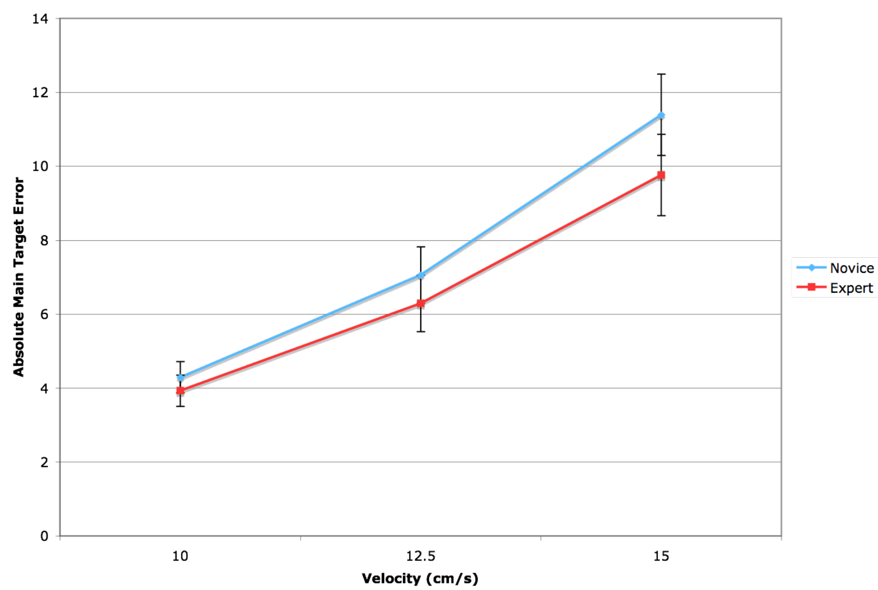


Differences in Accuracy by Distance Between Edge of Target Area for Novice and Expert Groups. (Dash Line Represents Power Based Trend Line)

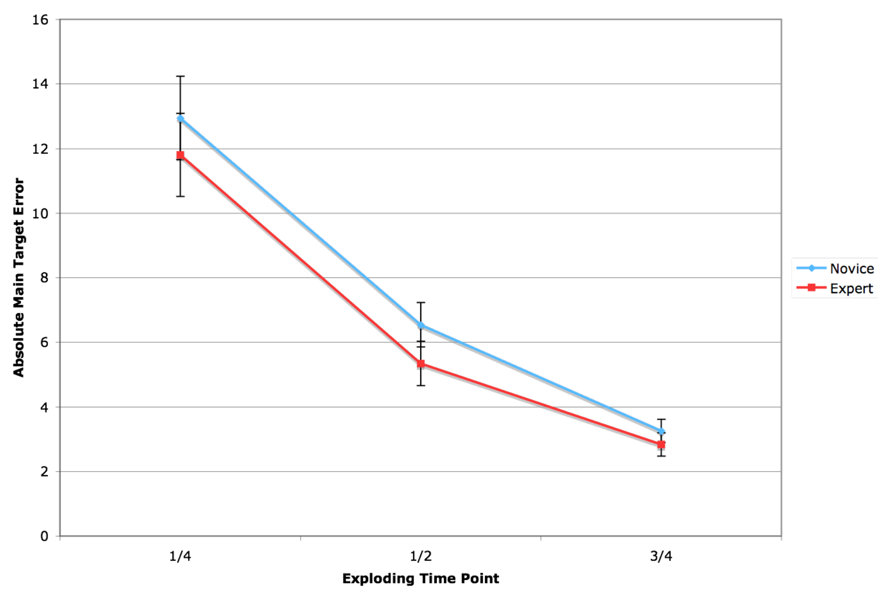


Absolute Main Target Error

Differences in Absolute Main Target Error by Velocity for Novice and Expert Groups

