Changes in Motor Performance when Throwing a Ball With and Without Visual Feedback

Honors Thesis

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**Abstract**

This study explored the roles that vision and proprioception play in learning while throw a ball repeatedly to a fixed location. In two experiments, participants threw a baseball to a target 12 meters away while wearing sound-cancelling headphones to block out auditory feedback. In Experiment 1 participants could freely see the target, but as soon as the ball left their hands, their vision of the ball’s flight and landing was occluded by liquid crystal goggles. Measurements of the ball’s distance of travel along the ground and variability of landing locations were recorded to observe participants’ throwing accuracy and consistency across 100 trials. Results show that participants almost always threw short. The throws improved in consistency for the first half of the trials, showing that people can use proprioceptive feedback to improve the consistency of their motor performance. Experiment 2 was similar to Experiment1, except half of the participants could see the ball’s flight trajectory. Both groups started out throwing short of the target, but the group with visual feedback threw increasingly closer to the target across the 30 repeated trials. Both groups improved their throwing consistency. Kinematic analysis showed that people depended on the ball’s initial velocity rather than the release angle to regulate the distance the ball traveled.

**1 Introduction**

Every day we employ our senses to help us perceive and respond to our dynamic environment. We also have experiences and knowledge that help us perform various actions and anticipate when our intended actions are about to go wrong. As represented in Figure 1, the internal model of motor control, introduced by Mittelstaedt von Holst (1950) and later advanced by other researchers including Marc Jeannerod (2006), illustrates how the motor system uses actual and predicted sensory feedback to perceive and execute actions. During action planning, our system produces a set of motor commands that dictates how our body should move and an efference copy that predicts what sensations we will experience during and after the movement. During action execution, the actual sensory feedback we receive is constantly being compared to our predicted feedback. In the short run, this online comparison process helps us to rectify mistakes in our perception and action by detecting discrepancies between our actual and expected feedback. In the long run, it helps us generate more precise motor commands and efferent predictions, thereby helping us to learn new and to improve existing motor skills.

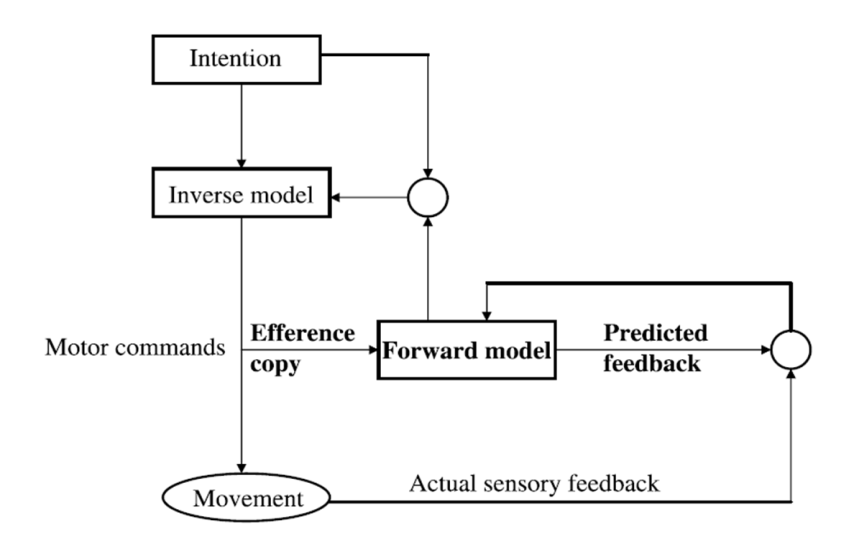
We are particularly interested in the roles that vision and proprioception play across learning trials for aimed throwing. When people throw a ball, they have two types of feedback. One is proprioceptive feedback, information from joint and muscle receptors involved in the actions of throwing. By comparing our expected to our experienced proprioceptive feedback, we can discern whether our motor commands were carried out as intended. This comparison, however, does not tell us whether our commands were effective in achieving specific action consequences. For instance, proprioceptive feedback cannot provide us information about how close the ball we threw landed from the target because, unless highly trained, our calibration of the force needed to get the ball to the target and the visually perceived distance to the target is never exactly accurate (Rieser, Pick, Ashmead, and Garing, 1995).

