MOTOR MODELS IN ACTION PREDICTION: A TEST OF PRACTICE EXPERIENCE GENERALIZATION WHEN THROWING DARTS WITH A WEIGHT

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Abstract

Previous studies have provided evidence consistent with the proposal that people "simulate" observed actions, based on their own motor experiences, to help predict the outcome of others' actions. This simulation is believed to be based on low-level activation of the observer's motor system at the time of the decision. In this experiment, we tested how closely people's motor experiences influence their ability to predict action outcomes and whether these experiences generalize to predicting outcomes of novel stimuli. To do this, we manipulated the experiences (and therefore, the type of internal model formed during physical practice), by asking people to practice throwing darts with or without a wrist weight. Participants were asked to predict outcomes of people throwing under opposite or the same conditions as those experienced during practice. Although we showed evidence that prediction ability is specific to one's practice experience, this was only seen in people who physically practiced without a weight and not for people who physically practiced with a wrist weight. The contribution of the motor system to these predictive decisions was also assessed by secondary-motor tasks designed to probe motor system involvement during prediction. Although we showed that predicting dart outcomes while wearing a wrist weight aided prediction accuracy, this was only observed in people who physically practiced without a weight. Contrary to previous studies, we were unable to show interference from a secondary, incongruent movement task (light press on a force gauge) after physical practice. Both physical and perceptual practice resulted in improvement in prediction accuracy post-practice, although this was strongest for the no-weight physical practice group. Overall, these data provide evidence that physical practice transfers to improvement in perceptually-driven predictive decisions. However, although the secondary tasks gave some evidence that prediction was dependent on the motor system (when holding a weight), and that the type of motor experience (weight or no-weight) impacts predictive decisions, evidence for motor simulation was not shown. Limits of the current methods are discussed.

Lay Summary

In the current experiment, I showed that physical practice throwing darts transfers to perceptual improvements. This was evidenced through improved accuracy in action prediction of another dart thrower after physical practice. This prediction improvement was somewhat specific to one's practice experience, with improvement following physical practice without a weight (as opposed to with a weight). Although this transfer, specific to conditions of practice, suggests that observers engaged in action prediction use this physical experience to make decisions, contrary to previous studies, prediction accuracy was not interfered with by action incongruent tasks. Although there were limits to this study with respect to number of participants and amount of improvement (potentially related to the technique adopted by the novice thrower), it does reinforce the idea that to improve accuracy in making predictions about others' action, specific action experiences are required.

Preface

The concept and design of this theses was developed through discussions with my supervisor, Dr. Nicola Hodges, based on previous work conducted by Dr. Desmond Mulligan. Feedback on the proposed procedural design was also provided by my committee members, Dr. Romeo Chua and Dr. Miriam Spering. I conducted the programming for the experiments based on original programming by Dr. Desmond Mulligan. I was responsible for the filming and editing of testing stimuli, with help from postdoctoral fellow Dr. Nicole Ong and undergraduate researchers Teresa Chang and Megan Zhu. I carried out data collection and data analysis along with undergraduate research assistants Kalvin Nguyen and Charlie Sushams. I was responsible for the statistical analysis and the preparation of this manuscript (including figures and tables) with feedback from Dr. Nicola Hodges. All experiments in this thesis were approved by the University of British Columbia Behavioral Research Ethics Board under the ethics certificate number H10-01346. No version of this thesis has been published at this time.

Table of Contents

List of Tables

List of Figures

List of Symbols

β	beta
n	number of participants
p	p-value
η_p^2	partial eta squared
r_p	Pearson's correlation coefficient
%	percentage
d'	sensitivity

List of Abbreviations

ANOVA	analysis of variance
AON	action observation network
cm	centimetre
F	F ratio
GMP	generalized motor program
HSD	honestly significant difference
M	mean
MNS	mirror neuron system
MANOVA	multiple analysis of variance
NW	no-weight
OP	occlusion point
RE	radial error
RM	repeated measures
s	second
SD	standard deviation
W	weight

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Chapter 1: Introduction

In daily life, we rely on cues from other people to be able to navigate successfully around our environment and how we understand these cues appears to depend on our own ability to generate them (Schütz-Bosbach & Prinz, 2007). Previous behavioral research on action perception has demonstrated that people covertly engage their motor system while observing others' actions (Jeannerod, 2001). This activation of the motor system, termed "simulation", aids in our ability to understand observed actions and to make predictions based on them. If what we perceive depends on what we can do, people with different motor experiences should have unique perceptual experiences of the same stimuli. In this thesis, I tested how closely people's motor experiences influence their ability to predict action outcomes. In the context of dart throwing, I manipulated people's practice experiences (and by default, the type of internal model formed during physical practice), by asking people to throw a dart, with or without a wrist weight.

In this review of the literature, I first discuss some of the theory underlying how we learn and adapt to new environments and how general this capacity may be (with respect to schema theory and internal models) and then I discuss some ideas about the relations between perception and action. In this second section, I relate these ideas to the neurophysiology more broadly and then specifically to the concept of action prediction and motor simulation and the rationale for my study.

1.1 Motor Learning Theory: Schemas, Internal Models & the Process of Adaptation.

1.1.1 Schema Theory

The schema theory of motor control, first postulated by Schmidt (1975), has been proposed to explain how discrete motor skills are learnt. According to schema theory, people learn and form a set of rules, called schemas, which relate task parameters to outcomes (recall schema) and expected sensory consequences to outcomes (recognition schema). Movements are produced by first selecting the appropriate generalized motor program (GMP), a broad movement plan for a particular class of action, and from there, parameter values of the movement are computed (e.g., appropriate forces) based on the desired outcome given the initial conditions. Through motor experience, the learner can begin to generalize the relationship between the parameter used for the GMP and the outcome to form a schema (e.g., use more force to throw a further distance). Accordingly, the more varied the practice experiences, whereby different parameters produce different outcomes, the more refined the schema becomes. A wider breadth of experiences allows for better generalization to unexperienced conditions and outcomes.

One benefit of the schema conceptualization is that it allows for the extrapolation of past experiences to produce novel movements that have not been generated by the learner before. Previously, Adam's conception of a closed-loop theory (1971) assumed that a separate motor plan was needed for every action and unless one possessed such a motor plan, carrying out actions that had not previously been produced was not possible. Unlike Adams' theory, in which each parameter and outcome association is needed to be stored to be recalled for future reference, in schema theory, these associations are lost in working memory and what remains is a schema that generalizes the parameter-outcome relationship. It is the set of rules within a given schema that becomes the basis for producing a new movement. For example, if a learner was to throw a football to a new distance, an estimate of the motor commands needed would be made based on the schema from past experience and these parameter values would be carried out through the GMP.

Schemas are also thought to be used to make predictions due to the relations between sensory consequences and outcomes. As the learner uses the schema to determine the appropriate specifications for an action, expected sensory consequences are generated based on past outcomes and past sensory consequences for the desired outcome. The expected sensory consequences are the learner's best estimate of the sensory consequences given a movement is enacted as planned and these consequences also consider the initial conditions from which the movement is taking place. This information is compared with the actual afferent information of the movement and any mismatch produces an error signal that is fed back to the central nervous system (CNS) to adjust the schema. Given more motor experience, the learner's ability to anticipate the sensory consequences of an action improves. In the current thesis, I tested the motor system's ability to generalize practice experiences to predicting outcomes of dart throws in similar and novel conditions to which practice was performed.

1.1.2 Internal Models

Another way action prediction has been conceptualized is through the idea of internal models. These internal models, also known as the computational approach, provide a link between the motor commands underlying actions and their consequences. There are two types of internal models: the forward model and inverse model. During movement execution, the forward model acts as a predictor of the next state of the motor system based on the commands sent out by the motor system (for a review see Wolpert, Ghahramani, & Jordan, 1995). One idea in motor control is that a copy of the descending motor commands, termed corollary discharge or an efference copy, is compared with incoming afferent information from the current movement to create an estimate of the predicted state of the body (Sperry, 1950; von Holst & Mittelstaedt, 1950). During action prediction, the observer's forward model estimates future states of the observed action and these estimates derive from the simulated motor commands in the observer based on their own motor experience of the action (for a review see Wolpert & Flanagan, 2001; for a review related to sports see Yarrow, Brown, & Krakauer, 2009).

1.1.3 Adaptation

The acquisition of internal models has been studied in what have been referred to as adaptation paradigms (typically using dynamic force field perturbations or visuomotor rotations). These paradigms capture learning which takes place on a more implicit /non-conscious level as well as learning which takes place on a more explicit, knowledge-driven level. In one version of these adaptation paradigms, people are asked to aim for visual targets in visually rotated environments. Upon returning to a normal environment, even with the knowledge that reaching or aiming should not be adapted, participants typically show large after-effects proportional to the size of the visual rotation and opposite in direction to the rotation. These after-effects provide evidence that some sort of internal model is being updated while learning to move in the visually rotated environment (Mazzoni & Krakauer, 2006). The difference between the predicted sensory consequences and the actual reafferent feedback of the limb results in a mismatch, which is used to update the forward model and "adapt" to the visually rotated environment.

Mere exposure to a visually rotated environment is not enough for adaptation to occur, rather self-initiated physical practice seems to be necessary component (e.g., Lim, Larssen, & Hodges, 2014; Ong & Hodges, 2010). In a self-initiated movement, motor commands are produced for the given movement which result in action. The efference copy of the motor command seems to be an important ingredient to generate a forward prediction of the movement and thus for the updating of internal models. It is when this prediction is compared with the actual state of the movement, through visual feedback, that adjustments can be made to counter any discrepancy between the intended and actual movement. These adjustments enable the updating of an internal model. Similarly, participants who were moved passively in a visually rotated environment, whereby movement occurred from an external source acting on the individual and movements were not self-initiated, after-effects were not observed in a retrograde (practice Task A, practice Task B, re-test Task A) interference paradigm (Sakamoto & Kondo, 2015). Because there were temporary benefits associated with previous passive exposure in a later physical practice phase, these results suggest that active motor experience is needed for motor learning, even though temporary adaptations can take place without this active sending of motor commands. Indeed, in a study of a deafferented individual "GL", who cannot perceive proprioceptive feedback, adaptation did occur, as well as after-effects (Bernier, Chua, Bard, & Franks, 2006). It seems then that adaptation can occur as long as there is an active sending of motor commands such that there is an efference copy which can be compared against the rotated visual feedback. Updating of an internal model does not appear to be dependent on incoming proprioceptive feedback.

There is evidence that adaptation, at least when considered with respect to evidence of after-effects is an automatic implicit process, unaffected by external cognitive strategies. Adaptation still occurs even when participants are made aware of the degree of visuomotor rotation and instructed to counter it by aiming toward the neighboring target in order to hit the proper target (Mazzoni & Krakauer, 2006). Failure to counter the rotation with an explicit strategy suggests one is unable to prevent adaptation even at the expense of achieving the goal task. Interestingly, the rate of adaptation between participants using a cognitive strategy and controls did not differ, which seems to indicate the system for adapting to visuomotor rotation is independent of cognitive strategies. In terms of the current study, although we are not interested in after-effects per se (i.e., how practice throwing darts with a wrist weight affects later motor performance without a weight), we would expect that the model of aiming formed from throwing with a weight would impact subsequent throwing and potentially predictions made about a person throwing under no-weight/normal conditions. These effects should be present even if participants become aware that the conditions of prediction are different than the conditions of practice.

With respect to this proposal, schema theory and the computational framework provide the theoretical background for how one can develop a model for predicting outcomes based on their practice experiences. The link between practice experiences and prediction ability will be further explored below where I discuss research relating to motor simulation and a potential common code for action and perception.

1.2 Conceptual Considerations in Action-to-Perception Transfer

1.2.1 Common Coding

According to common coding theory, action production and perception share common representations in the cortex (Prinz, 1997). This relationship is thought to be bidirectional, such that observing an action (or anticipating consequences of an action) should activate the motor system in the observer and corresponding motor commands, and executing an action should activate the perceptual system in the performer along with anticipation of the perceptual consequences (Prinz, 1997). The idea of a common representation has also been supported by imaging studies, as the brain regions active during action execution are also active during action observation (Ramnani & Miall, 2004; for a review relevant to sports see Karlinsky, Zentgraf, & Hodges, 2017).

1.2.2 Mirror Neuron System

There are several lines of research that suggest action observation is mediated through what has been termed the mirror neuron system (MNS), a distinct set of brain regions involved in both execution and observation of actions (for reviews see Cattaneo & Rizzolatti, 2009; Rizzolatti & Craighero, 2004; Rizzolatti, Fogassi, & Gallese, 2001). Early evidence from the study of monkeys led to the identification of an area, F5, which contained a motor representation for both the hand and mouth area (Martelli, Luppino, & Pizzolatti, 1985). The neurons in this area discharged both when a monkey performed a specific goal-directed hand action as well as when it observed another monkey performing the same action (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996). These termed “mirror neurons” were arguably part of a broader system in humans for matching observed and executed motor actions through a common motor representation and provide a neural mechanism for action recognition.

1.2.3 Action Observation Network

In humans, the “action observation network” (AON), has been adopted as a term to encompass all the cortical areas involved in action observation and visual analysis (Cross, Kraemer, Hamilton, Kelley, & Grafton, 2008). Although the exact role of the AON has been under debate, the identified cortical areas are also thought to be involved in action understanding, action prediction, inferring the action of others, motor planning and motor control (Cross, Hamilton, Kraemer, Kelley, & Grafton, 2009). Some of these areas include the inferior parietal lobule, premotor cortex, supplementary motor area, primary motor area, superior temporal sulcus, and primary visual cortices (Cross et al., 2008; for a meta-analysis see Molenberghs, Hayward, Mattingley, & Cunnington, 2012).

1.2.4 Motor Simulation & Motor Imagery

The motor system is thought to be involved during action observation. One hypothesis, known as the motor simulation theory, is that during action observation, the observer covertly engages their motor system as if they were performing the movement themselves without actual movement (Jeannerod, 2001). These motoric processes are believed to share similar pathways to those involved in motor preparation and action execution (Grèzes & Decety, 2001; Meister et al., 2004) and have been reported to be active during the mental rehearsal of an action, known as motor imagery (for a review see Munzert, Lorey, & Zentgraf, 2009). The idea that there are parallels between cortical areas involved in simulation, motor imagery and certain representations in motor preparation and action execution has led to what is known as the functional equivalence hypothesis (Jeannerod, 1994). However, the extent of this overlapping activation is under debate. There has been evidence of activity in the pre-motor cortex (PMC) during motor imagery (Gerardin et al., 2000), as well as in the supplementary motor area (SMA), which has also been found to play an important role in inhibiting primary motor cortex (M1) activity to prevent overt movement (Kasess et al., 2008). Although motor imagery is believed to share similar neural structures as those involved in motor execution, M1 has not consistently shown to be active in motor imagery and some reported only a partial overlap of SMA neurons during motor imagery and motor execution (Deiber, Ibanez, Sadato, & Hallett, 1996; Stephan et al., 1995). Of the 122 experiments examined in a meta-analysis of motor imagery and brain activation by Hétu et al., (2013), only 22 of them have reported M1 activity during motor imagery. Some evidence in support of M1 activation during motor imagery includes an fMRI study in spinal cord injury patients (Sabbah et al., 2002) and a transcranial magnetic stimulation (TMS) study in healthy individuals (Vargas et al., 2004). Given the discrepancy in results, there are several factors that may contribute to the involvement of M1 during motor imagery which need to be addressed, including vividness of the script used, motor experience, and activation thresholds of the muscles involved in the task (Hétu et al., 2013; Lotze & Halsband, 2006).

There has been much interest in using motor imagery to engage the motor system to promote learning. Motor imagery training has been well documented by various authors to improve motor performance compared to control conditions in a variety of disciplines including surgery (Arora et al., 2011), table tennis (Caliari, 2008), high jump (Olsson, Jonsson, & Nyberg, 2008), dart throwing (Mendoza & Wichman, 1978), golf (Smith & Holmes, 2004) and trampoline (Isaac, 1992). Typically, these results have shown that motor imagery is better than no practice, while physical practice results in greater motor improvement compared to motor imagery alone. These results indirectly suggest that during motor imagery, some sort of learning is occurring in the motor system resulting in improved performance, likely due to activation of functionally equivalent pathways during imagery and motor preparation and/or execution.

1.3 Role of Motor Expertise in Action Observation & Prediction

Our ability to understand the actions of others seems to depend on our own motor experience for performing the observed action. Functional magnetic resonance imaging (fMRI) of cortical motor areas has shown that there is an increase in activation of cortical areas when motor experts observe actions that are in their own motor repertoire, compared to observing unpracticed actions. For example, in expert dancers, motor areas associated with the MNS showed greater activation when they viewed moves in their own motor repertoire, compared to moves in an unfamiliar type of dance (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard 2005, 2006). This greater activation suggests that understanding an observed action depends on what one can do physically, as one's own motor representations are associated with the perceptual experience to make sense of what is observed.

In the domain of sports, expert-novice differences have also been observed in one's ability to predict outcomes. Experts were able to anticipate badminton stroke direction more accurately compared to controls, with fMRI data also revealing greater activation in the AON within experts compared to activation amongst controls (Wright, Bishop, Jackson, & Abernethy, 2010). Activation in the superior parietal lobe was correlated with superior anticipation performance only in tasks containing contextual information specific to one's domain of motor expertise (Balser et al., 2014).

Not only does motor experience result in greater cortical activation during observation, people seem to be better able to recognize and predict outcomes from self-generated action sequences compared to actions generated by others. The closer the perceptual input is to the observer's motor representation of the same action, the more accurate the prediction (Knoblich & Flach, 2001). In a dart-throwing task, participants were able to more accurately predict the final landing position of a dart from a temporally occluded video when they watched themselves throw the dart compared to another player (Knoblich & Flach, 2001). This suggests that there is an advantage to recognizing self-generated actions since the observed actions are produced by the same system that is involved in predicting the action outcome.