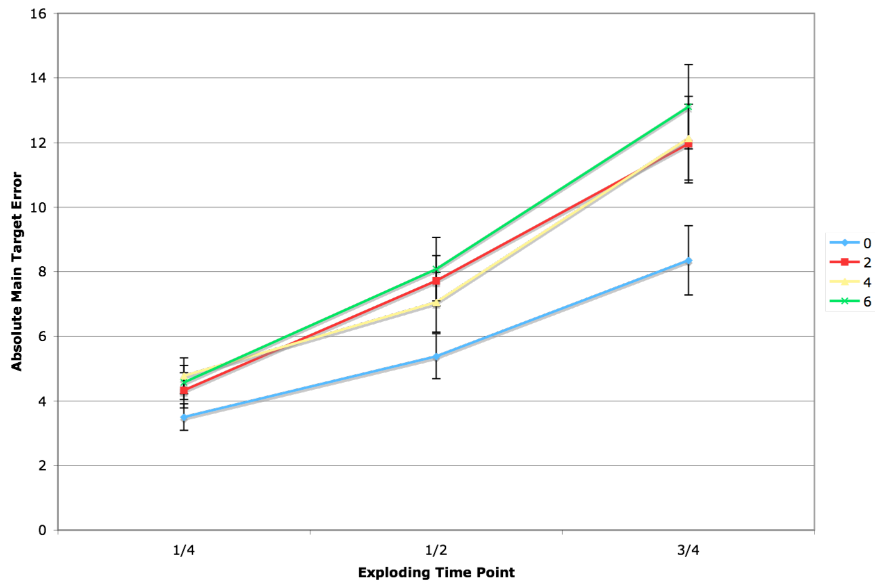


Differences in Absolute Main Target Error by Exploding Time Point for Novice and Expert Groups

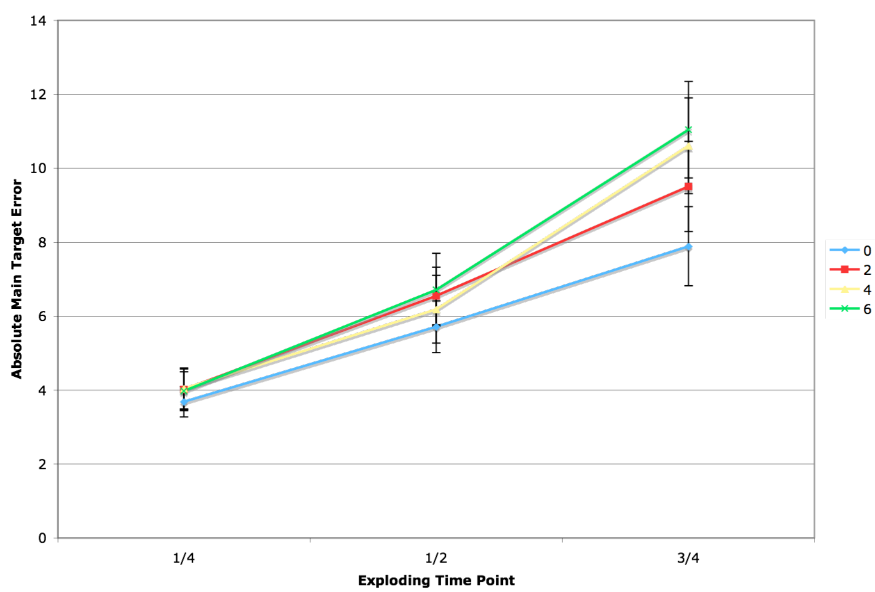


Differences in Absolute Main Target Error by Velocity and Number of Shrapnel Pieces for Novice and Expert Groups