Figure 1: Internal Model of Motor Control

From: Jeannerod, M. (2006). Motor Cognition: What Actions Tell to the Self. Oxford University Press: New York.

The second type of feedback is visual feedback, which is information that comes from viewing the ball’s flight and landing. By letting people compare where the ball actually landed relative to where it was expected to land, vision can do what our proprioception cannot, namely provide information to change the calibration of throws. It is important to note that auditory feedback can, in principle, also affect throwing accuracy. However, its role in throwing is arguably less essential than visual feedback. It was not varied in our experiments and it will not be discussed in detail. While visual and proprioceptive feedback dominates our motor perception and action, most research in this area has focused mainly on vision in short-term motor performance. In the following section, we will discuss some of these prior studies, their findings and limitations, and how our study might further the research in this area.

*1.2 Related Studies*

Recent studies on throwing have suggested that when perceptual-motor competence is well-developed, even our prominent sense of sight is not necessary for effective action execution and prediction of action consequences. For example Krist, Fieberg, and Wilkening (1993) demonstrated that, even without external feedback (i.e., visual feedback and knowledge of results), preschool and school-age children and adults consistently produced and also verbally estimated the physical force needed in order to propel a ball to a target that varied in distance across trials. This display of perceptual-motor competence across different age groups suggests that efference or what the authors call “schemas of action events” can be so well developed that visual feedback is not necessary for predicting and executing actions.

This conclusion is supported by McManus, Lin, Erdemir, Bailey, Rieser, and Bodenheimer’s (2011) study on projectile motion in virtual reality. In this study, adults threw a physical ball while viewing the thrown ball’s trajectory in a helmet mounted display. Motion tracking was used, so that the ball’s physical flight was tracked and it was either mirrored accurately in the helmet mounted display or it systematically differed from it. In one condition, the visually rendered trajectory differed only in changes in its horizontal velocity; in another condition, it differed only in its vertical velocity. The participants reliably detected when the flight they observed was modeled after the actual flight versus when it differed from it. McManus, *et al*. (2011) found that above certain thresholds people could detect small kinematic perturbations placed on the visual feedback of their own actions in virtual reality. The authors theorize when a person produces actions (as opposed to observing others produce them), motor competence based on past experiences contributes to a precise and reliable prediction of sensory feedback, enough so that faulty external feedback that differs from the prediction can be detected.

Looking back at the internal model of motor control, it is the online comparison between predicted and actual sensory feedback that helps guide our actions. However, for common and well-practiced actions, it is theoretically possible for the motor system to produce motor commands and efferent sensory predictions good enough to function without the benefit of external sensory feedback. If an action is well-executed in terms of control and consistency and the person trusts that he has performed the action well, feedback is unnecessary. This explanation, however, can be suspected but not concluded from the findings of the two studies discussed above because participants in both studies were constantly experiencing proprioceptive feedback. Because the effect of proprioception was inseparable from the effect of efference, it is not clear how much of the observed motor competence without visual feedback was due to efference and how much was due to proprioception.

*1.3 Overview of current study*

We believe the effect of proprioceptive feedback can be inferred by studying learning. In our study, we wished to assess the role that visual and proprioceptive feedback play in motor learning. Two experiments were conducted where the adult participants were asked to throw a baseball repeatedly so that it would land on top of a target on the ground that was twelve meters away. This distance was chosen because it was far enough to make the task challenging, thus allowing room for learning, but close enough so that the task is within participants’ physical capacity to achieve. Participants were asked to use an underhand toss. They wore sound-cancelling headphones at all times so they could not hear where or when the ball landed.