Although the influence of motor expertise has been well documented in action observation, there is debate as to what extent the motor system is involved in action prediction. It is thought that simulation not only aids in one's ability to understand and interpret actions, but also in anticipation accuracy of action outcomes (Blakemore & Decety, 2001). Motor expertise has been shown to influence anticipatory decisions and this concept has been investigated mainly by assessing one's ability to predict action outcomes in participants with varying degrees of motor and visual experience. In a study by Aglioti, Cesari, Romani, & Urgesi, (2008), basketball players (motor experts) were able to predict the outcome of a free-throw shot more accurately and earlier compared to expert watchers (no motor but comparable visual experience) and novices. The expert players used early body kinematics to make judgements, whereas expert watchers mainly relied on ball trajectory to achieve accuracy in their decisions (see also Urgesi, Savonitto, Fabbro, & Aglioti, 2012). It seems motor experience is directly linked with action prediction performance, such that the more physical experience one has executing a movement, the more accurate they will be anticipating the same movement and its effects when observing someone else performing the movement. These results suggest that individuals have an increased perceptual sensitivity for actions in their motor repertoire and that differences in prediction accuracy arise from motor, not visual expertise.

1.4 Motor and Visual Experience in Action Prediction

One question of interest to researchers concerns the degree to which enhanced perceptual ability arises from motor experience alone or the interaction between motor and visual experiences during learning. This was also addressed by Aglioti et al. (2008), by using TMS and measuring motor evoked potentials (MEPs) in the muscles that would be involved in the action to see whether the motor system was activated during action prediction. Both visual and visuo-motor experts showed an increase in MEPs while observing basketball shots, however only the visuo-motor experts showed MEPs correlated with accuracy, in which there was increased excitability of the motor cortex for missed basketball shots. These results suggest only motor expertise provides the motor system with the ability to distinguish between correct and erroneous performance.

Motor and visual experiences have also been experimentally manipulated to help control and determine how these experiences impact decision processes. In a study by Mulligan and Hodges (2014), groups received different types of physical and visual training during a motor task (i.e., dart-throwing practice) to differentiate the role of these different experiences on the anticipation of later observed, action outcomes. In the anticipation task, novice dart-players were asked to predict, from temporally occluded videos, the landing position of a dart. Only participants who trained in the full-vision and no-vision "motor" groups significantly improved their predictions from pre-to post-test, compared to observation-only and no-practice control groups. In fact, prediction accuracy between the no-vision and full-vision group did not differ in the anticipation post-test, which suggests motor experience alone was responsible for improvements in prediction performance.

In various sports, evidence has been presented showing that expert athletes are able to provide earlier and more accurate predictions about the outcome of an action compared to novices. Interestingly, the cues used for anticipation amongst experts seem to differ based on their own motor and visual expertise (Urgesi et al., 2012). In an experimental manipulation of the type of practice experiences achieved by volleyball students, a visuo-motor training group improved their anticipatory judgements when the stimuli were based on body kinematics (Urgesi et al., 2012). In contrast, an observation only training group improved their anticipatory judgments only on videos based on ball trajectory, while no improvement was seen on videos based on body kinematics. These results suggest that visual experience may help to develop visual representations of an action, leading expert observers to rely more on the perception of visual stimuli, like ball trajectory, as the basis for their predictions. In general, this study in volleyball and others in soccer (e.g., Abreu, Candidi, & Aglioti, 2017), provide further evidence that physical experiences lead to different observation and prediction processes than visual experiences.

One way of testing whether the motor system is activated and responsible for better prediction accuracy in physically experienced performers is to engage the motor system in a secondary task during prediction. Incongruently activating the muscles involved in producing the observed action is thought to interfere with one's ability to engage in simulation. Since critical parts of one's motor system cannot be "engaged" (or at least are tasked with doing something else motoric), then there is reason to think that action predictions would be interfered. Decrements in performance amongst physically-trained, skilled individuals, would provide evidence for the motor simulation hypothesis in action prediction. In line with evidence presented earlier, expert dart-throwers were more accurate in predicting the landing position of a dart from temporally occluded videos compared to novices (Mulligan, Lohse, & Hodges, 2016a). However, when expert right-handed dart-throwers engaged in prediction while concurrently performing a right-arm action-incongruent secondary task (i.e., pushing with their fist against a force gauge, with their arm in full extension), their prediction accuracy scores decreased, while novices were unaffected (Mulligan et al., 2016a). In a follow-up study where short term motor and visual experiences were manipulated, only novice participants who initially received motor training were affected by the right-arm force task. No interference was observed amongst participants who underwent perceptual training (Mulligan, Lohse, & Hodges, 2016b). These results provide evidence that the motor system has a direct impact on decision accuracy.

1.5 Automaticity of Motor Simulation during Action Prediction

There has been evidence that the motor system may automatically engage in action observation, even to one's detriment. When expert dart players observed and predicted (with veridical feedback) the landing position of a dart thrown by a novice player, their motor performance on a subsequent throwing task decreased compared to their baseline performance (Ikegami & Ganesh, 2014). This deterioration, although small, was task specific. A change in performance was only observed when expert dart players observed and predicted outcomes from novice dart players and not novice 10-pin bowlers. Moreover, deteriorations in physical performance were only observed when the dart players were asked to make predictions about the accuracy of the novices' throw, when both the desired target outcome was known in advance of the throw and actual outcome feedback was provided after the prediction. Moreover, negative effects of watching the novice were only shown when the expert-observer had shown improved ability to make predictions about the novice's outcomes across trials. These results provide behavioral evidence that the visual and motor pathways have a common representation and that these systems are tightly linked in a way where what we observe can also affect what we can do. The process of predicting how other people will perform (i.e., anticipating action outcomes in others), inadvertently affects the person's own actions (and sometimes to their detriment), suggesting that a shared system is responsible for executing and predicting.

It is thought that the observer uses their own motor experiences, gathered during physical practice experiences, to run through a program of the action they are observing and arrive at some sort of outcome prediction (Mulligan et al., 2016b). However, the conditions under which action simulation is enacted and the specificity of these experiences to the perceptual situation is unknown. One idea is that action simulation only occurs when the observed situations are highly specific to the acquired action experiences of the observer. In this case, similar, yet different motor experiences would not be applied to help make predictions about other's actions. Alternatively, the observer with action experiences that are similar, yet different in a specific way to that observed, might apply these experiences and simulate "inappropriately". Under these circumstances, outcome predictions would be biased and incorrect. This is the aim of the current study, to further test evidence for motor simulation during an action prediction task, following manipulated physical or perceptual training, as well as the specificity of these types of training experiences for action prediction processes. Based on the work of Ikegami and Ganesh (2014), there would be reason to suspect that the experiences of the actor are applied to "new situations" (in their case, watching novice dart players throw), perhaps somewhat automatically, even if this might be to the later detriment of the observer.

1.6 Current Study

Previous studies have provided evidence consistent with the proposal that people "simulate" observed actions, based on their own motor experiences, to help predict the outcome of others' actions (Aglioti et al., 2008). In this thesis, my aim was to determine how closely linked this relationship is between physical ability and practice experiences and action prediction. Does a person's ability to predict outcomes and the manner by which they do this, depend on the specific experiences and internal models formed during physical practice (i.e., relations between motor commands, action effects and motor outcomes)? To address this question, I manipulated the physical experiences during practice with the idea that this would impact the type of internal model (or schema) formed of throwing. Participants practiced throwing darts either with or without a wrist weight, and then were asked to predict outcomes of people throwing under opposite or the same conditions as those experienced during practice.

If people use the same model formed during physical practice to make predictions, participants who undergo physical training wearing a wrist weight ("weighted throw") should show an increase in prediction errors and a bias to under-predict the landing position of a dart thrown without a weight ("no-weight throw"). If they do not use the same model or are unable to use their prior experiences, then there should be no improvement or detriments in predictions when making predictions under opposite conditions (e.g., practised with a weight and making predictions of a person throwing without a weight).

Replicating other research using this dart-throwing prediction paradigm (e.g., Mulligan et al., 2016a, b), I also attempted to measure the motor system contributions to these predictive decisions by including a secondary motor task (i.e., pressing against a force gauge with the throwing arm whilst watching). The purpose of the force gauge task was to determine the involvement of the motor system during action prediction and whether incongruently activating the muscles involved in throwing would disrupt simulative processes believed to aid action prediction. Assuming that participants are simulating based on the model of a weighted throw, this bias to under-predict the landing position would disappear when simultaneously performing the right-arm interference task. The right-arm interference task has been shown to disrupt prediction accuracy and presumably, processes associated with simulation. Therefore, this case of practice with a weight would lead to one being unable to use the model associated with a weighted throw to make a prediction (Mulligan et al., 2016a). No interference would be expected from a left-arm force task (for right-handed individuals).

A novel condition was also added to the following experiment, which involved wearing a weight during the prediction task, whilst the elbow was bent and resting on a surface. This condition was designed to help better bring about the conditions of practice for the weighted group and hence promote simulation (and subsequent biases in landing outcomes). There have been studies to suggest that an individual's perceptions are influenced by their current conditions, as well as by their own capabilities and experiences (for a review see Witt, 2011). For example, observers wearing a heavy backpack perceived the slope of a hill to be steeper compared to observers who were not wearing a backpack (Bhalla & Proffitt, 1999).

By having participants wear a wrist weight, I aimed to create viewing conditions that would influence their predictions positively or negatively depending on the condition. When the observed videos were of a model throwing with a wrist weight, also wearing a weight while watching may produce more congruent viewing conditions for the observer. The wrist weight may facilitate greater understanding of the actions being observed, which would be reflected through an increase in prediction accuracy. However, when the observed videos show an actor throwing without a weight, wearing a weight while observing may result in a bias to report the dart landing position lower than in the control condition.

In prior work, perceptual training experiences, where individuals watch and make predictions about the dart-throwing performance of a thrower (the same as that later shown in the prediction task), improvements in predictions are shown, but not interference in the right-arm force task (Mulligan et al., 2016b). This perceptual training condition, therefore serves as an important "control" to provide evidence that any learning and interference effects are indeed a product of physical training experiences. There is some evidence that people are more likely to apply perceptually acquired models to different contexts (more so than physical experiences), and hence, it may be that the errors (biases) we expect to see in individuals trained under weighted conditions would be larger in the perceptually trained groups while viewing no-weight stimuli.

Chapter 2: Methods

2.1 Participants

Twenty-eight female participants, between the ages of 19 to 35, with normal or corrected vision, and no neurological deficits, took part in the study. Participant recruitment was achieved through advertisements placed around the University of British Columbia as well as an online career database accessible to university students and alumni. All participants were self-reported dart novices with no previous dart throwing experience. Participants were also self-reported right-hand dominant and threw right-handed. Handedness was confirmed via the Edinburgh Handedness Inventory (Oldfield, 1971). Participants were randomly allocated into one of four groups: a “no-weight” physical practice group, a “weighted” physical practice group, a “no-weight” perceptual practice group, and a “weighted” perceptual practice group. All participants were informed on the nature of the experiment, but were blind to the experimental hypotheses and other groups. Signed consent was obtained before beginning the study in accordance with the ethical protocols set by the University of British Columbia. A remuneration of ~$12.65/hr was paid to participants for their involvement in the study.

2.2 Task and Design

The task and procedures were based on those adopted in previous work (e.g., Mulligan & Hodges, 2014; Mulligan et al., 2016a). There were three phases in the experiment including pre-testing, training, and post-testing. Pre-testing consisted of a motor proficiency and prediction test. Training involved either physical or perceptual practice. Post-testing consisted of a prediction and motor proficiency test. A schedule of procedures is outlined in Table 1.

The study took place over one day. During the prediction pre-test and post-test, participants predicted from visually occluded videos the outcome of a dart throw and indicated the section (top, middle, or bottom) associated with their predicted landing position of the dart. During physical practice, participants were instructed to aim for the centre of a section (top, middle, or bottom). During perceptual practice, participants watched a set of videos, similar to those presented in the prediction test, and received feedback to the actual landing position of the dart.

Condition	Motor Pre-test	Prediction Pre-test	Physical or Perceptual Practice	Prediction Post-test	Prediction Weight-video	Motor Post-test	Motor Post-test	Perceptual Matching
(# Trials)	(9)	(108)	(135+)[1]	(108)	(108)	(9)	(9)	(18)
	Top Middle Bottom	Control Weight RH force		Control Weight RH force	Control Weight RH force	Top Middle Bottom	Top Middle Bottom	
NW Practice Group	NW	NW Stimuli	NW Physical Practice	NW Stimuli	W Stimuli	NW	W	NW & W Stimuli
W Practice Group	NW	NW Stimuli	W Physical Practice	NW Stimuli	W Stimuli	NW	W	NW & W Stimuli
NW Perceptual Practice Group	NW	NW Stimuli	NW Perceptual Practice	NW Stimuli	W Stimuli	NW	W	NW & W Stimuli
W Perceptual Practice Group	NW	NW Stimuli	W Perceptual Practice	NW Stimuli	W Stimuli	NW	W	NW & W Stimuli

Table 1. Order of procedures organized by testing phase and group. NW = no-weight; W = weight.

[1] Physical practice ended when participants reached a criterion such that the minimum number of trials was 150 and the maximum number was 180. The number of trials in the perceptual training group was always 135. Although the number of trials between the physical and perceptual practice groups differed, the total time spent in practice was similar regardless of which condition of practice participants engaged in.

2.3 Apparatus and Stimuli

2.3.1 Dartboard

A rectangular board of polystyrene was used as the dartboard. The polystyrene board was placed at a height and distance typically observed in a standard game of darts. Participants stood at a distance of 2.37m away from the board, and the board was mounted at a height of 1.73m (from the floor to the bulls-eye). The dimensions of the polystyrene board were 75.2cm by 45.1cm, with the height of the board matched to a standard dartboard, while the width of the board extended to the diameter of a standard dartboard to create a rectangular throwing surface (see Figure 1). This rectangular board allowed us to divide the dartboard into three equally sized throwing areas, unlike the dartboard used in Mulligan et al. (2016a), where the area of the top and bottom sections were smaller due to the circular shape of a standard dartboard.

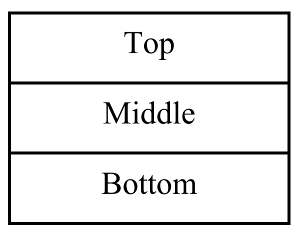

Figure 1. Polystyrene dartboard sectioned into three landing areas.

2.3.2 Wrist Weight & Darts

The "no-weight" physical practice group threw steel tip darts with a weight of 26g and the "weighted" physical practice group threw the same steel tip dart while also wearing a wrist weight (455g/1lb). The wrist weight was tightly fastened to the distal end of the participant's throwing arm. This same wrist weight was worn by participants in the weighted arm prediction condition as detailed below. Supplementary information about pilot testing with a wrist weight can be found in Appendix A.1.

2.3.3 Video Clips

2.3.3.1 Prediction Test Videos

Prediction test video clips featured a moderately skilled actor throwing darts either with or without a wrist weight. The videos were filmed using a Panasonic HC-V770 camera with a capture rate of 30 frames per second (33ms per frame). Both sets of videos showed the actor throwing darts to the top, middle and bottom section of a dartboard. The actor was filmed from the side view perspective and the darts were thrown to the centre of each section in an attempt to minimize any kinematic variability between throws to the same target area. As well, the wrist weight worn in the "weighted" videos was hidden under a long-sleeve shirt so that participants were unaware that the actor was throwing with a weight. The purpose of hiding the wrist weight was to ensure that the weight would only affect the kinematics of the dart throw and to prevent participants from cognitively appraising the landing position of the dart based on knowing that the dart was thrown with a wrist weight.

Each video showed the actor preparing to throw and, depending on the occlusion point (OP), various stages of the dart throw up to the moment after dart release. The videos were edited so that ~2s of the initial set up phase was presented, showing the actor raise their arm up to the point of maximal retraction. Depending on the OP, either two more frames (+ 66 ms, OP 1), four more frames (+66 ms, OP 2) or six more frames (+199 ms, OP 3) were shown with the final frame remaining on the screen for an additional 1.5s (Mulligan et al., 2016b).[2] This created

[2] Initially during pilot testing, we set the duration of the still image to 2s. However, during the debrief sessions for some participants, they reported using a cognitive strategy to predict the landing position of the dart by lining up the release point of the dart to a slightly lower point on the dartboard. In an attempted to avoid this, we reduced the still image length so that people would have less time to think before responding. We determined 1.5s was still long enough to process information at the occlusion point, while not providing people too much time to think. If the

three possible temporal OPs that were each two frames further in the throwing sequence. Lastly, participants reported how confident they were in their response based on a 5-point Likert scale.

E-prime 2.0 software (Psychology Software Tools, Inc., Sharpsburg, PA) was used to present the stimuli and for recording participant responses. Video clips were displayed on a 228 by 304 cm projector screen (Cineplex Pro, Dallas, TX) using a ViewSonic PX700HD projector, and the size of the video was adjusted to mimic a life size image of the actor throwing. Video clips were viewed by participants from a distance of 4 m at an angle of ~ 45^o to 60^o to the screen, which matched the perspective from where the video clips were filmed.