Novice

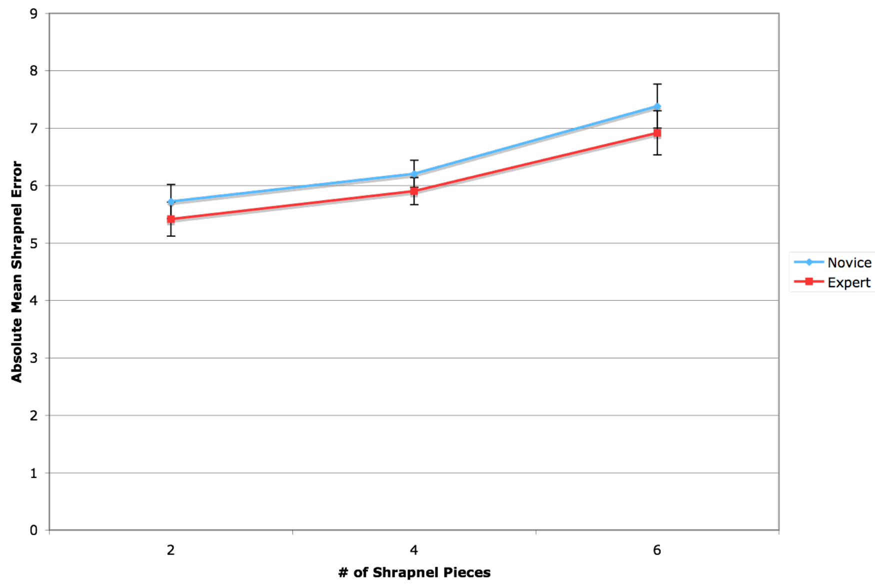


Expert

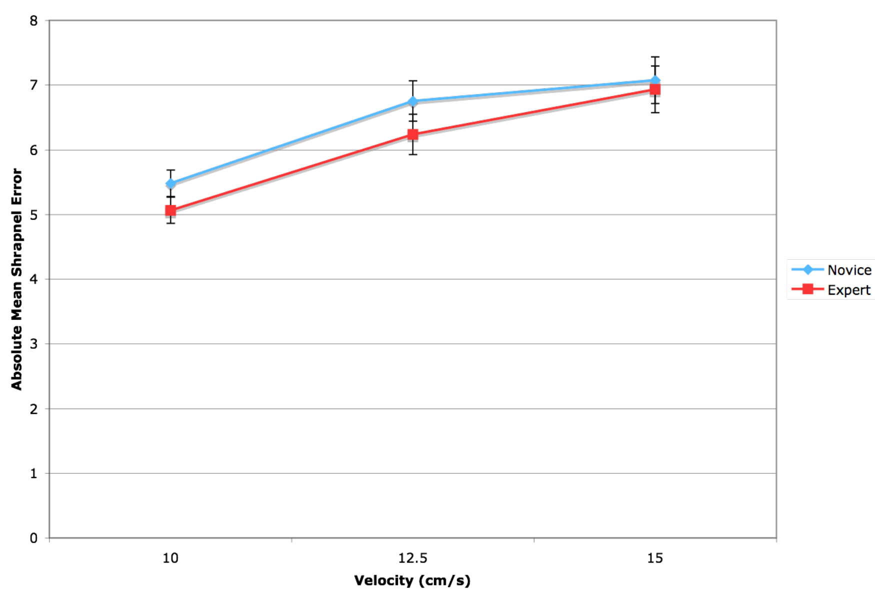


Absolute Mean Shrapnel Error

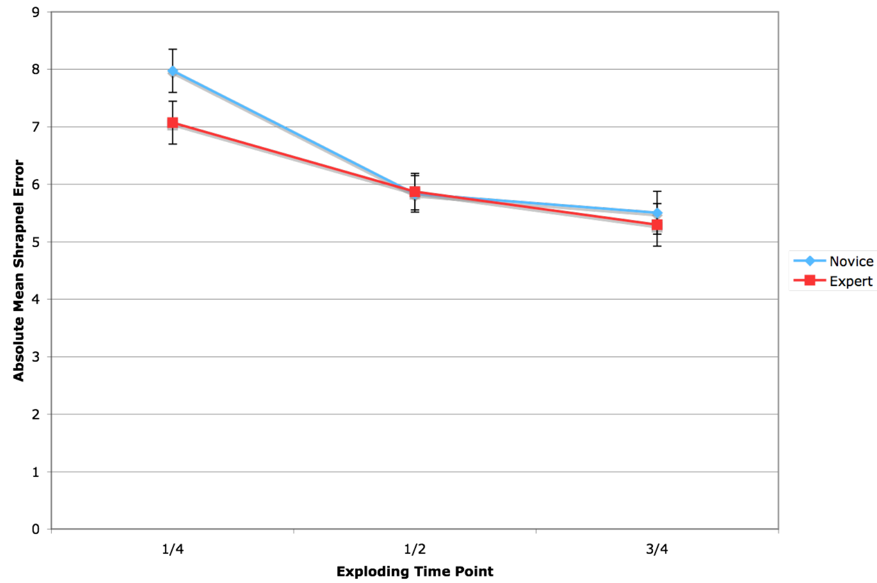
Differences in Absolute Mean Shrapnel Error by Number of Shrapnel Pieces for Novice and Expert Groups



Differences in Absolute Mean Shrapnel Error by Velocity for Novice and Expert Groups