**2 Experiment 1**

In Experiment 1, eight adults threw a baseball to the fixed target one hundred times without being able to hear or see the ball during its flight or landing. We recorded each throw’s distance on the ground and evaluated the performance in terms of accuracy and consistency. In order to provide a basis for computing throw-to-throw consistency, repeated throws were blocked into groups of 10 trials each. Accuracy was computed by averaging the thrown distances of the ten trials in each block. Consistency was computed as the standard deviation of the distances for the ten trials in each trial block. This experiment was designed to find out if people could improve their throwing across repeated trials without any visual or auditory feedback to indicate where the ball had landed relative to the target. It also revealed, if learning occurred, whether it was a steady improvement across the 100 repeated trials or progress that took place only during the earlier sets of trials.

We predicted that while participants’ throws would not become more accurate over time, they would become more consistent. Improving accuracy requires knowing the extent and direction of one’s errors. Blocking vision and hearing eliminates feedback of one’s errors; therefore, there is no basis for people to improve the accuracy of their throws. Inconsistency, however, can be detected by both internal as well as external feedback. The consistency of one’s throw depends on the consistency of one’s body movement. In theory, participants could compare their current and experienced proprioceptive feedback to detect trial to trial discrepancies in their body movements and use it to reduce inconsistency in their throws.

*2.1 Participants*

Eight participants, 4 male and 4 female, participated in the study. All were adult volunteers from the university.

*2.2 Method*

The experiment took place on a flat grassy field on the Vanderbilt University campus. Participants were asked to throw a baseball one hundred times, underhanded, so that it landed on top of a stationary target located on the ground twelve meters away. Stretching from the place where participants stood to where the target was placed and 2 meters beyond was a measuring tape that marked distance in decimeters. Immediately after each throw, an experimenter recorded the ground distance the ball traveled before landing.

Throughout the entire experiment, participants wore liquid crystal goggles and sound-cancelling headphones. The goggles were wired to a small switch that was fastened to the palm of the participant’s throwing hand. Every time the ball was released from the hand, the switch was triggered, causing the goggles’ lenses to immediately become opaque (the lag was 3 milliseconds), preventing visual feedback of the ball’s flight trajectory and landing location while permitting a free view of the target up to the instant of the release. The sound-cancelling headphones prevented participants from being able to hear where or when the ball landed.

**3 Results**

To measure throwing accuracy, we measured the distance the ball traveled and averaged the distances for each block of 10 trials. We ran a one-way analysis of variance (ANOVA) with repeated measures for Trial Block. Because we were interested in the pattern of our data across repeated trials, we also performed a trend analysis. Figure 2 shows that the mean distance the ball traveled for all participants for every block of 10 trials. As expected, there was no significant effect of Trial Block, (*F*(1,7)=.471, *p*=.889); and no significant trend was observed. Every participant threw the ball too short a distance on most or all of their repeated trials. Across trials and subjects, the average throw distance was 2 meters short of the target, with some subjects averaging throws that were 6 meters short across the 100 trials.

Figure 2: Ball’s mean distance traveled. Trials blocked by 10. Twelve meters was the target’s distance. The error bars show one standard error of the mean. Note: Twelve meters marks the distance location of the target.

Consistency was measured by variable error, which was computed as the standard deviation of the distances of each block of ten throws. Variable error was also analyzed using a one-way ANOVA with repeated measures for Trial Block and a trend analysis. Trial Block was not statistically significant, but the trend analysis showed that the quadratic trend approached significance (*F*(1,7)=4.621, *p*=.069). Figure 3 illustrates this marginally significant quadratic trend in mean variable errors. A repeated-measures ANOVA and a trend analysis were also performed on the first five trial blocks. The analysis showed a marginally significant effect of Trial Block, (*F*(1, 7)=3.353, *p*=.055) and a significant linear trend (*F*(1,7)=6.309, *p*=.04).

Figure 3: Mean standard deviation of every block of ten trials. The error bars show one standard error of the mean.