2.3.3.2 Perceptual Practice Videos

During perceptual practice, a novel set of videos were presented that were different from the ones presented during the prediction test. These videos started in the same way as the prediction test videos; however, after participants indicated their response, an additional close-up still image of the actual landing position of the dart on the dartboard appeared for 2s. The original temporally occluded clip was subsequently replayed to help the participant understand the relation between pre-dart throw cues and the outcome of the throw. These additional segments presented after the original throwing sequence provided feedback that could then be associated to the observed action sequence upon re-watching the occluded video. A total of 135 video clips were presented. Of 135 video clips, 27 of them were unique and were randomly repeated five times. Similar to the prediction test videos, the moderately skilled actor in the perceptual practice videos wore a long-sleeve shirt to disguise the presence of a wrist weight.

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image length was too short (ie. 1s), the video could possibly be experienced as a perturbation, which we wanted to avoid. Therefore, we selected a 1.5s still image clip length.

2.3.4 Force Gauge for Secondary Task

A force plate was used for the secondary motor interference task. The force plate (Neulog, Rochester, NY) was mounted on an iron post and adjusted to the height of the participant's hand when standing erect with their arms extended and adjacent to their body (for a full depiction see Mulligan et al., 2016a). The force plate was connected to Neulog software where real-time force measurements were tracked.

2.4 Conditions and Procedures

2.4.1 Motor Proficiency Task

Participants performed a motor proficiency test by throwing three darts to the top, middle, and bottom sections of the dartboard (9 in total) to establish a baseline of throwing proficiency. These proficiency tests were scheduled at the start and end of testing to determine the influence of physical or perceptual practice on throwing performance. The number of trials were limited to three throws to each section to reduce the potential for any learning effects, while still being able to assess performance. Before the motor proficiency test, one additional trial was provided as a way for participants to familiarize with throwing a dart. Participants were also instructed to throw by holding the dart like a pencil, standing face on to the dartboard, and by extending the elbow without any side arm movement (to match the action of the video model).

2.4.2 Prediction Tests

Participants also completed multiple prediction tests, during which they observed temporally occluded video clips of female actor (who was moderately experienced), throwing a dart with or without a disguised wrist weight.[3] After a preparatory prompt, the video clip was played, and then a response screen was displayed asking participants to predict the final landing position of the dart (top, middle or bottom) and to indicate a confidence rating for their decision from 0-100% based on a 5-point scale.

Participants watched three sets of prediction tests. The first two prediction tests were completed immediately before (pre) and after (post) the training session (physical or perceptual training) and these tests featured clips of dart throws without a weight. The third prediction test was completed immediately after the post-test (see Table 1 above). This third set of videos featured stimuli of the model throwing with a weight, and thus was called the 'weight-video'. For the no-weight group, this test was essentially a transfer test to determine whether their prediction ability would transfer to similar yet novel contexts.

Within each set of prediction tests, participants were exposed to three different testing conditions. In these conditions, participants either stood still (control), wore a wrist weight, or pushed lightly against a force gauge with their right-arm. The order of the three conditions (control, weight, and force) was counterbalanced across all participants. Within each condition, 27 video clips were played in a random order without feedback as to the outcome of the throw.

Participants were also given short breaks (1-2 minutes) between each condition and an enforced 5-minute break between the second and third set of prediction tests to reduce the impact of fatigue on prediction ability.

[3] Initially during pilot testing, we had intermixed videos with and without a weight and these video clips were randomly presented. However, we speculated that intermixing the videos made the task unnecessarily more difficult and therefore we decided to present prediction video with and without a weight separately.

2.4.2.1 Weight Task

Participants wore a small wrist weight around their throwing arm while predicting outcomes during the prediction tests. Participants were instructed to raise their throwing arm and to keep it held in maximal retraction while watching the videos to statically mimic the start of the throwing position of the action seen on the screen. Participants were provided with a surface (shelf of a step-ladder) which acted as an arm rest for their elbow.

2.4.2.2 Force Production Task

In the secondary force task condition, participants were instructed to make a fist and to press the lateral side of their right-hand against the force gauge while observing the prediction videos. Participants were instructed to press at 15% of their maximum voluntary contraction and this amount was determined by averaging the values of three maximal contractions held for three seconds (at the start of the force gauge conditions). Participants were instructed to begin pressing into the force plate following a start prompt and to continue pressing for the duration of the video clip until the response screen was displayed, at which time they were to release their hand.

2.4.2.3 Control Task

Participants stood still with their arms relaxed and extended. Participants were instructed not to cross their arms or to fidget to minimize any potential interference that could occur by activating the motor system. Participants stood and watched the prediction videos from the same distance and position in which they stood in the previous two conditions.

2.4.3 Training

2.4.3.1 Physical Practice

During physical practice, the “weighted physical practice group” practiced throwing darts with the same wrist weight worn during the “weight condition” during the prediction tests, while the "no-weight physical practice group" practiced throwing darts without a weight. In the first instance, all participants threw 135 darts, divided into 9 blocks (15 throws per block), with an equal number of throws to each target area. In blocks 1-3, practice was scheduled in a semi-blocked order such that participants threw three darts to the same section of the dartboard before collecting the darts from the dartboard and awaiting instructions about the section to throw to next. In blocks 4-6, each set of three darts were thrown in a schedule alternating between a blocked order and then a random order. In the blocks 7-9, a completely random order was adopted, such that every throw was to a different section of the dartboard within the set of three throws. After each block of throws, the number of correct throws was tallied and feedback provided to participants so that they could better assess their performance in hopes that they would strive for a higher score in the following block of throws.[4]

After 135 practice trials, participants completed up to 45 additional practice trials. The number of additional throws was dependent on reaching a criterion performance, in which participants needed to successfully throw five darts in a row to each of the three areas on the dartboard. Upon throwing five darts in a row for each of the three sections, physical practice ended (min = 15 trials, max = 45 trials). The purpose of the criterion test was to ensure that

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[4] We thought that beginning the first bock of practice with three consecutive throws to the same section would allow for optimal learning as the participant would be able to use the feedback from the first throw to immediately correct and update their internal model on the subsequent throws to the same section. This idea is based on the idea of contextual interference, where blocked practice has been found to be more effective for the immediate performance of motor skills compared to random practice (Shea & Morgan, 1979). At the same time, we wanted to provide some degree of practice challenge to encourage participants to be actively engaged in the task, planning their throws and evaluating feedback to change their throws when needed. As participants gained facility with the task, a more random type of practice was adopted as this practice has been shown to have benefits for performance in retention tests as a result of this additional cognitive effort (for a review of the so termed contextual interference effect see Lee, 2012). Overall, this hybrid practice schedule, which involved a progression from a low to high amount of contextual interference, was thought to best facilitate learning in one practice session.

participants had sufficient physical practice and reached some motor competence, as we wanted participants to have developed a "good" motor model for throwing the dart.

2.4.3.2 Perceptual Practice

There were two perceptual practice groups: one which trained by watching darts thrown with a weight (weighted group) and another without a weight (no-weight group). Each video provided feedback to participants about the actual landing position of the dart. There were 135 trials in total. After every 10 minutes of video watching, participants were requested to take a 5-minute break to help mitigate the influence of fatigue on people's prediction ability. Two 5-minute breaks were enforced during perceptual practice.

The number of practice trials in perceptual practice was not matched on an individual level to subjects in the physical practice group due to fatigue and time constraints. However, the amount of time spent in perceptual practice was similar to the time spent in physical practice (including the criterion test).

2.4.3.3 Perceptual Matching Test & Debrief

At the end of the study, participants watched an additional set of prediction videos where clips of the actor throwing with and without a weight were intermixed. Eighteen videos were taken from the original videos in the prediction test, and participants were asked to respond "yes" or "no" to the question, "Was the actor throwing the dart with a wrist weight?". Our aim during the original prediction tests was to disguise the presence of the weight. The perceptual matching test was intended to validate whether the weight indeed was hidden from participants' awareness. Following the perceptual matching test, participants were debriefed on the nature of the study. They were also asked what strategies they used for predicting the dart landing position and whether they noticed any differences between various sets of videos (which unbeknownst to them consisted of throwing with and without a wrist weight). The perceptual matching test was eventually removed from the testing protocol.[5]

2.4.4 Incentives

As a way to boost participant engagement and effort, we offered a monetary incentive to participants in the physical practice groups. Participants were informed at the beginning of the study that the top two performing people in each group would receive a bonus $15 reward which was based on the correct number of throws to the desired target location (tallied on a board during practice). At the end of the study, participants were informed that the incentive would be randomly awarded to give each participant an equal chance of winning.

2.5 Measures and Data Analysis

2.5.1 Participant Data Analysis Inclusion Criteria

In the physical practice groups, only data from participants who improved by at least 10% (comparing the last 2 blocks of practice to the first 2 blocks of practice) and who demonstrated an overall average of 50% motor accuracy were included in the analyses. Eight participants who did not meet these criteria were excluded. This resulted in analysis of 12 participants (n = 6 per group) for the physical practice groups.

All participants in the no-weight, perceptual training group (n = 9) and weighted, perceptual training group (n = 7) were included in data analysis. Since the perceptual training task was the same as the prediction test task (although different sets of video clips were

[5] Even though participants were unaware of the wrist weight during the prediction tests (as confirmed by participant self-reported debrief feedback), the presence of the weight became obvious in the perceptual matching task when we asked participants to determine if the actor was wearing a wrist weight. Unfortunately, the bulge of the wrist weight was somewhat noticeable, especially when participants' attention was directed toward the wrist weight. Therefore, we considered the perceptual matching task to be an ineffective way of determining whether participants were aware of the weight or not. This was discovered part way though testing, and also due to time constraints of the testing session we decided to remove this part of the study.

displayed in each) and I tested fewer participants in these groups, no inclusion/exclusion criteria based on improvement were used for these groups.

2.5.2 Prediction Tasks

Participants' verbal predictions of the dart landing position were recorded and compared against the actual dart landing position. From these correct/incorrect responses a percentage prediction accuracy score was calculated for each condition. These prediction scores were analyzed in a 2 Weight Practice (weight, no-weight) X 2 Test (pre, post) ANOVA, with RM on the last factor, for each practice type (physical, perceptual) separately. In addition to comparisons between the pre-test and post-tests, I also analyzed the post-test (no-weight) and weight-videos separately. One omnibus ANOVA was run comparing across the perceptual and physical practice tests (2 Practice Type X 2 Weight Practice X 2 Test ANOVA, with RM on the last factor). Prediction accuracy was also distinguished by occlusion point and only descriptive statistics was conducted on these data.

For the weight and force conditions, prediction accuracy was also compared between-condition to the control condition. A difference score was calculated (weight/force minus control condition) and analyzed in a 2 Practice Type X 2 Weight Practice X 2 Test ANOVA, with RM on the last factor. A negative score would show interference and a positive score would show facilitation. This was carried out for the weight and force condition separately. For all ANOVAs, partial eta squared (η_p^2) was reported as an estimate of effect size.

Perceptual sensitivity (*d prime*) was also calculated to determine how accurately the target areas were distinguished from one another during prediction for each individual. To achieve this, the proportion of throws in which the dart landing position was correctly and incorrectly identified was tallied. This was done for both the top section and the bottom section separately to yield two separate d prime values. For example, discrimination of the top (from the middle and bottom) was tabulated by tallying the number of hits (responding 'top' when the dart hit the top), misses (responding 'middle' or 'bottom' when the dart hit the top), correct rejections (responding 'middle' or 'bottom' when the dart did not hit the top) and false alarms (responding 'top' when the dart hit the middle or bottom). These calculations were made for each condition separately, before and after practice and in the prediction weight-video. As well, beta (β) was determined as a measure of response bias. Only descriptive analysis was performed on these data.

2.5.3 Physical and Perceptual Practice

Training data (i.e. dart location accuracy in terms of hits and misses) were analyzed to determine trends in improvement across practice. Percentage throwing accuracy as a function of block (15 trials) was calculated for the no-weight and weighted, physical practice groups. Percentage prediction accuracy was calculated for the no-weight and weighted, perceptual groups.

Data were analyzed in 2 Weight Practice (weight, no-weight) by 9 Block ANOVA, with RM on the last factor, for each practice type separately (physical, perceptual). An additional analysis was run to determine an improvement score by comparing the first 2 blocks of practice with the last 2 blocks of practice through a 2 Weight Practice by 2 Block ANOVA, with RM on the last factor.

Pearson correlations were conducted to determine whether there was a relationship between improvement in physical or perceptual practice (from the first 2 blocks of practice to the last 2 blocks) and improvements in prediction accuracy (from pre- to post-test in the control, no-weight condition).

2.5.4 Motor Proficiency Test

A picture was taken of the dartboard after each throw to record the landing position (top, middle or bottom) of the dart. Radial error was then calculated for each throw, in relation to the centre of the dart section, to serve as a more precise behavioral measure of performance. A 2 Practice Type (physical, perceptual) X 2 Test RM ANOVA, with RM on the last factor, was also conducted to determine the effect of practice type (physical or perceptual) on throwing accuracy between the motor pre- and post-test as well as the post-test and weight-video. A 2 Weight Practice (weight, no-weight) X 2 Test was conducted for each practice type separately. Data from one participant from the weighted, physical practice group was missing and not used for these analyses.

2.5.5 Video Model Analysis

Kinematic cues from the video model actor were measured and analyzed to determine whether wearing a wrist weight impacted throwing kinematic and changed as a function of landing position. These kinematic markers were based on darts landing in the centre of each target area. Kinematic cues were measured at OP 2 and were taken from 3 videos for each target area, for each weight/no-weight video type. Six different kinematic markers were measured: shoulder angle, elbow angle, elbow height, wrist angle, vertical dart position, and dart angle. The markers in the no-weight and weighted videos were compared.

Chapter 3: Results

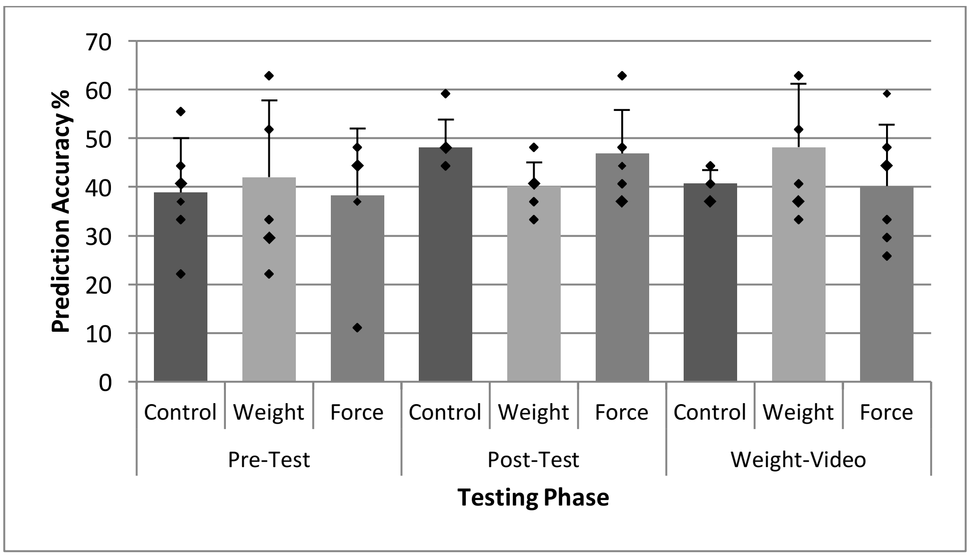
3.1 Prediction Tasks

General graphs for % prediction accuracy as a function of condition for each group, pre- and post-practice are shown in Figures 2a-d and the general trends are described first before statistical analysis. For ease of analysis, I first performed a general comparison of the physical and perceptual groups and then separately analyzed the groups to compare across conditions and testing phases. I analyzed the physical groups before the perceptual groups and analysis was first conducted on the control condition (comparing the pre- and post-practice control conditions for both no-weight and weighted prediction test conditions to determine whether practice led to improvements in prediction accuracy). Finally, I ran some cross-group and cross-condition comparisons to assess processes involved in action prediction and the specificity of the training to improvements.

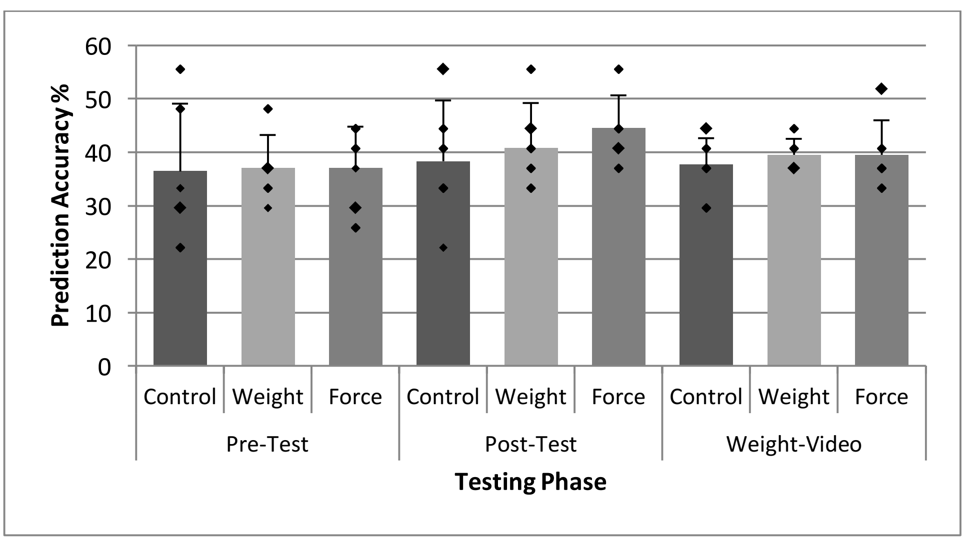
Overall, there were pre- to post-test improvements in prediction accuracy for both physical practice groups in the control condition, however the no-weight group improved more than the weighted group when watching no-weight videos. When both physical practice groups predicted outcomes from the weighted video in the weight-video, there was little evidence of improvement in prediction accuracy compared to pre-test scores. Holding a weight whilst making predictive decisions had a small beneficial effect on accuracy for the no-weight physical practice group when watching throws in the weighted videos (and a small interfering effect when watching no-weight videos, Figure 2a). Contrary to our expectations, there was generally no interfering effect of the force condition when compared to the control condition, across all groups.