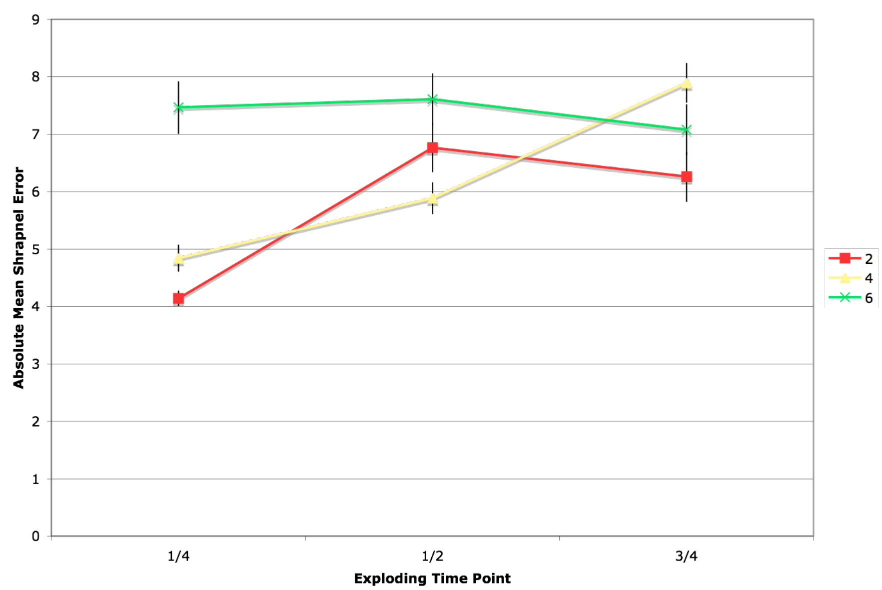


Differences in Absolute Mean Shrapnel Error by Exploding Time Point for Novice and Expert Groups

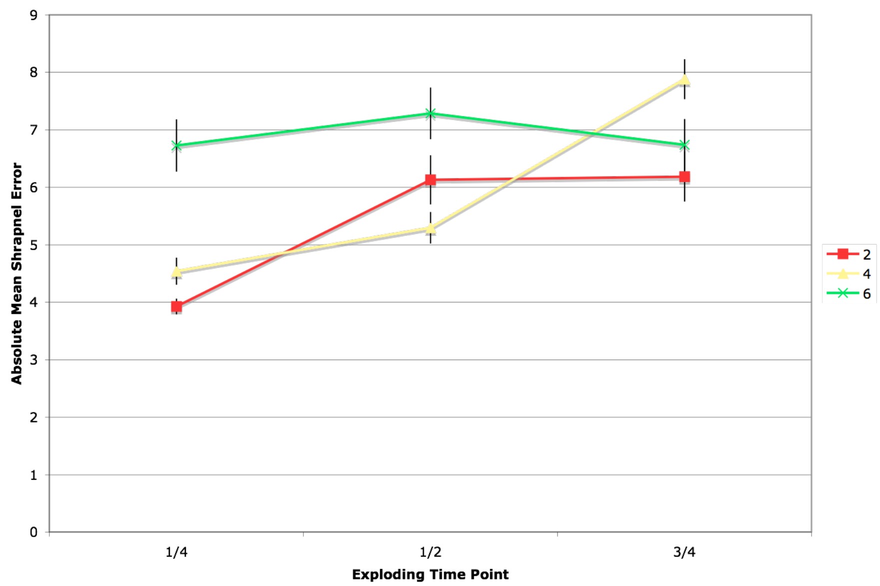


Differences in Absolute Mean Shrapnel Error by Velocity and Number of Shrapnel Pieces for Novice and Expert Groups