**4 Discussion and Conclusion**

As we predicted, the lack of systematic change in the ball’s travel distance shows that participants did not improve throwing accuracy in the absence of external feedback. However, we did not anticipate that all subjects would throw too short a distance. Follow-up interviews found that participants did not realize they were throwing short and, in fact, thought they were throwing either on target or a bit too far past the target. It is likely that participants threw inaccurately because of a misalignment between their internal representation of the physical space and the actual physical space. People might throw too far or too short if they overestimate or underestimate the distance to the target or misjudge the amount of force necessary to propel the ball to the target. As previously stated, these errors in calibration cannot be corrected without knowledge of the external environment provided by visual feedback.

Analysis of the variable errors produced mixed results. For the first half of the trials, there was a decrease in error. This suggests that motor practice even in the absence of external visual and auditory feedback leads to greater consistency in one’s throws. However, the learning seemed to stop and variable error increased after the first 50 trials, thus, the marginally significant quadratic trend in the overall data pattern. In Experiment 2, we increased the number of subjects, in order to increase the power of our experiment. In addition, to address the concern that people were becoming bored and tired from throwing 100 times, we reduced the total number of trials.

Overall, our hypotheses were partially supported by these results. In our subsequent experiment, we explored how learning without visual feedback compares to learning with visual feedback. In other words, what are the benefits of having both proprioceptive and visual feedback as opposed to just proprioceptive feedback? In addition, we wished to know, with more participants and thus more statistical power, whether there would be statistically significant increases in throwing consistency across the blocks of repeated trials.

**5 Experiment 2**

In Experiment 2, sixteen adults threw the ball thirty times to the same 12 meter fixed target. Half of them threw without visual feedback and the other half with visual feedback. In addition, the throws were video recorded and two kinematic features of the throws were calculated from the video recordings. One was the initial velocity of each throw. The other was the angle of the ball’s trajectory at the instant it was released by the thrower. From these kinematic variables, we were able to find out whether people tended to control how far their thrown balls traveled by controlling the initial velocity, the release angle, or both.

We compared the accuracy and consistency of participants’ throws across trials in the two different conditions: Visual Feedback (VF) and No Visual Feedback (NVF). VF participants were able to watch the ball’s flight and landing during each trial. By comparing this visual feedback to their own expectations, VF participants could, in theory, update their action plans for subsequent trials to improve how accurately they throw the ball to the target and how consistent their throws are from trial to trial. Thus, for this group, we expected to see a learning effect for throwing accuracy and consistency over time.

For the NVF group, we wanted to know if the results from the first experiment were replicable. We anticipated that the increase in consistency observed in the first experiment would become statistically significant overall in the second experiment because of a larger sample size and the resulting increase in statistical power. Our prediction remained the same for this group: participants’ throws would become more consistent, but not more accurate over time. As previously stated, without external feedback, participants cannot know the extent and direction of their errors in relation to the target, thus their throwing accuracy cannot improve. However, participants may use their internal proprioceptive feedback to improve the consistency of their throws.

We also computed two kinematic features of the throws from the videotapes (i.e., the ball’s release angle and the ball’s initial velocity) in order to understand what features of their throws participants used to regulate how far the ball traveled. The physical relationship between a ball’s travel distance and initial velocity is linear; when all other kinematic components are constant, the greater the initial velocity, the greater the distance the ball will travel. On the other hand, the relationship between ball’s travel distance and release angle is quadratic. Theoretically, there is an optimal angle to release the ball in order to achieve the farthest travel distance. However, there has been no conclusive evidence on what that angle may be. The further the ball is released away from that optimal angle in either direction, the shorter the distance the ball will travel. We are primarily interested in how participants use angle and velocity to regulate their throwing distances.

*5.1 Participants*

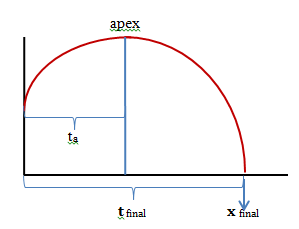
Thirty-two adults participated in the study. All were undergraduate student volunteers from the university and were given psychology class credit for their participation. Half of the participants (8 male and 8 female) were assigned to the VF Condition and the other half (8 male and 8 female) to the NVF Condition.