The perceptual practice groups both showed improvement in prediction accuracy in the control condition (pre to post), however these improvements were not as large compared to the no-weight physical practice group. As well, prediction accuracy in the weight and force condition was similar to accuracy in the control condition in general, showing little evidence of interference or improvement.

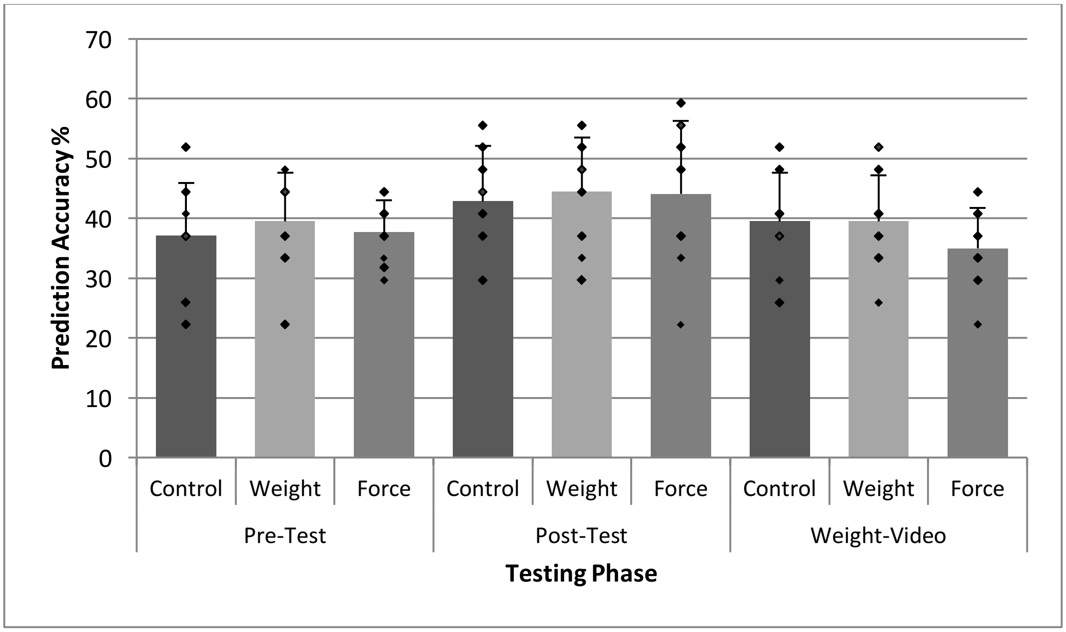
a) No-Weight Physical Practice Group



b) Weighted Physical Practice Group



c) No-Weight Perceptual Practice Group



d) Weighted Perceptual Practice Group

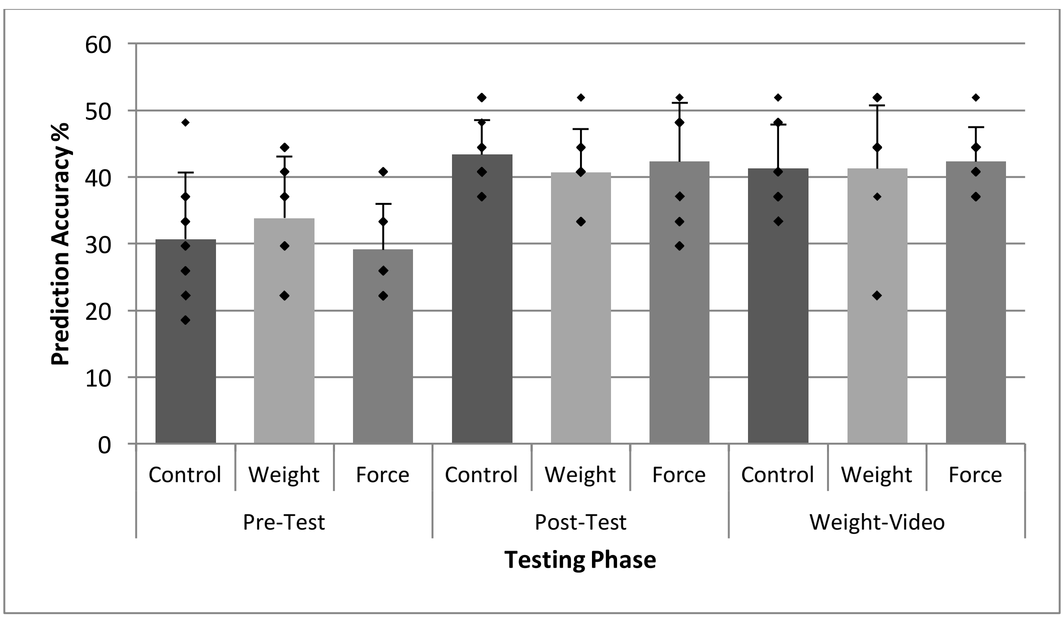


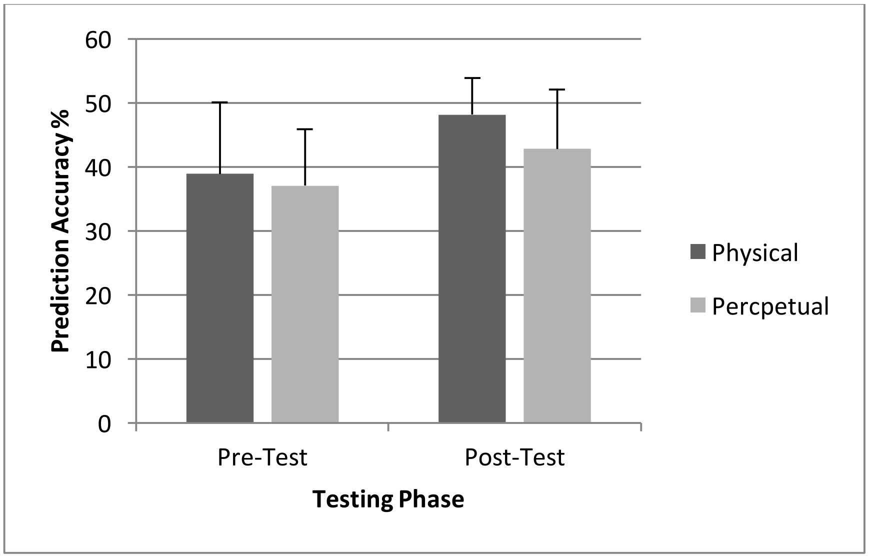
Figure 2. Prediction accuracy percentage as a function of testing phase and condition for a) no-weight physical practice group, b) weighted physical practice group, c) no-weight perceptual practice group, and d) weighted perceptual practice group. Error bars show between subject SDs. Data points show prediction accuracy for individual subjects.

3.1.1 Control Condition Comparisons

3.1.1.1 Physical vs. Perceptual Practice (combined analysis for % accuracy)

In a comparison of pre- to post-test prediction accuracy between all practice groups, there were no significant between-group differences as illustrated in Figures 3a and 3b. Although there was a main effect of test, $F(1, 24) = 11.18$, $p < 0.01$, $\eta_p^2 = 0.32$, there was no main effect of Practice Type nor a Practice Type X Test interaction (*Fs* < 1). This was despite our predictions that physical practice would yield larger improvements in prediction accuracy compared to perceptual practice. Overall, both types of practice showed a trend for better accuracy when throwing without a weight versus a weight, $F(1,24) = 2.46$, $p = 0.13$, $\eta_p^2 = 0.09$ (Practice Type X Weight Practice X Test interaction, $F(1,24) = 2.63$, $p = 0.12$, $\eta_p^2 = 0.10$).

a) No-weight Practice



b) Weighted Practice

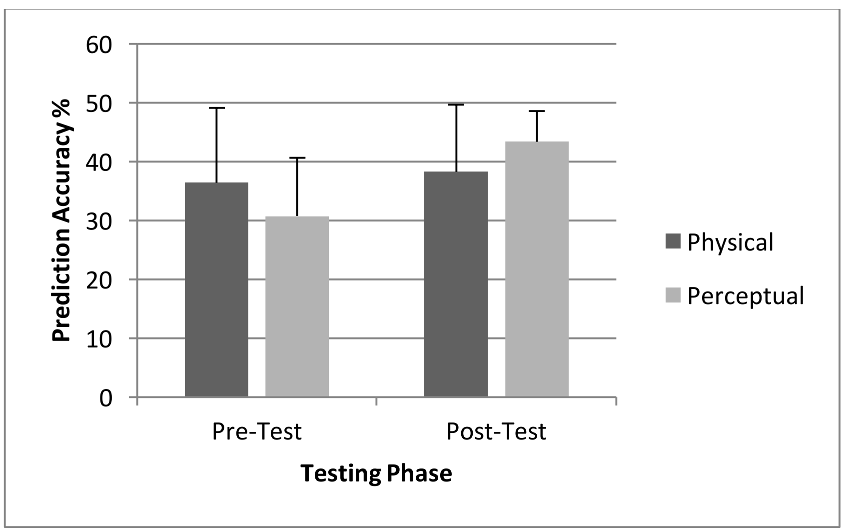


Figure 3. Prediction accuracy percentage as a function of Practice Group X Test for a) no-weight and b) weighted practice. Error bars show between-subject SDs.

3.1.1.2 Separate Analysis of Physical and Perceptual Practice Groups (% accuracy)

Mean prediction accuracy percentage scores for the physical practice groups are shown in Figure 4. In the pre-test, there were no significant differences between groups ($F < 1$). After physical practice, there was a ~10% improvement in the no-weight, physical practice group's post-test predictions of the no-weight stimuli (*M* = 38.89%, *SD* = 11.17; to *M* = 48.15%, *SD* = 5.74), but the weighted practice group improved by less than 2% (*M* = 36.42%, SD = 12.70; to *M* = 38.27%, *SD* = 11.40).

Analysis of the groups as a function of test yielded no main effect of group, $F(1,10) = 2.25$, $p = 0.17$, $\eta_p^2 = 0.18$. As well, the main effect of test (pre to post) was not significant, $F(1,10) = 1.51$, $p = 0.25$, $\eta_p^2 = 0.13$, neither was there a Group X Test interaction, $F < 1$. Despite our prediction that the group which trained with a weight would be more accurate in the weighted video, there was only a small improvement for this group from pre-test (~1%).

Physical practice groups overall

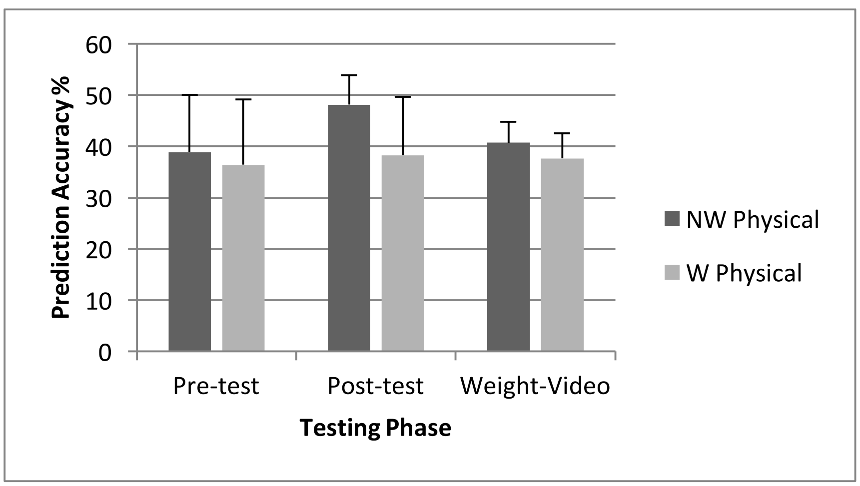


Figure 4. Prediction accuracy percentage data from the control condition as a function of testing phase. Error-bars show between-subject SDs.

For the perceptual practice groups, mean prediction accuracy percentage data are shown in Figure 5 for the no-weight, control condition. There were no significant differences between groups in the pre-test, $F(1, 14) = 1.81$, $p = 0.20$, $\eta_p^2 = 0.12$. Both groups improved as evidenced by a main effect of Test, $F(1,14) = 25.39$, $p < 0.001$, $\eta_p^2 = 0.65$. There was a trend for a Group X Test interaction, $F(1,14) = 3.59$, $p = 0.08$, $\eta_p^2 = 0.20$ with surprisingly more improvement for the weighted practice group than no-weight practice group.

In the weighted video test, the weighted group showed more improvement from the pre-test than the no-weight perceptual practice group (as expected). However, the weighted perceptual practice group was not more accurate in the weighted video test than the no-weight post-test. There was no group or Group X Test interaction ($Fs < 1$) when comparing across the two post-tests.

Perceptual practice groups overall

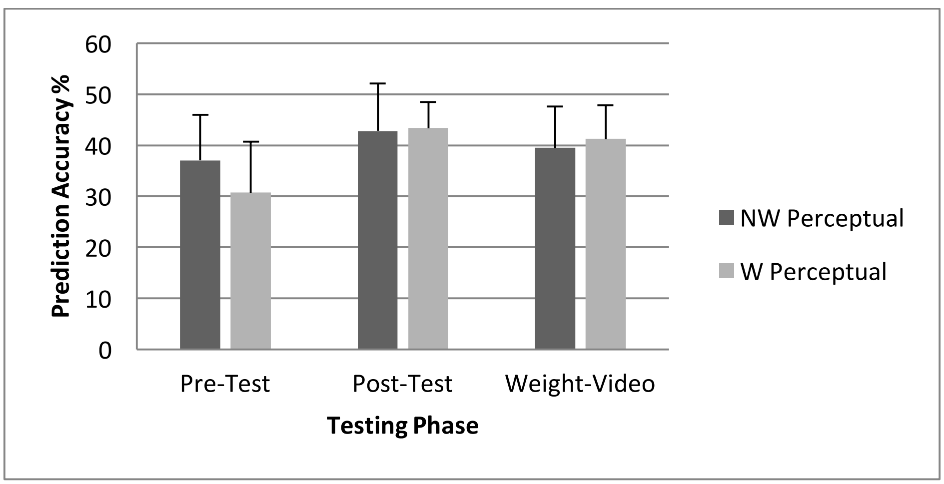


Figure 5. Prediction accuracy percentage data from the control condition as a function of testing phase. Error-bars show between-subject SD.

3.1.1.3 Sensitivity (*d'*) and Bias (*β*) Comparisons

A summary of mean sensitivity (*d*') and bias (*β*) data for all practice groups are shown in Table 2 for the control condition. In general, the trends in sensitivity matched the trends in % accuracy (i.e., general increase from pre- to post-test, which was strongest in the no-weight physical practice group). With respect to bias, there was an overall increase in bias to respond "top" (and decreased bias to respond "middle or bottom"), particularly when predicting throws from the weighted videos versus the no-weight videos.

Group	Pre-test	Post-test	Weight-Video
No-weight Physical			
***d'* Top**	**0.66**	**0.89**	**0.57**
***d'* Bottom**	**0.40**	**0.75**	**1.13**
beta Top	0.56	0.21	0.11
beta Bottom	0.61	0.89	0.99
Weighted Physical			
***d'* Top**	**0.57**	**0.53**	**0.25**
***d'* Bottom**	**0.20**	**0.21**	**0.88**
beta Top	0.70	0.14	-0.12
beta Bottom	0.73	1.22	1.28
No-weight Perceptual			
***d'* Top**	**0.51**	**0.90**	**0.62**
***d'* Bottom**	**0.21**	**0.42**	**0.59**
beta Top	0.47	0.72	0.41
beta Bottom	0.77	0.48	0.76
Weighted Perceptual			
***d'* Top**	**0.52**	**0.62**	**0.58**
***d'* Bottom**	**0.05**	**0.19**	**0.65**
beta Top	0.78	0.37	-0.11
beta Bottom	0.45	0.62	0.83

Table 2. Prediction task sensitivity (*d'*)[6] and bias (β)[7] data by group and testing session for the no-weight, control condition.

[6] For comparison, a perfect *d'* score in this task would be 3.508.
[7] See Appendix B.1 for an explanation on how beta was interpreted.

Physical practice, no-weight group: Similar to % accuracy, there was an increase in sensitivity to throws to the top (vs. middle and bottom) (d'_{change} = 0.23) and also to the bottom (vs. middle and top) (d'_{change} = 0.35) from pre- to post-test in the no-weight videos). Comparing the no-weight post-test to the weighted videos, there was a decrease in sensitivity to the top and an increase to the bottom section (top: d'_{change} = -0.32; bottom: d'_{change} = 0.38), even though there was an overall decrease in % accuracy. Contrary to our prediction, there was increased bias to respond "top" when predicting videos with a weight versus no-weight, post-practice (top: β_{change} = 0.10, increased bias to top; bottom: β_{change} = 0.10, decrease bias to the bottom).

Physical practice, weighted group: From pre- to post-test, there was little to no change in sensitivity (top: d'_{change} = -0.04; bottom: d'_{change} = 0.01). Despite our prediction that the weighted, physical practice group would show a bias to under-predict the landing position when watching videos without a weight, there was an overall increase in response bias to the top section from pre- to post-test (top: β_{change} = 0.56, increased bias to top; bottom: β_{change} = 0.49, decrease bias to the bottom). Comparing the no-weight videos to the weighted videos post-practice, we expected the weighted, physical practice group to improve in their ability to distinguish both top and bottom throws. However, only an increase in sensitivity to the bottom section was observed (top: d'_{change} = -0.28; bottom: d'_{change} = 0.67). With regards to response bias, the weighted group showed a bias to respond "top" when predicting throws from the weight-videos versus the no-weight video post-practice (top: β_{change} = 0.26, increased bias to top; bottom: β_{change} = 0.06, decrease bias to the bottom).