Novice

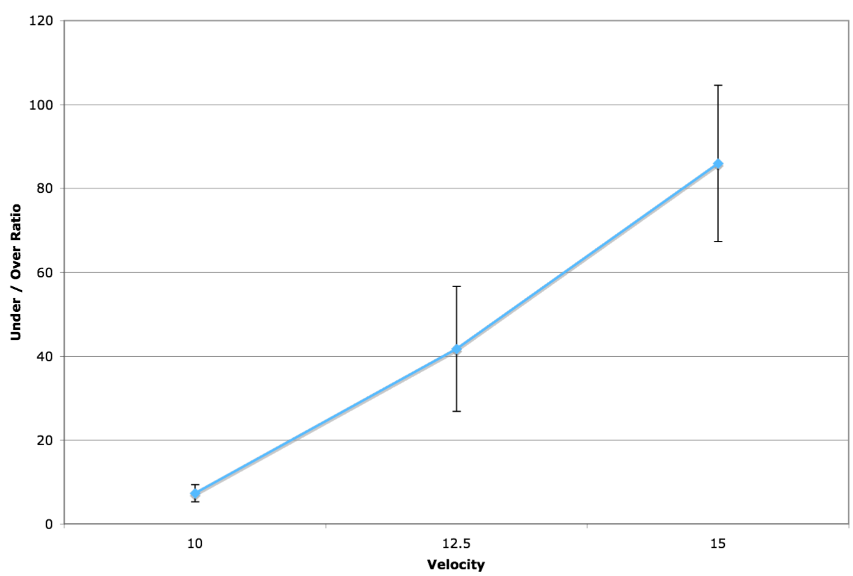


Expert

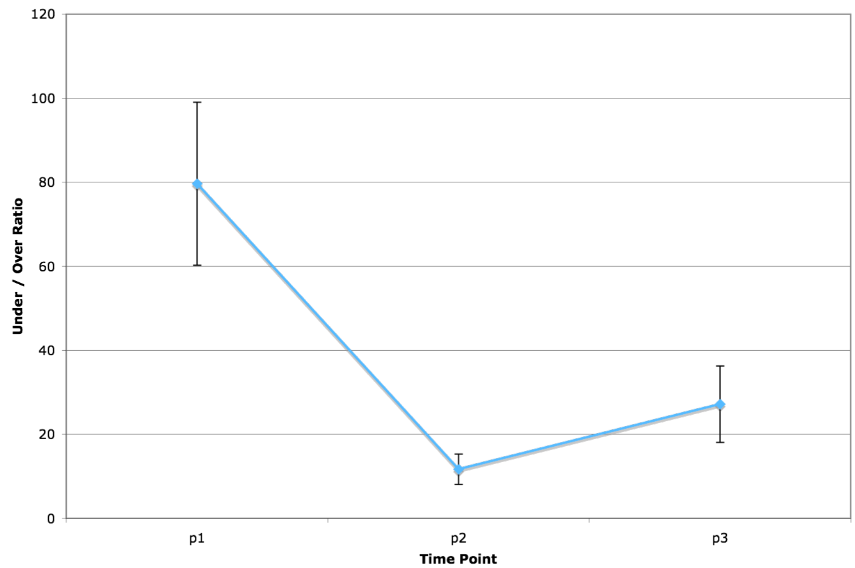


Analysis of error patterns computed via a ratio of underpredicted locations versus overpredicted locations. *A ratio of 1 would signify an equal number of underpredictions as overpredictions.*

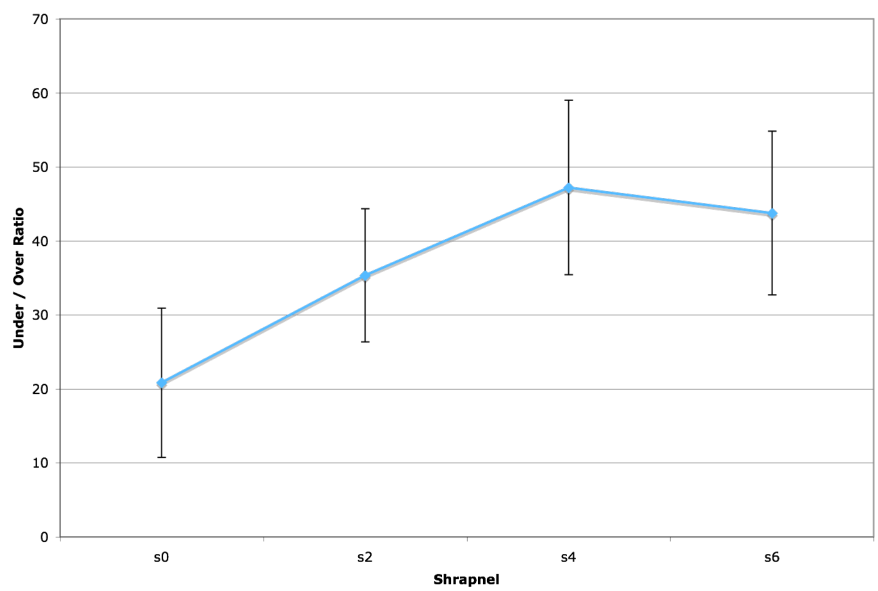
Under/Overprediction Ratio by Velocity



Under/Overprediction Ratio by Exploding Time Point



Under/Overprediction Ratio by Shrapnel Condition



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