*5.2 Method*

The location and procedure of this experiment were similar to Experiment 1. However, instead of throwing one hundred times, participants threw a baseball to a 12-meter target thirty times. We chose this number of trials based on the fatigue effect suspected in the first experiment and in additional pilot studies. For half of the participants, a camcorder was placed at a fixed distant location equally far from the participant and the target, far enough away so that both the participant and the area approximately two meters beyond the target were within the video’s frame of view. The camcorder recorded the participants’ throws at the rate of 60 frames per second. From the video recordings, we extracted information about the kinematics of participants’ throws. Because this analysis was an extension of the main study, only half of the participants, 8 male and 8 female, had their throws recorded.

Participants in both conditions wore sound-cancelling headphones and liquid crystal goggles with the operating switch fastened to the palms of their hands. While the headphones were turned on in both conditions in order to prevent auditory feedback, the goggles were only active in the NVF condition. Thus, participants in this group could not see the ball’s flight trajectory and landing location. The goggles remained transparent throughout the experiment in the VF condition, allowing participants in this group to freely see the ball’s movement.

**6 Results**

 We measured the ball’s flight distance, initial velocity, and release angle for each trial. The distances were grouped into blocks of five trials each and the average distance and the variable error was computed for each block. The average distances and variable errors for each block were each analyzed using a mixed-design ANOVA, where the between-subjects factor was Condition (VF vs NVF) and the repeated measures factor was Trial Block. We also performed a trend analysis for each dependent variable to examine the patterns within our data. For each throw, we extracted from the video recording the ball’s flight time until apex (ta), total flight time (tfinal), and distance traveled (Xfinal) in order to calculate initial velocity (Vi ) and release angle (Ai). Figure 4 shows how we define these different components of a ball’s flight. Listed below are the formulas involved in the calculation:

Vix = Xfinal / tfinal

Viy = ta ∙ g

Vi = Vix 2+Viy2,

Ai = tan-1(Viy/ Vix)

Figure 4: Illustration of ball’s flight.

For each dependent variable, we looked for effects of Trial Blocks (the within-subject factor), Condition (the between-subject factor), and the interaction between Trial Block and Condition. Table 1 summarizes the statistical analyses.

In addition, we wished to investigate whether subjects varied the trial-to-trial distances of their throws by varying the ball’s initial velocity, the ball’s release angle, or both. To find out, we correlated the ball’s travel distance and initial velocity, travel distance and release angle, and initial velocity and release angle. The correlations were computed for half of the participants in the VF and NVF groups, those for whom we had videotaped their throwing trials. The only strong correlation was that between distance and velocity: The average *r*=.7428 (sd=.2854) for the VF group and average *r*=.6162 (sd=.3207) for the NVF group. We ran a mixed design ANOVA with Type of Correlations (DistancexAngle vs DistancexVelocity) as the repeated measures factor and Condition (NVF vs VF) as the between-subjects factor. Results revealed a main effect for Type of Correlation only (*F(1,14)=15.356, p=.002*). Graphs for each analysis follow.

*6.1 Table 1: Results for repeated measures ANOVA and trend analysis* 

Note: “*n.s*” indicates non-significant result

Figure 5: Mean distance ball traveled. Trials blocked by 5. Twelve meters was the target distance. The error bars show one standard error of the mean. Note: scale does not start at 0.

Figure 6: Mean standard deviation of every block of five trials. The error bars show one standard error of the mean.

Figure 7: Mean initial velocity. Trials blocked by 5. The error bars show one standard error of the mean. Note: scale does not start at 0.

Figure 8: Mean release angle. Trials blocked by 5. The error bars show one standard error of the mean. Note: scale does not start at 0.