Perceptual practice, no-weight group: There was an increase in sensitivity to throws to the top (d'_{change} = 0.39) and bottom sections (d'_{change} = 0.22) after perceptual practice, as expected. From post-test (no-weight) to weight-videos, sensitivity decreased to throws to the top

(d'_{change} = -0.28), but showed a small improvement in sensitivity to the bottom (d'_{change} = 0.17). Also from post-test (no-weight) to weight-videos, there was also an overall increase in bias to the top (top, β_{change} = 0.31, increased bias to top; bottom, β_{change} = 0.28, decreased bias to bottom).

Perceptual practice, weight group: Similar to the no-weight perceptual group, there was an increase in sensitivity to the top and bottom sections from pre- to post-test (top: d'_{change} = 0.10; bottom: d'_{change} = 0.14). From post-test (no-weight) to weight-videos, although there was no change in sensitivity to the top section (d'_{change} = -0.04), there was a large increase in sensitivity to the bottom (d'_{change} = 0.46). With respect to bias, also from post-test (no-weight) to weight-videos, there was an overall increase in responding "top" (beta top: β_{change} = 0.48, increase bias to top; beta bottom: β_{change} = 0.21, decrease bias to the bottom).

3.1.1.4 Prediction Accuracy by Occlusion Point

Consistent with expectations that prediction accuracy would improve on later occlusion points (OPs), there was a general increase in % accuracy with OP as shown in Figure 6. These trends were independent of practice type or weight.[8]

[8] We showed a main effect of Occlusion Point, $F(2,48) = 20.66$, $p < 0.001$, $\eta_p^2 = 0.46$ and a significant linear trend of Occlusion Point $F(1,24) = 29.14$, $p < 0.001$, $\eta_p^2 = 0.55$. There was no Occlusion Point x Practice Type interaction (F < 1) or Occlusion Point X Weight Practice (F < 1) interaction.

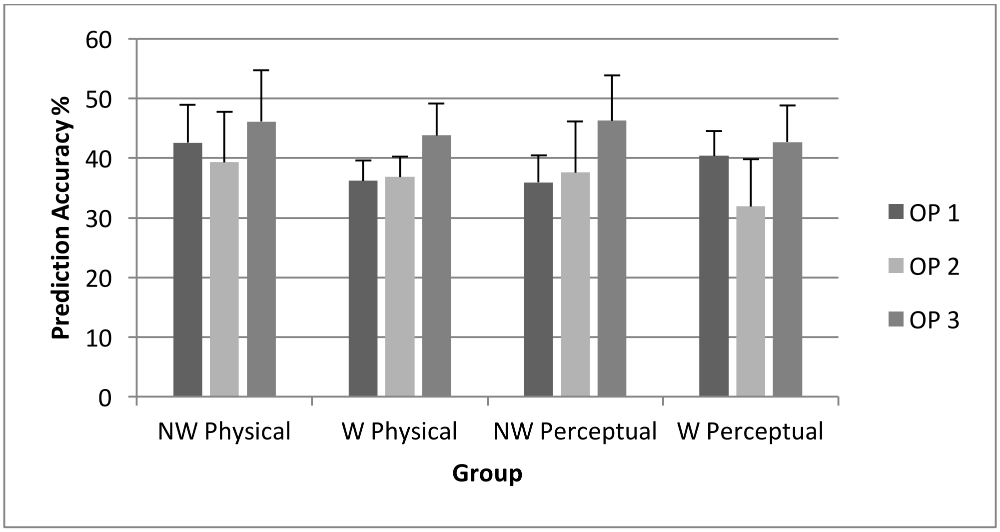


Figure 6. Prediction accuracy data as a function of occlusion point (OP) and group in the no-weight, control condition. Error bars show between-subject SDs.

3.1.2 The Weighted Prediction Condition

3.1.2.1 Between-Condition Comparison (weight vs. control)

Prediction accuracy data for each condition are presented individually by group in Figures 2a-d above and difference scores in prediction accuracy (weight minus control condition) are shown in Figure 7. Positive differences mean that the weight aided accuracy and negative values mean that the weight interfered. Analysis of the difference scores showed no effect of Test (from pre- to post), $F(1,24) = 1.76$, $p = 0.20$, $\eta_p^2 = 0.07$ (there were also no Test X Practice Type or Test X Weight Practice interactions, Fs < 1). The no-weight physical group showed a large decrease in prediction accuracy in the no-weight post-test, which was supported by a trend for a Test X Practice Type X Weight Practice interaction, $F(1,24) = 2.24$, $p = 0.15$, $\eta_p^2 = 0.15$. There was no difference between groups as a function of Weight Practice ($F < 1$) or Practice

Type (F < 1). There was also no Practice Type X Weight Practice interaction, $F(1,24) = 1.86$, $p = 0.19$, $\eta_p^2 = 0.07$.

From the post, no-weight video test to the weight-videos, there was no main effect of Test, $F(1,24) = 2.36$, $p = 0.14$, $\eta_p^2 = 0.09$. Despite our prediction that holding a weight would facilitate prediction for the weight practice groups, there was no main effect of Weight Practice (no Test X Weight Practice interaction, $F = 1.31$ or Practice Type X Weight Practice interaction, $F < 1$). It was the no-weight physical group that showed an improvement in prediction accuracy when holding a weight in the weight-videos, which was evidenced by a 3-way interaction between Test, Practice Type and Weight Practice, $F(1,24) = 3.91$, $p = 0.06$, $\eta_p^2 = 0.14$. There was no main effect of Practice Type ($F < 1$) and no Test X Practice Type interaction, $F(1,24) = 1.80$, $p = 0.19$, $\eta_p^2 = 0.07$. Additional between-test, within-condition analysis is presented in Appendix B.2 for the weight condition.

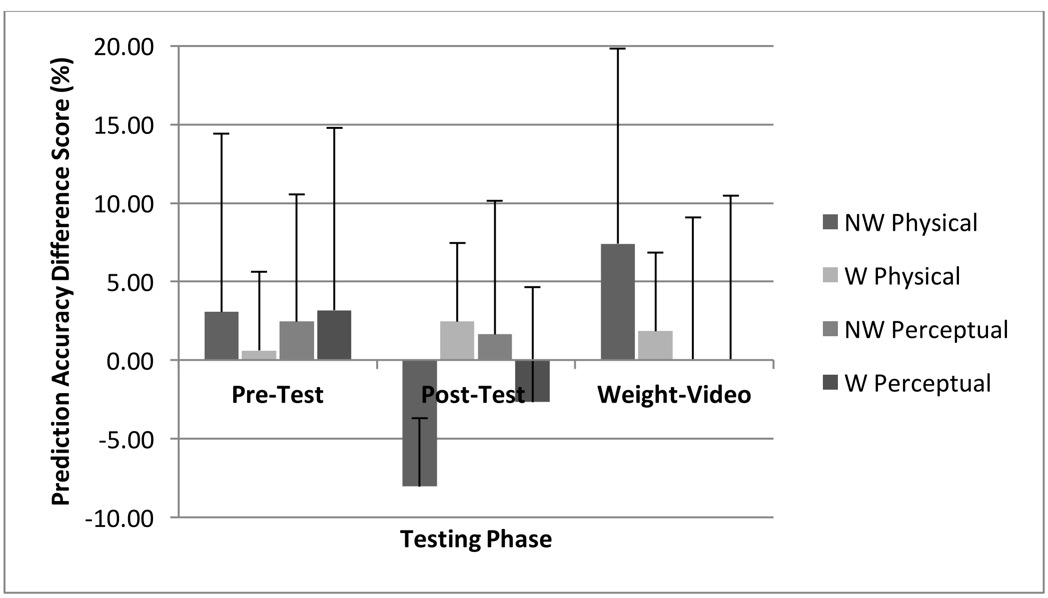


Figure 7 Prediction accuracy difference scores (weight minus control condition) as a function of group and testing phase. Error-bars show between-subject SDs.

3.1.2.2 Sensitivity (*d'*) and Bias (*β*) Comparisons

A summary of mean sensitivity (*d*') and bias (*β*) data for all practice groups are shown in Table 3 for the weighted condition. Our main questions of interest were to determine whether sensitivity data was consistent with prediction accuracy data and whether there was an increase in bias to the bottom section when predicting weighted videos versus no-weight videos, post-practice.

From pre- to post-test, there were no clear trends in sensitivity that matched % accuracy. Comparing the no-weight post-test to the weight-videos, there was an overall increase in sensitivity to the bottom section across all groups, but the strongest trends were in the no-weight physical practice group (top: $d'_{\text{change}} = -0.01$; bottom: $d'_{\text{change}} = 0.66$). This increase also coincided with an increase in % accuracy in the no-weight physical practice group only, whereas all other groups showed a decrease in % accuracy from post-test to weight-videos.

In terms of response bias, there was an increase in bias, although small, to respond "bottom" from post-test to weight-videos in the no-weight physical practice group (top: $\beta_{change} = 0.13$, decreased bias to top; bottom: $\beta_{change} = 0.13$, increase bias to bottom). In all other groups, there was an overall increase in bias to respond "top" (and a decrease in bias to respond "bottom"), similar to the biases observed in the control condition.

Group	Pre-Test	Post-Test	Weight-Video
No-weight Physical			
***d'* Top**	**0.22**	**0.68**	**0.67**
***d'* Bottom**	**0.61**	**0.41**	**1.07**
beta Top	0.61	0.01	0.14
beta Bottom	0.87	1.04	0.91
Weighted Physical			
***d'* Top**	**0.66**	**0.46**	**0.33**
***d'* Bottom**	**0.12**	**0.18**	**0.59**
beta Top	0.43	-0.09	-0.10
beta Bottom	0.79	1.27	1.25
No-weight Perceptual			
***d'* Top**	**0.73**	**0.91**	**0.54**
***d'* Bottom**	**0.24**	**0.51**	**0.67**
beta Top	0.29	0.71	0.45
beta Bottom	1.06	0.35	0.65
Weighted Perceptual			
***d'* Top**	**0.61**	**0.40**	**0.45**
***d'* Bottom**	**0.08**	**0.30**	**0.81**
beta Top	0.52	0.22	0.02
beta Bottom	0.47	0.72	0.74

Table 3. Prediction task sensitivity (*d'*) and bias (*β*) data by group and testing session for the weight condition.

3.1.3 The Incongruent-Force Task Prediction Condition

3.1.3.1 Between-Condition Comparison (force vs. control)

Prediction accuracy data for the force condition are shown by group in Figures 2a-d and difference scores in prediction accuracy (force minus control condition) are shown in Figure 8.

Negative values mean that the force condition interfered with prediction accuracy relative to the control and positive indexed improvements.

From pre- to post-test, the weighted physical practice group actually improved on prediction when concurrently pushing against the force gauge versus the control condition. All other groups showed relatively small differences between conditions, and there was no effect of Test comparing across pre- and post-practice ($F < 1$ and no between-test interactions, *F*s < 1). Post-practice, we would have predicted to see a decrease in prediction accuracy in the force versus the control condition, but there was no main effect of Practice Type ($F < 1$). There were no other group-related differences ($F < 1$) and no group-related interactions ($F < 1.20$). From post-test to weight-videos, the no-weight perceptual practice seemed to show interference in the force task, while all other groups showed little to no change (less than ~3% between force vs. control condition). However, there was no 3-way interaction of Test, Practice Type, and Weight Practice, $F(1,24) = 1.44$, $p = 0.24$, $\eta_p^2 = 0.06$. There was also no effect of Test ($F < 1$) and no other between-test interactions (*F*s < 1). In the weight-videos, both no-weight groups showed more interference (relative to the control condition) than the weighted practice groups (trend of Weight Practice, $F(1,24) = 2.16$, $p = 0.16$, $\eta_p^2 = 0.08$). However, there were no effect of Practice Type ($F = 1.16$) and no Practice Type X Weight Practice interaction ($F < 1$). Additional between-test, within-condition analysis is presented in Appendix B.2 for the force condition.

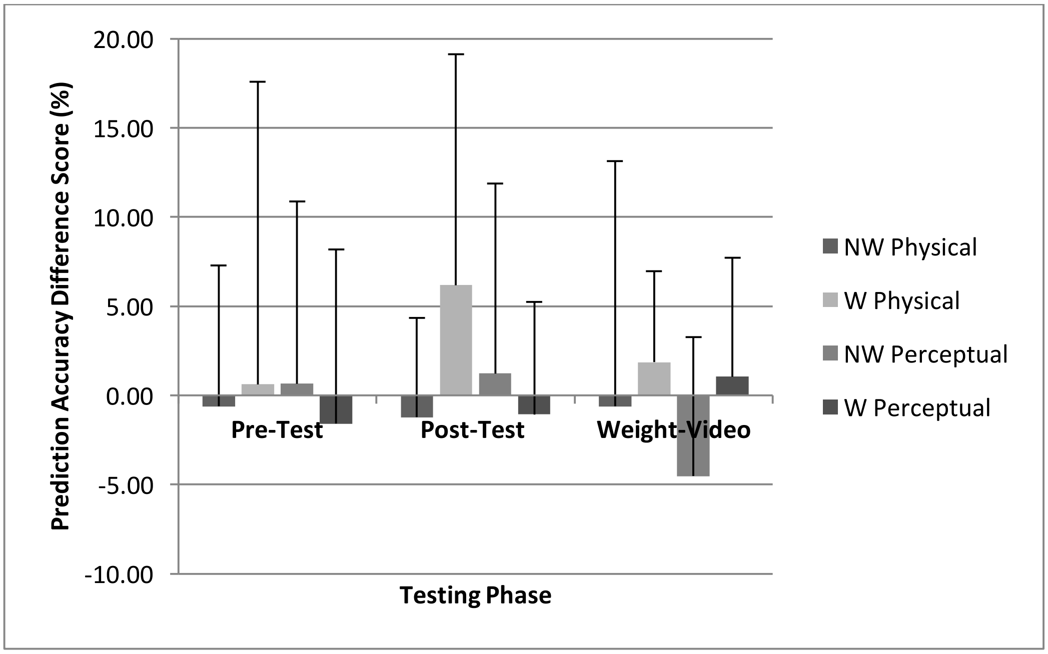


Figure 8. Prediction accuracy difference scores (force minus control condition) as a function of group and testing phase. Error-bars show between-subject SDs.

3.1.3.2 Sensitivity (*d'*) and Bias (*β*) Analysis

A summary of mean sensitivity (*d*') and bias (*β*) data for all practice groups are shown in Table 4 for the force condition.

Although we predicted that there would be interference (no increase in sensitivity) in the physical practice groups after practice, there was a general increase in sensitivity for all practice groups from pre- to post-test. These data also matched the trends in % accuracy. From post-test to weight-videos, there was an overall decrease in sensitivity to the top section and an increase in sensitivity to the bottom section, even though there was a decrease in % accuracy for each group. With regards to bias, from post-test to weight-video, we showed increased bias to respond "top" and decreased bias to respond "bottom", with the physical practice groups showing larger biases compared to the perceptual practice groups.

Group	Pre-Test	Post-Test	Weight-Video
No-weight Physical			
***d'* Top**	**0.75**	**1.12**	**0.67**
***d'* Bottom**	**0.60**	**0.22**	**0.98**
beta Top	0.52	0.19	0.30
beta Bottom	0.67	0.94	1.01
Weighted Physical			
***d'* Top**	**0.65**	**0.68**	**0.72**
***d'* Bottom**	**0.05**	**0.27**	**0.70**
beta Top	0.10	-0.10	-0.20
beta Bottom	1.03	1.13	1.34
No-weight Perceptual			
***d'* Top**	**0.46**	**0.83**	**0.30**
***d'* Bottom**	**0.10**	**0.39**	**0.55**
beta Top	0.39	0.82	0.44
beta Bottom	0.93	0.45	0.74
Weighted Perceptual			
***d'* Top**	**0.31**	**0.64**	**0.50**
***d'* Bottom**	**0.02**	**0.08**	**0.65**
beta Top	0.76	0.21	-0.05
beta Bottom	0.63	0.81	0.65

Table 4. Prediction task sensitivity (*d'*) and bias (*β*) data by group and testing session for the force condition.

3.2 Training Data

3.3.1 Physical Practice

As shown in Figure 9, both the no-weight and weighted, physical practice groups significantly improved their throwing accuracy across practice as evidenced by a main effect of

Block, $F(8,80) = 7.18$, $p < 0.001$, $\eta_p^2 = 0.42$, and a significant linear trend to the block effect, $F(1,10) = 28.60$, $p < 0.001$, $\eta_p^2 = 0.74$. There was no Block X Weight Practice group interaction, $F < 1$. There was however a near significant effect of Weight Practice group, $F(1,10) = 4.49$, $p = 0.06$, $\eta_p^2 = 0.31$. Because we included individuals in the physical practice group based on their overall improvement across the first to the last two blocks of practice, a second analysis was conducted.[9]

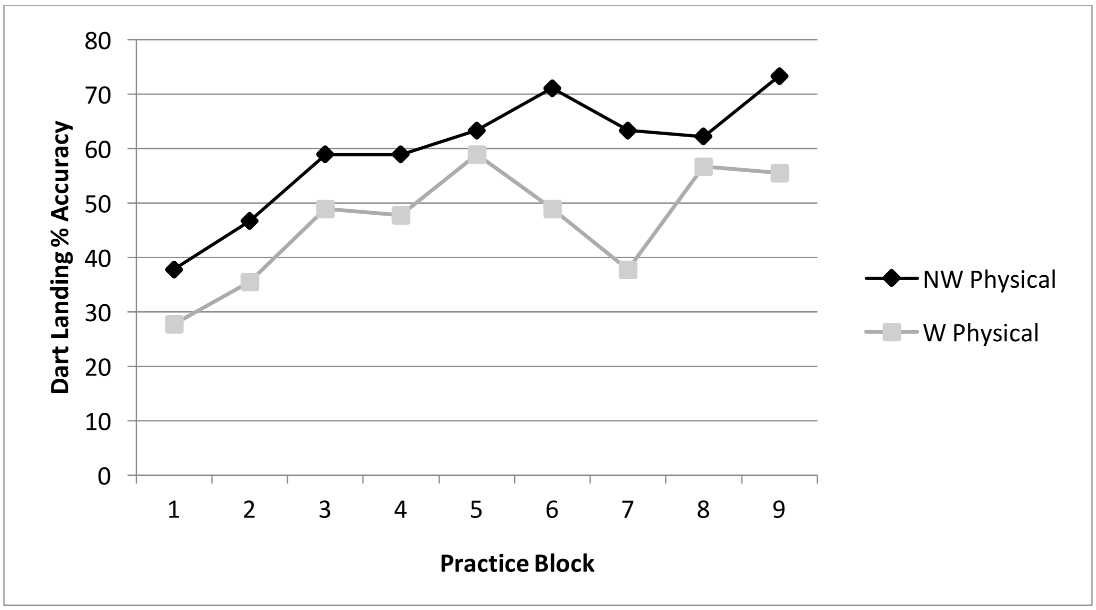


Figure 9. No-weight and weighted, physical practice acquisition data as a function of practice block

3.3.2 Perceptual Training

Both the no-weight and weighted, perceptual practice groups improved their throwing accuracy across practice (Figure 10). Despite there being no main effect for Block, $F(8,112) =$

[9] There was ~15% improvement in throwing accuracy for both groups (no-weight; first block, $M = 42.22\%$, $SD = 16.41$; last block, $M = 67.78\%$, $SD = 13.88$; weight; first block, $M = 31.67\%$, $SD = 17.32$; last block, $M = 56.11\%$, $SD = 13.77$). There was a trend for the no-weight group ($M = 59.52\%$, $SD = 16.93$) to be more accurate than the weight group ($M = 46.42\%$, $SD = 19.72$), $F(1,10) = 4.49$, $p = 0.06$, $\eta_p^2 = 0.31$. There was no Weight Practice X Block interaction, ($F < 1$).

1.68, $p = 0.11$, $\eta_p^2 = 0.11$, there was a significant linear trend block effect, $F(1,14) = 36.88$, $p < 0.05$, $\eta_p^2 = 0.35$. The no-weight perceptual group ($M = 51.03\%$, $SD = 16.64$) was more accurate than the weighted perceptual group ($M = 40.53\%$, $SD = 13.02$), $F(1,14) = 9.71$, $p < 0.01$, $\eta_p^2 = 0.41$. There was no Weight Practice group X Block interaction, $F < 1$.

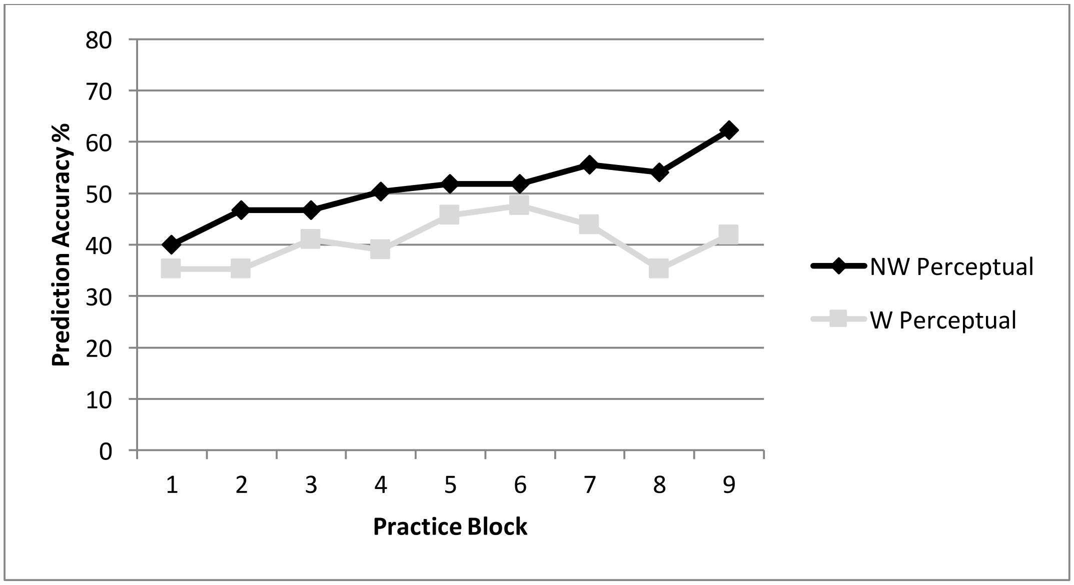


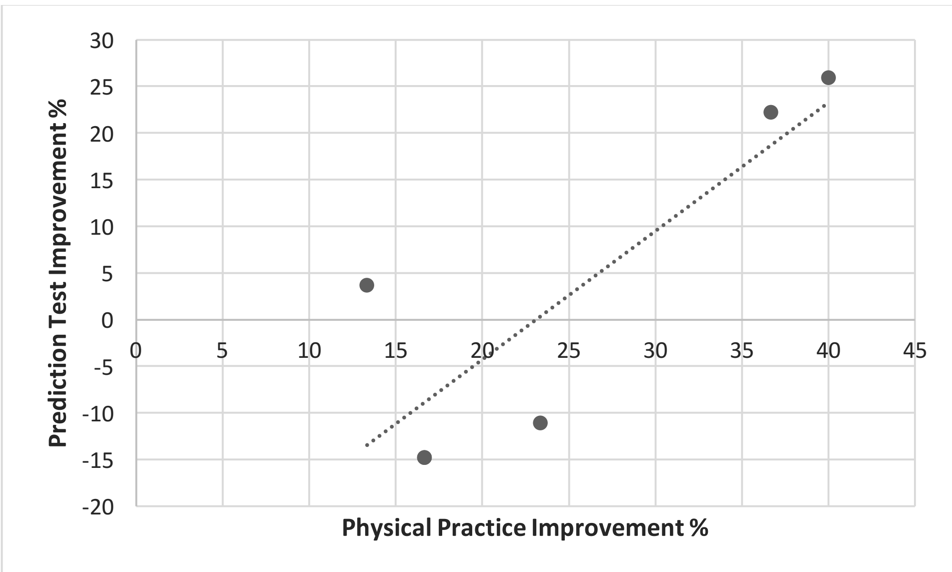
Figure 10. No weight and weighted, perceptual training acquisition data as a function of practice block.

The no-weight, perceptual practice group showed a ~15% improvement in prediction accuracy when comparing the first 2 blocks of practice ($M = 43.33\%$, $SD = 12.99$) to the last 2 blocks of practice ($M = 58.15\%$, $SD = 17.98$). However, the weighted, perceptual practice group improved by only ~3% in prediction accuracy between first 2 blocks of practice ($M = 35.23\%$, $SD = 8.84$) and the last 2 blocks ($M = 38.57\%$, $SD = 12.86$).

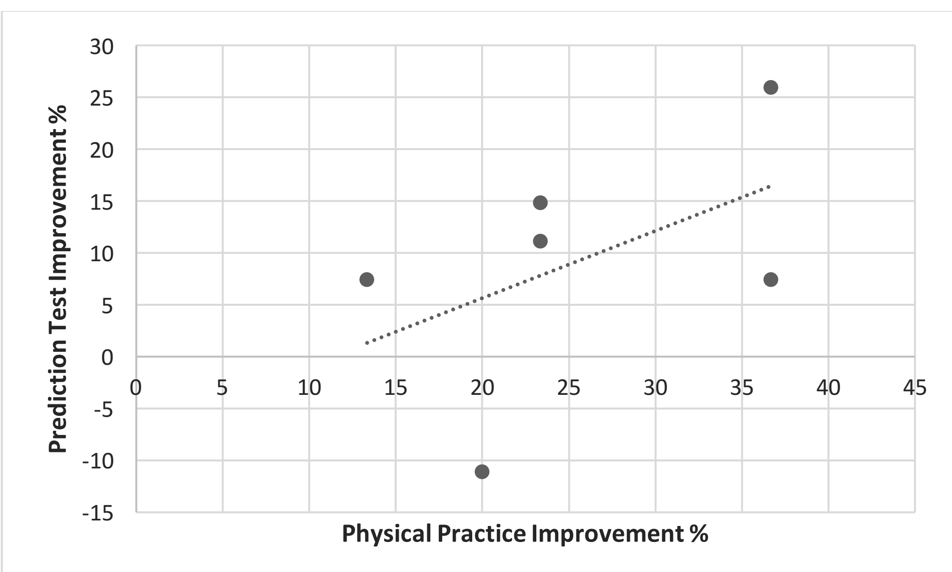
3.3.3 Relationship between Training Improvement and Prediction Test Improvement

For the physical practice groups, as shown in Figure 11a (no-weight) and 11b (weighted), there were positive correlations between improvement in practice and improvement in the prediction task (no-weight; $r_p(6) = 0.50$, $p = 0.31$; weighted, $r(6) = 0.84$, p = 0.04). However, these correlations were not observed for the perceptual practice groups (see Figure 11c, and d). For the no-weight, perceptual training group there was no correlation, $r(9) = 0.07$, $p = 0.85$, whereas for the weighted, perceptual training group there was a negative correlation, $r(7) = -0.59$, $p = 0.17$.

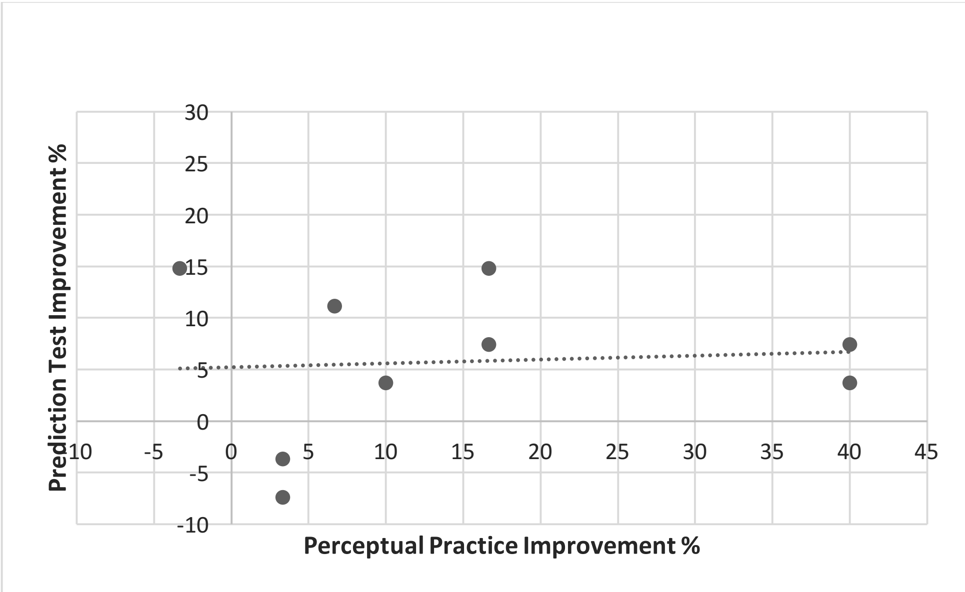
a) No-weight Physical



b) Weighted Physical



c) No-weight Perceptual



d) Weighted Perceptual

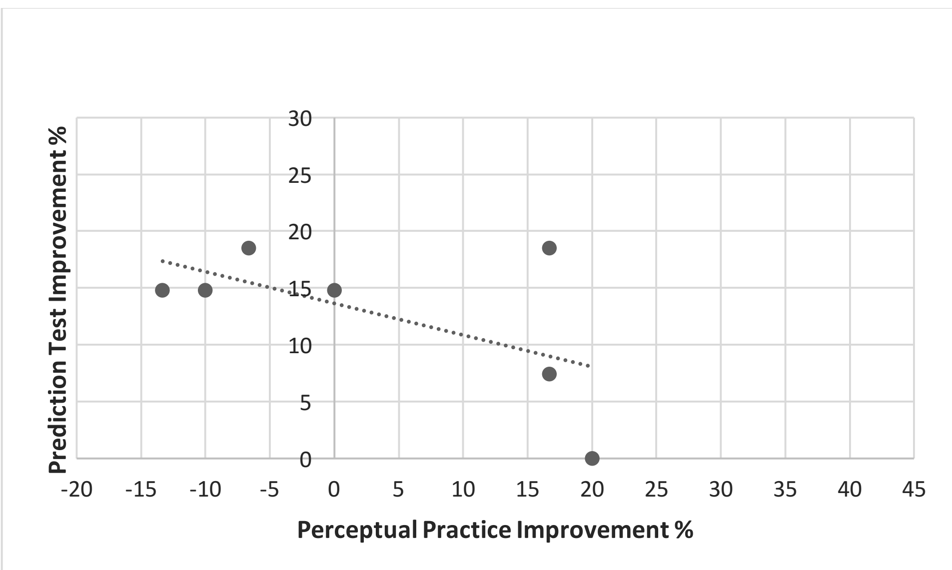


Figure 11. Correlation between improvement in practice and improvement in the prediction task for the a) no-weight physical, b) weighted physical, c) no-weight perceptual, and d) weighted perceptual group.

3.3 Motor Proficiency Tasks

3.3.1 Training Type Comparisons

A comparison of radial error for the physical and perceptual practice groups (irrespective of practice with or without a weight) is shown in Figure 12. After practice, the physical groups showed a ~6% reduction in error, but there was no change in the perceptual groups. There was a reduction in error from pre- to post-test, $F(1,25) = 5.46$, $p < 0.05$, $\eta_p^2 = 0.18$, and a Practice Type group X Test interaction, $F(1,25) = 5.96$, $p < 0.05$, $\eta_p^2 = 0.19$, due to the reduction in error for the physical practice groups only. As shown in Figure 12, between the no-weight post-test and weighted post-test, both groups increased error by ~6% as evidenced by a main effect of Test, $F(1,25) = 12.30$, $p < 0.01$, $\eta_p^2 = 0.33$ (Test X Practice Type, $F < 1$).

Physical vs. Perceptual (Overall)

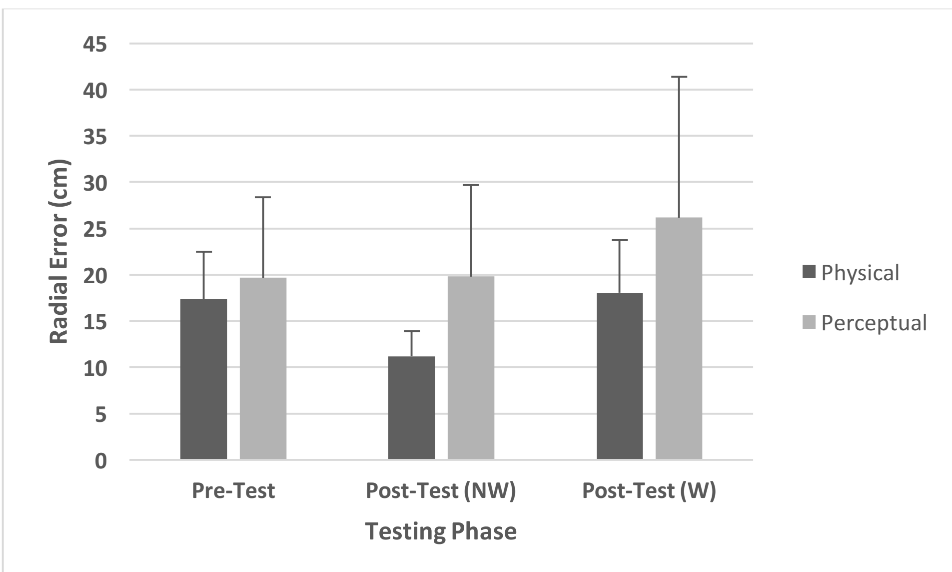


Figure 12. Motor-test radial error as a function of group and testing phase. Error bars show between-subject SDs.

3.3.2 Separate Analysis for the Physical and Perceptual Practice Groups

For the physical practice groups, practice with a weight had no significant effect on motor proficiency ($F < 1$ for main effect of weight). Both physical practice groups showed a decrease in radial error after practice (Figure 13), $F(1,9) = 12.55$, $p < 0.01$, $\eta_p^2 = 0.58$. There was no Weight Practice X Test interaction ($F = 1.74$). Comparing the weighted post-test to the no-weight post-test, both groups showed increased radial error throwing with a weight, $F(1,9) = 9.68$, $p = 0.01$, $\eta_p^2 = 0.52$. The weighted practice group did not show the same increase in error moving between conditions, although the Weight Practice X Test interaction was not significant, $F(1,9) = 2.28$, $p = 0.17$, $\eta_p^2 = 0.20$. There was no main effect of Weight, $F < 1$.