**7 Discussion and Conclusion**

Our hypotheses were that participants in both conditions would improve in throwing consistency over time. However, only VF participants should improve in throwing accuracy. Our results support these predictions.

Figure 9: Correlation of distance and angle and of distance and velocity. The error bars show one standard error of the mean.

For the ball’s travel distance, the significant Condition x Trial Block interaction and the significant linear trend indicate that, over time, VF participants were increasingly outperforming NVF participants. We ran separate Trial Block ANOVAs, for each of the two conditions and found that while the effect of Trial Blocks was significant for the VF Condition (*F*(1,15)=21.057, *p*<.001), it was not significant for the NVF Condition. Overall, these results suggest that while participants in both conditions started out throwing the same distance short of the target, only VF participants began throwing closer to the 12-meter target over time. For variable error, the repeated measures ANOVA revealed Trial Block to be the only significant factor. This means that participants in both groups decreased the variability of their throws at a similar rate. The significant linear and quadratic trends suggest that, while there was an overall decrease in variable error, the rate of decrease diminished over time. Figure 5 and 6 illustrate the findings for travel distance and variable error.

In the kinematics analysis, we found Trial Block to be significant for the initial velocity. However, analysis of the release angle yielded no significant effect. This suggests that overall participants increased their velocity across trials in order to throw farther and farther and did not vary the release angles. The ANOVA for correlation types (DistancexAngle and DistancexVelocity) corresponds well to the trend we have observed above. The test revealed the correlation between distance and velocity to be stronger than the correlation between distance and angle, regardless of Condition. Overall, the analysis of the kinematic features suggests that people control the ball’s travel distance by controlling the ball’s initial velocity rather than the release angle and people in both Conditions did this equally well. This conclusion might not be obvious if one visually compares Figure 5 (Ball’s Travel Distance) to Figure 7 (Initial Velocity) because the sample sizes represented by these graphs are different. As previously stated, only half of the participants had the kinematics of their throws recorded and analyzed.

**8 General Discussion**

Our study explored the effect of practice with and without visual feedback on learning. By doing so, we were also able to make inferences about the role of proprioceptive feedback. In Experiment 1, participants threw repeatedly to a target without visual feedback. In Experiment 2, half of the participants performed the same task without visual feedback and the other half with visual feedback. We assessed the performances by measuring the throwing accuracy and consistency across trials. In Experiment 2, we also recorded the kinematics of the throws to understand how people varied the ball’s initial velocity and/or release angle to affect the distances of their throws.

We found that results from Experiment 1were replicated in Experiment 2. The trend of increased throwing consistency without visual feedback, which was approaching significance in the first 50 trials of Experiment 1, was observed in Experiment 2. In Experiment 2, we found that participants in both conditions improved their throwing consistency at the same rate, indicating that people can use proprioceptive feedback to regulate consistency just as well with and without the benefit of visual feedback. People with vision and proprioception, however, appear to throw increasingly more accurately than those with just proprioception. Overall, regardless of Condition, people relied on the ball’s initial velocity to control the travel distance.

In the future, we wish to explore the generalizability of improved performance based on proprioceptive feedback. Consider, for example, whether the reduced variability learned while throwing without vision will transfer to throwing without vision with the other hand, and whether it will transfer to novel throwing distances. If it does transfer, will the magnitude of the transfer hold steady across repeated transfer trials or will the improvement diminish over repeated trials? Will children rely on proprioceptive feedback and on visual feedback to similar degrees as adults, or alternatively, are children biased to weigh either visual feedback or proprioceptive feedback more heavily than adults?

Finally, we are interested in some of the practical implications of the study. For example, growing numbers of persons with blindness or other severe visual impairment are playing beep ball, goal ball and other sports. But little is known about how to instruct them to toss a ball with greater accuracy or greater consistency. We wish to investigate the accuracy and consistency with which persons with visual impairment learn to throw a ball to auditory targets, and characterize the effects of auditory feedback and proprioceptive feedback on their learning.

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