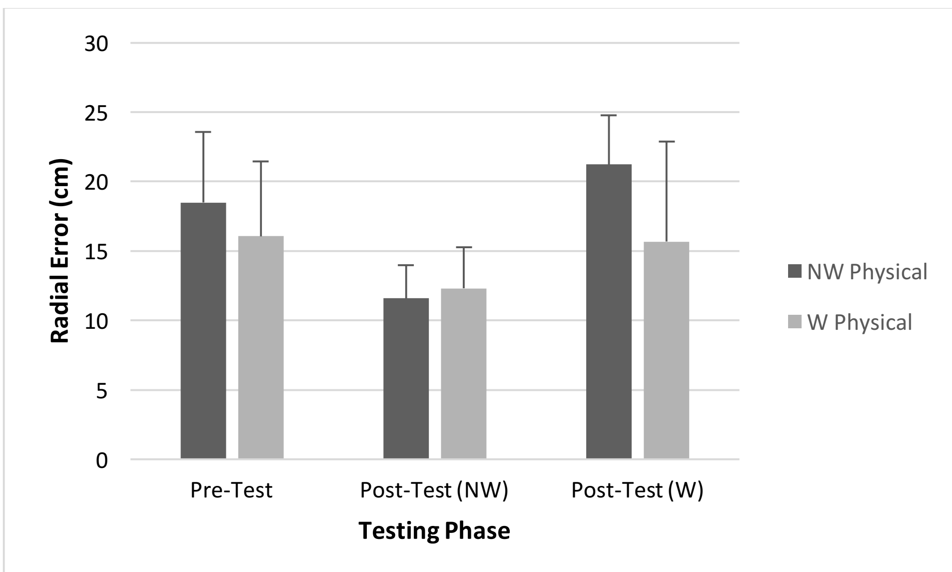


Figure 13. Motor-test radial error as a function of group and testing phase. Error bars show between-subject SDs.

The perceptual practice groups (Figure 14) did not show a decrease in radial error from pre- to no-weight post-test ($F < 1$). However, error significantly increased from the no-weight to weighted post-test, $F(1,14) = 5.00$, $p < 0.05$, $\eta_p^2 = 0.26$, but this was for both groups (no main effect of group, $F < 1$).

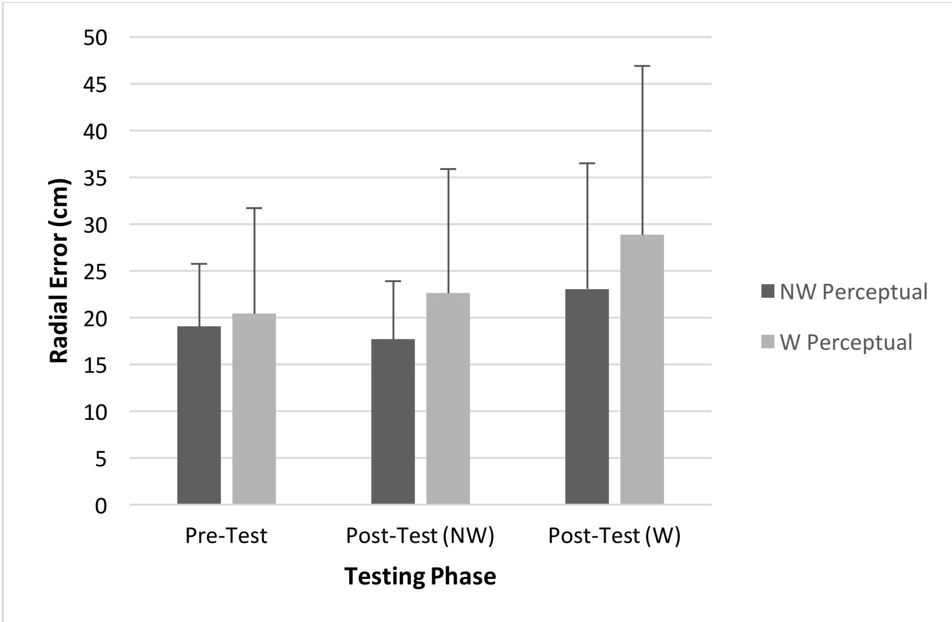


Figure 14. Motor-test radial error (RE) data for the a) physical practice and b) perceptual practice group as a function of test. Error bars show between-subject SDs.

3.4 Video Model Analysis

Kinematic data comparing the no-weight and weighted throws are presented in Table 5. The differences between the videos were small, but generally there was a trend for the shoulder angle to be larger for the weighted condition (*M* = 92.65°, *SD* = 3.50) than no-weight condition (*M* = 91.53°, *SD* = 2.07). As can be seen in the table, other differences between the weighted and no-weight conditions include a larger elbow angle (weight, *M* = 130.45cm, *SD* = 4.26); no-weight, *M* = 129.84cm, *SD* = 2.92) and a lower vertical dart position (weight, *M* = 200.35cm, *SD* = 8.81; no-weight, *M* = 201.38cm, *SD* = 5.94) when throwing with a weight. Statistical analysis (based on n = 9 videos per condition) did not yield any condition differences (shoulder angle, $F = 1.76$, all others $F < 1$).

Comparisons between markers as a function of section did show more discrimination as shown in Table 5. Based on descriptive analysis, shoulder angle, elbow height and dart angle were larger in the weighted versus no-weight condition for throws to the top and middle section. Based on a statistical analysis, four different markers showed a significant (or near significant) main effect of section: i) shoulder angle, $F(2,12) = 10.77$, $p < 0.01$, $\eta_p^2 = 0.64$, ii) elbow angle, $F(2,12) = 3.16$, $p = 0.08$, $\eta_p^2 = 0.35$, iii) elbow height, $F(2,12) = 3.00$, $p = 0.09$, $\eta_p^2 = 0.33$, and iv) vertical dart position, $F(2,12) = 4.61$, $p < 0.05$, $\eta_p^2 = 0.43$. Post hoc analysis (Tukey HSD) determined that the effect of section on shoulder angle was between the top and middle section ($p < 0.05$) and the top and bottom section ($p < 0.01$). Post hoc analysis on vertical dart position showed effects between only the middle to bottom section ($p < 0.05$).

		Shoulder Angle (degrees)		Elbow Angle (degrees)		Elbow Height (cm)		Wrist Angle (degrees)		Vertical Dart Position (cm)		Dart Angle (degrees)	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Top													
	No-weight	93.21	1.88	112.59	13.93	130.55	3.27	215.24	7.19	203.38	5.85	62.01	10.32
	Weight	96.22	1.97	121.36	5.43	133.34	4.80	211.46	1.70	203.34	12.06	66.31	3.36
Middle													
	No-weight	90.22	2.23	118.35	2.85	129.47	4.16	214.21	2.53	204.83	3.82	67.28	3.28
	Weight	92.79	1.85	117.09	5.31	132.10	0.86	215.28	8.78	204.92	2.15	74.33	14.94
Bottom													
	No-weight	91.17	1.26	113.16	6.59	129.49	2.22	219.10	2.58	195.92	4.94	68.26	25.66
	Weight	88.92	1.31	102.02	7.72	125.90	1.09	219.45	5.51	192.78	5.43	56.77	5.74

Table 5. Mean (*M*) and standard deviation (*SD*) of key kinematic markers as a function of section and weight.

Chapter 4: Discussion

Our key aims in this study were i) to determine how closely people's practice experiences influence their ability to predict action outcomes, and ii) to assess the motor system's contribution to these predictive decisions. To address the first aim we manipulated people's experience (and therefore the type of internal model formed) during practice (with weight or no-weight) and tested people through a prediction task in the same or opposite condition to which they practiced. To address the second aim, assessing the role of the motor system during prediction, we had participants perform a secondary force task that was designed to interfere with the motor system and thus one's ability to "access" their motor system and engage in simulation. As well, there was a "weight" condition where participants would wear a wrist weight during prediction, and we predicted that this may facilitate prediction depending on one's practice and may result in a bias to under-predict the dart landing position.

4.1 Influence of Physical Practice on Prediction

One of the main theoretical ideas our hypotheses were based on is the idea that with motor experience, people should be better able to predict outcomes from watching and that this enhanced perceptual ability is a result of the visual-motor experiences which are specific to one's practice experience. This is in line with research showing basketball motor experts being able to predict outcomes better than novices (Aglioti et al., 2008).

We showed evidence that prediction ability is specific to one's practice experience. When predicting dart throwing outcomes without a weight post-practice, the no-weight physical practice group showed superior prediction accuracy compared to the weighted, physical practice group.These prediction scores were also supported by a higher *d'* in the no-weight group compared to the weighted group. When predicting weighted videos, the no-weight, physical group performed worse (deterioration of ~7%) compared to predicting no-weight stimuli, which also represents a regression in prediction accuracy back to pre-test accuracy. Contrary to our predictions, however, the weighted physical practice group did not show improved prediction ability on weighted videos and performed no better on this prediction test than on videos without a weight. These results provide some evidence that prediction ability is specific to one's practice experience, such that superior prediction performance on darts thrown without a weight arises from physical practice also without a weight and not from physical practice with a weight. The supporting sensitivity data also provides evidence that improvements in prediction accuracy are associated with an improved ability to discriminate the landing position of the dart.

Since our findings showed improved prediction accuracy in only prediction conditions that match people's practice experience (in the no-weight group), this would suggest that there are distinct internal models for throwing, which are highly specific and may only transfer to predicting corresponding stimuli. Related to Schmidt's conception of schema theory, this proposed rationale would mean that there are unique GMPs for throwing with and without a weight. Accordingly, the presence of a weight would not be considered a variation in initial conditions and more varied practice within one condition likely would not generalize to throws in the opposite condition. Based on this rationale, the no-weight physical practice group would have used the model based on throwing without a weight to make predictions of darts also thrown without a weight. However, this model may have also been inappropriately applied to predicting weighted throws, resulting in a decrease in prediction accuracy. In the same way, the weighted physical practice group could have also inappropriately applied their weighted model of throwing to predict no-weight stimuli. Contrary to this argument, however, the weighted, physical practice group did not improve on the prediction of weighted stimuli, though this result could potentially be due to other factors: such as the lack of improvement for the weighted group during physical practice in comparison to the no-weight group.

With respect to the weighted videos and the lack of improvement for the weight group, one factor that could have impacted the results may have been the kinematic cues in the weighted videos, which may have been more variable and difficult to understand relative to the no-weight videos. This would have led to poor prediction accuracy in both groups.

We filmed the prediction videos with an actor who had moderate experience throwing darts, however upon consulting with an expert darts' player (part way through data collection), they informed us that the actor's movements were more variable and included more movement than would be seen if an "expert" player were to throw. Related to this, prediction accuracy has been shown to be lower when predicting observed actions based on artificially edited movement profiles compared to natural human-like movement profiles (Stadler, Springer, Parkinson, & Prinz, 2012) and show less interference when given as a prime before a prediction tasks when actions are more directly related to action outcomes than when they are not (Takeuchi et al, 2018). Therefore, it is possible that there were extraneous movements in the video which provided participants with unhelpful or misleading cues. Although these more novice-like movements of our trained video model would have been present in both no-weight and weighted videos, wearing a wrist weight could have also exaggerated these idiosyncrasies, resulting in decreased prediction accuracy performance across all groups in the weighted videos. This account may also explain why overall prediction accuracy after training was fairly low (average ~48% for the no-weight physical group) compared to prediction accuracy reported in a previous study (~70% for the equivalent motor practice group; Mulligan et al., 2016b).

Fatigue could have also been a confounding variable in our design as the weighted videos constituted the final prediction test participants completed in the testing session. Before the weighted videos, participants would have already watched a minimum of 162 trials of video clips (~45 mins of video) to a maximum of 297 trials (~80 mins of video) depending on whether they were allocated to the physical or perceptual training group. Even though we attempted to mitigate the influence of fatigue by enforcing multiple breaks between conditions and testing phases, some fatigue was inevitable given the duration of our testing session and the repetitive nature of how stimuli were presented (repeated exposure to video clips that seem quite similar).

4.2 Evidence of Internal Model Updating

Both physical and perceptual practice resulted in improvement in prediction accuracy post-practice, though this was strongest for the no-weight physical practice group. As well, both physical practice groups showed a higher correlation between improvement in practice and improvement in prediction accuracy compared to the perceptual groups. This link between motor ability and prediction success provides support that the cortical areas underlying motor production and action perception share a common representation (Prinz, 1997). In line with other action prediction studies, we showed that people who have motor experience (no-weight, physical group) perform better when anticipating outcomes than those who have a comparable amount of visual experience (no-weight, perceptual group) (Aglioti et al., 2008, Mulligan et al., 2016b).

Improvement in motor ability was also confirmed through motor proficiency tests, in which we showed a significant reduction in radial error in the physical practice groups post-practice but not in the perceptual practice groups. According to Mulligan et al., (2016b), the mechanism underlying action prediction based on motor experience are different than action prediction based on visual experience. The physical practice groups would have developed a motor-based internal model for dart throwing, which would be updated and refined through physical practice. It is believed that forward-models based on these motor representations can be used to simulate the observed action and to generate predictions (Kilner, Friston, & Frith, 2007). In contrast, the perceptual training groups would have acquired an understanding of the visual dynamics of the dart flight, including stimulus-response associations between the trajectory of the dart and the landing position outcome (Urgesi et al., 2012). This perceptually-driven internal model seems to be independent of the motor system (as evidenced by no motor improvement) and in previous studies has been shown to be unaffected by incongruent motor actions designed to interfere with the motor system (Mulligan et al., 2016b). By only receiving observational practice, the perceptual groups lacked the motor experience needed to acquire the dart throwing action. Consistent with other motor learning studies, the perceptual group would not have formed or updated an internal model for dart throwing, as this would require sending a motor command from the motor cortex to the spinal cord and comparing the intended result with the actual outcome (Ong & Hodges, 2010).

4.3 Some Evidence of the Weighted Condition Facilitating Prediction

In previous research, it has been shown that action-specific perception can be influenced by people's physical viewing conditions (Bhalla & Proffitt, 1999; Witt, 2011). The weight condition seemed to have had a positive effect when the viewing conditions were similar to the prediction stimuli (ie. viewing weighted videos while wearing a weight), and a negative effect on prediction accuracy when the viewing conditions were incongruent with the prediction stimuli (ie. viewing no-weight videos while wearing a weight). However, these results were only seen for the no-weight, physical practice group and not the weighted, physical practice group. As discussed earlier, this may be a result of the greater improvement in actual motor ability (accuracy and potentially consistency) for this no-weight group.

We also predicted that if people use their motor system to simulate outcomes based on their model of throwing, the weighted, physical practice group would show a tendency to under-predict the landing position of a no-weight dart throw. Contrary to our expectations, both physical practice groups showed a response bias to the top section and this was no different from the control condition. Although training with a weight did not bring about any "after-effects" in response bias, we still saw no improvements in prediction in the no-weight post-test, which may indeed be suggestive of "after-effects". In comparison, visuomotor adaptation studies that have shown after-effects when moving in a normal environment after physically training in a visually-rotated environment (Lim et al., 2014; Ong & Hodges, 2010). Overall, it seems that the weighted condition did not help bring about similar conditions of practice for the weighted group to aid in prediction, nor did the weight condition result in any change in landing position verbal response bias compared to the control condition.

Given that we failed to see any difference in prediction accuracy between the weighted condition and the control condition in all groups except the no-weight, physical group, it is possible that our 'weight' manipulation was not heavy enough, and therefore ineffective in bringing about changes to people's prediction performance. During the weighted condition, participants were instructed to rest their elbow on a surface and the purpose of this instruction was to reduce the fatigue caused by wearing the weight. However, resting the elbow could have potentially reduced the effect of the weight and therefore led to a similar experience to that of the control condition. If participants were to wear the weight without assistance of the supporting surface, it is possible larger differences in prediction accuracy could arise between conditions as participants embody the full 'heaviness' of the weight.

4.4 No Evidence of Motor Interference via Force Condition

The force condition was designed i) to test the proposal that a low-level activation of the motor system (motor simulation) is responsible for mediating predictive decisions in the observer and ii) to determine the specificity of this effect with respect to whether the internal model developed during physical practice could generalize to predict outcomes of stimuli in the opposite condition of practice (weight/no-weight). Similar to the paradigm in Mulligan et al., (2016a, b), we had participants press on a force gauge (thereby incongruently activating the motor system) during action prediction. Interference in the motor system was measured as a decrease in prediction accuracy in the force condition compared to the control condition.

Contrary to previous studies where the force task has been shown to disrupt prediction accuracy and presumably, processes associated with simulation, we were unable to show motor interference post-practice (Mulligan et al., 2016a,b). There were no significant differences in prediction accuracy in the force and control conditions across all testing phases and in both physical and perceptual groups. Although we showed no interference in the perceptual groups as well as in all the pre-tests (which is consistent with previous findings), we were surprised that there was no evidence of motor interference in the physical practice groups. Based on motor simulation theory, the motor processes associated with the observed action are thought to be activated in the observer during prediction as if they were performing the observed action themselves (Jeannerod, 2001). Assuming that the observed action is an action in the observer's motor repertoire, we would expect to see improved prediction accuracy if motor simulation aids prediction. Surprisingly, we showed both improvement in motor throwing accuracy (which demonstrates some motor experience) and improvement in prediction in the no-weight condition, yet no evidence of motor interference. Therefore, it is unclear whether our motor interference task failed to adequately interfere with muscles involved in throwing, thus participants were indeed still able to engage in motor simulation, or whether participants were able to use another, more perceptual-based/cognitive strategy to aid in prediction. In line with the latter explanation, it has been suggested that motor experts can use both motor- and visual-based prediction processes during action prediction. In a soccer study where experienced kickers and goalkeepers predicted the fate of a penalty kick, only kickers were susceptible to deceptive actions (thus resulting in poorer prediction accuracy) while the goalkeepers (with both motor and visual experience) were unaffected (Tomeo, Cesari, Aglioti, & Urgesi, 2012). The authors concluded that the kickers were unable to prevent motor simulation of the deceptive action, while the goalkeepers (who had more visual familiarity than kickers) seemed to be able to inhibit or bypass this interference and perhaps use a visual-based process instead.

4.5 Additional Methodological Considerations and Future Directions

In future studies, it will be important to consider ways to better promote learning during training and/or improve the reliability of kinematic cues in the occluded video clips so that they are relatable and predictive of the dart-landing outcome. It would be advisable that future work involving the anticipation of outcomes from video clips be filmed with an expert performer to minimize movement variability in each throw. Another option would be to also use a heavier weight to bring about larger differences in kinematic cues between throwing with and without a weight. However, physical practice with a heavier weight may also result in reduced overall % throwing accuracy, as shown in the weighted versus no-weight physical practice group during acquisition. During pilot testing, we had made several adjustments to our experimental procedure in an attempt improve the quality of the videos and to bring about improvements in prediction post-practice. These procedure manipulations are described further in Appendix A.2. In addition, our initial pilot work with new videos of our trained, yet relatively novice thrower did differentiate between weighted and non-weighted throws (see Appendix A.3). Despite this, these videos were not used in the current study because they contained extraneous gestures and shadows behind the actor's throwing arm.

Given that motor experience seems to be a critical element in modulating prediction accuracy success (Aglioti et al., 2008; Mulligan et al. 2016a, b; Tomeo et al., 2012), we must also consider whether participants received enough physical practice in our experimental design and whether a more distributed type of practice would have resulted in more improvements in prediction accuracy. Unlike expert studies where participants are already highly skilled, we trained novice participants and we hoped that they would improve enough on the dart throwing task (and in doing so update their internal model for throwing) to bring about enhancements in their prediction ability. Since we showed improvement in throwing performance, which was measured during acquisition and at the end of testing, there is evidence that the physical practice participants gained some level of proficiency in the dart-throwing task. However, we do not know whether more training or training interspersed across a two-day protocol (allowing for consolidation of learning), would have brought about greater improvements in prediction accuracy or whether a lack of prediction accuracy improvement (in conditions where we were expecting improvements) was due to insufficient training. Based on the overall throwing performance at the end of acquisition, it seems that participants were more successful at throwing without a weight (~60% accuracy) compared to throwing with a weight (~46% accuracy), even though both groups improved by a similar margin (~25% improvement) from the beginning to end of practice. It is likely that the effect of the weight made the throwing task more strenuous compared to the throwing without a weight, which could account for the lower overall throwing accuracy in the weighted, physical practice group. As well, the difference in throwing accuracy between groups may help to explain why evidence of practice condition specific improvement in prediction and the weight condition aiding prediction was only observed in the no-weight, physical practice group and not the weighted, physical practice group.

The order of the motor post-tests could also be altered to match the condition in which people trained. Therefore, the weighted physical practice group would complete the weighted then no-weight motor post-test, while the no-weight physical practice group would complete the no-weight then weighted motor post-test. This is different to our current design, in which the no-weight motor post-test was always held before the weighted post-test regardless of people's practice experience. It is possible that each time there was a switch in throwing conditions (between throwing with and without a weight), the first dart thrown in the new throwing condition was experienced as a perturbation due to potential after-effects that might have arisen depending on one's practice experience. The impact of this would likely result in an increase in radial error for the first few throws until participants adapted to the new throwing condition. The purpose of the new design would be to minimize the number of switches between throwing conditions to avoid capturing potentially more errorful data confounded by these after-effects. Further, an additional practice throw could be given between throwing conditions in hopes that participants would use the outcome feedback from the throw to adapt to the new throwing condition, thus reducing the size of potential after-effects. In this way, the subsequent throws would provide a better indication of motor proficiency post-practice.

It may also be useful for future work to better distinguish the cues that observers are attending to during prediction. Although we have attempted to distinguish between types of cues (body kinematic cues vs. dart trajectory cues) by occlusion point, eye tracking information would provide evidence on exactly where people are looking during prediction. Previous studies have shown that people with motor experience rely more on body kinematic cues to make predictions, compared to people with visual experience, who tend to rely on object flight trajectories (Tomeo et al., 2012; Urgesi et al., 2012). By using eye tracking during the secondary-motor interference task, we could see if and how the cues people attend to are affected by motor interference. We can determine whether the cues people attend to change depending on whether they are engaged in motor simulation or if this process is impaired. Since we showed some evidence that key kinematic markers were correlated with dart-landing position, eye tracking could also tell us whether people are attending to these same cues and whether gaze behavior changes depending on people's practice experience.

Chapter 5: Conclusion

In summary, we provide evidence that physical practice transfers to improvement in perceptually-driven predictive decisions. We showed some evidence that prediction ability is specific to one's practice experience and that predictive decisions are dependent on the motor system (when holding a wrist weight). We were unable to show that predictive decisions were impaired by an incongruent force task, which was designed to interfere with the involvement of the motor system during prediction. However, understanding if and when the motor system is involved in the prediction of actions still remains an important question so that we can make more informed conclusions about the processes underlying action prediction. Research investigating the specificity of motor-based internal models and the link between simulation and action prediction ability can address conceptual questions about the mechanism underlying action prediction, particularly the involvement of the motor system. These potential answers can have implications for how motor and perceptual skills are taught and provide a rationale for refining future training approaches, especially in domains where accurately predicting outcomes is important for task success (ie. table tennis, cricket, baseball, boxing, etc.). For example in table tennis, there are multiple types of serves (forehand, backhand, sidespin, backspin, etc.), each of which may have different kinematics and may be represented by distinct internal models. Based on our current findings, an improved ability to predict serve outcomes would arise from acquiring motor experience with each of these serves individually, and motor experience from one type of serve alone may not generalize to another type of serve. Knowledge, such as this, can lead to enhanced perceptual training methods, which could benefit sports in which superior predictive ability provides a competitive advantage.

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Appendices

Appendix A Pilot Testing

A.1 The Effect of Wearing a Wrist Weight

I pilot tested people throwing with a wrist weight to ensure the weight had an impact on one's throw, while also ensuring that throwing with a weight was not overly fatiguing. To do this, I piloted 5 individuals who threw first without a weight to gain practice. When they were sufficiently practised, we first removed vision using occlusion goggles (to remove feedback), then we also added a weight. The aim was to see what the consequences of adding a weight were to throwing accuracy when participants were not motivated to correct. We also told them not to correct, but just to continue aiming to the defined target areas. For 4 of 5 participants, throwing with the weight resulted in a noticeable change in landing position, where the dart consistently landed one to two sections below the intended target area.

A.2 Procedure Changes During Pilot Testing

The biggest challenge we faced during pilot testing was showing an improvement in prediction accuracy after practice. Given that our participants were novice dart-throwers, it was imperative that they receive sufficient physical training in hopes that their acquired dart-throwing experience would bring about improvements in their prediction abilities. During pilot testing, we made numerous alterations to our procedure in an attempt to promote learning during the practice phase of the study and to present quality video clips with throwing cues that seemed reliable.

To promote learning, we initially carried out training with a random practice schedule, which was the same as the practice order used in Mulligan et al., (2016b). After testing a few participants, from which we showed no prediction accuracy improvements in the no-weight control condition, we experimented with making practice 'easier' by implementing a blocked order practice schedule. We eventually structured practice in a hybrid schedule which consisted of progressively increasing the switching between throw locations from blocked to serial order, to a random schedule in the final blocks of practice.

At the same time, we reevaluated the quality of our video clips and questioned whether poor video resolution could be making it more difficult to distinguish the sections of the dartboard from one another. We upgraded our projector from a BENQ MP515 to a new ViewSonic PX700HD, which improved the colour contrast and the display resolution of the video. We made new dartboards and changed throwing surface colour from a white background with black lines (to delineate the sections) to a black throwing surface with white lines. This background colour change helped provide maximum contrast in the videos so that the black dartboard would stand out against the white backdrop to which the dartboard was mounted. Also, we refilmed the prediction video clips several times to remove shadows behind the actor's throwing arm and to remove extraneous cues during the set-up phase which we thought might be misleading.

A.3 Kinematic Analysis

An additional set of prediction test videos were used in pilot testing and the kinematic cues (from the actor) were also analyzed to determine the effect of weight. In these videos, the procedure and the actor were the same as the ones in the current videos, however these videos were not used due to poor lighting and the presence of an extraneous movement. These previously filmed videos showed a main effect of weight for shoulder angle, $F(1,18) = 36.26$, $p < 0.05$, $\eta_p^2 = 0.32$; elbow height, $F(1,18) = 14.31$, $p = 0.001$, $\eta_p^2 = 0.44$; dart angle, $F(1,18) = 11.46$, $p < 0.05$, $\eta_p^2 = 0.39$; and wrist angle, $F(1,18) = 49.93$, $p < 0.001$, $\eta_p^2 = 0.74$. As well, there was a main effect of section for shoulder angle, $F(2,18) = 4.31$, $p < 0.05$, $\eta_p^2 = 0.32$; elbow height, $F(2,18) = 7.28$, $p < 0.01$, $\eta_p^2 = 0.45$; and vertical dart position $F(2,18) = 6.68$, $p < 0.01$, $\eta_p^2 = 0.43$. Post hoc analysis using Tukey HSD determined the effect of section was between top to bottom and top to middle section.

Appendix B Supporting Analysis

B.1 Calculation of Beta

An additional explanation is provided to clarify how response bias was interpreted. If $\beta = 0$, a subject's response bias is neutral (Table 6a). This would mean that the proportion of responses 'yes' is relatively similar to the proportion of responses 'no'. If $\beta < 0$, this indicates bias to the 'yes' response (Table 6b). The interpretation of bias would depend on how responses are defined (top or bottom). For example, when calculating the bias for the top versus middle/bottom sections, a 'yes' response would be a response to the top section. However, when calculating bias for the bottom versus top/middle sections, a 'yes' response would be a response to the bottom section. On the contrary, if $\beta > 0$, this indicates bias to the 'no' response (Table 6c). When calculating bias for the top versus middle/bottom sections, a 'no' response would be a response to the middle or bottom section.

a) Scenario 1: No bias

Trial type:	Signal	Noise
No. of trials =	**9**	**18**
	Trial type	
Response type	Signal	Noise
"Yes"	**5**	**9**
"No"	4	9
Sensitivity, d' =	0.140	
Response Bias, β =	**-0.070**	
P(correct)=	0.519	

b) Scenario 2: Bias to respond 'yes'

Trial type:	Signal	Noise
No. of trials =	**9**	**18**
	Trial type	
Response type	Signal	Noise
"Yes"	**9**	**17**
"No"	0	1
Sensitivity, d' =	0.000	
Response Bias, β =	**-1.593**	
P(correct)=	0.370	

c) Scenario 3: Bias to response 'no'

Trial type:	Signal	Noise
No. of trials =	**9**	**18**
	Trial type	
Response type	Signal	Noise
"Yes"	**1**	**0**
"No"	8	18
Sensitivity, d' =	0.694	
Response Bias, β =	**1.568**	
P(correct)=	0.704	

Table 6. Explanation of beta calculation showing a) no bias, b) bias to respond 'yes', and c) bias to respond 'no'.

B.2 Weight Condition: Separate Analysis of Physical and Perceptual Practice Groups

Physical Practice, No-Weight and Weighted Groups: Between-test prediction accuracy data within the weight condition are shown in Figure 15. From pre- to post-test, as expected, there was no improvement in prediction accuracy when holding the weight (no main effect of Test, $F < 1$). There was also no Weight Practice group or Weight Practice group X Test interaction ($Fs < 1$). Comparing the no-weight post-test to the weight-videos (where the model is wearing a weight in the second testing phase only), the no-weighted physical group improved their prediction accuracy when holding the weight by ~8% (no change for the weighted group; Test X Weight Practice group, $F(1,10)= 2.18$, $p = 0.07$, $\eta_p^2 = 0.21$). Although the interaction was not significant, the trends in the data were in the predicted direction for the no-weight group.

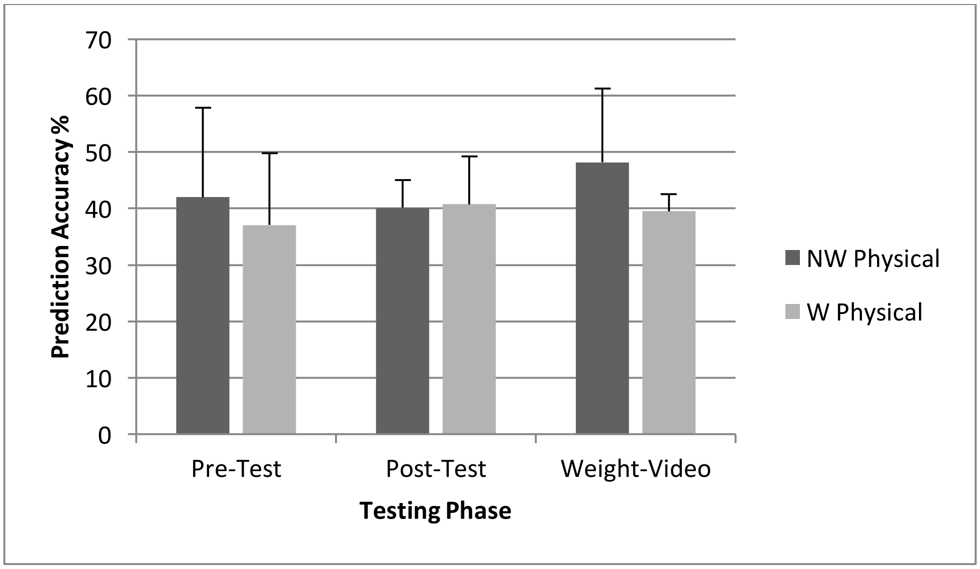

Figure 15. Prediction accuracy percentage data for the physical practice groups from the weight condition as a function of group (weight/no weight) and testing phase. Error-bars show between-subject SDs.

Perceptual Practice, No-Weight and Weighted Groups: There was an improvement in prediction accuracy from pre- to post-test while making predictions wearing a weight (Figure 16), $F(1,14) = 3.72$, $p = 0.07$, $\eta_p^2 = 0.21$. There was no Weight Practice group X Test interaction ($F < 1$). Although the no-weight group was more accurate than the weighted group (pre to post), there was no group effect, $F(1,14) = 2.68$, $p = 0.12$, $\eta_p^2 = 0.16$. Comparing across the weighted conditions for the no-weight video in the post-test and the weight-videos, did not yield between test differences ($F < 1$) or any effects of weight practice (Weight Practice group, $F < 1$; Test X Weight Practice group interaction, $F = 1.15$).

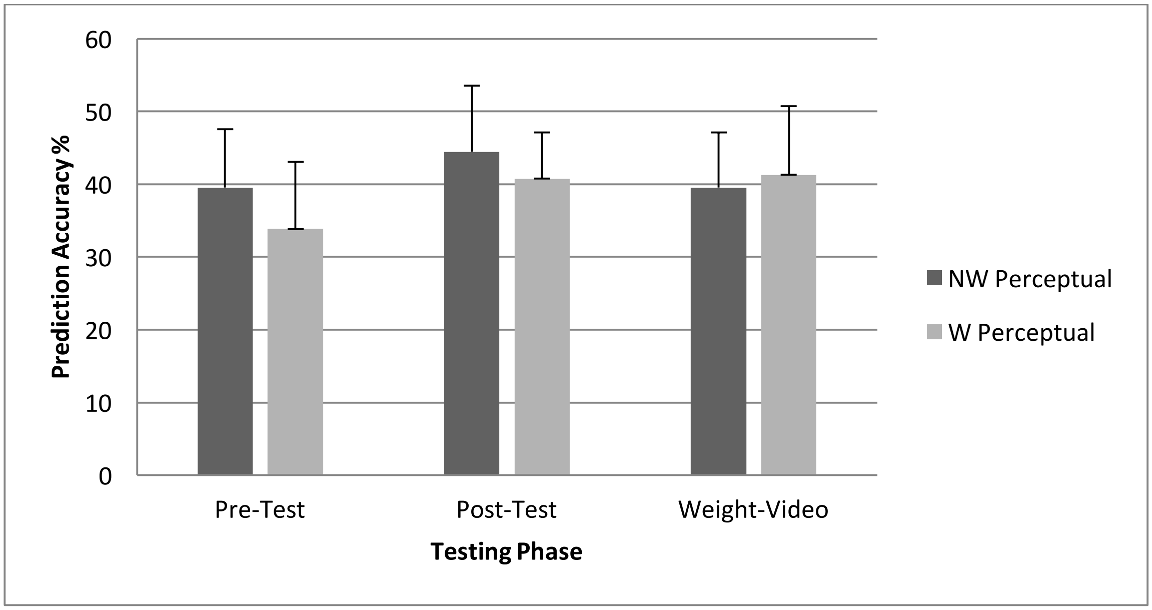

Figure 16. Prediction accuracy percentage data from the weighted condition as a function of perceptual group and testing phase. Error-bars show between-subject SDs.

B.3 Force Condition: Separate Analysis of Physical and Perceptual Practice Groups

Physical Practice, No-Weight and Weighted Groups: Despite our prediction that there would be no improvement, both the no-weight and weighted, physical practice groups showed an improvement in prediction accuracy after practice in the force task (Figure 17), which was close to significant, $F(1,10) = 4.04$, $p = 0.07$, $\eta_p^2 = 0.29$. There was no group-related differences ($Fs < 1$). From the post-test to weight-videos, both groups showed a decrease in prediction accuracy. This was supported by a near significant main effect of Test, $F(1,10) = 2.73$, $p = 0.13$, $\eta_p^2 = 0.21$. There was no interaction ($F < 1$) and there were no between-group differences ($F < 1$).

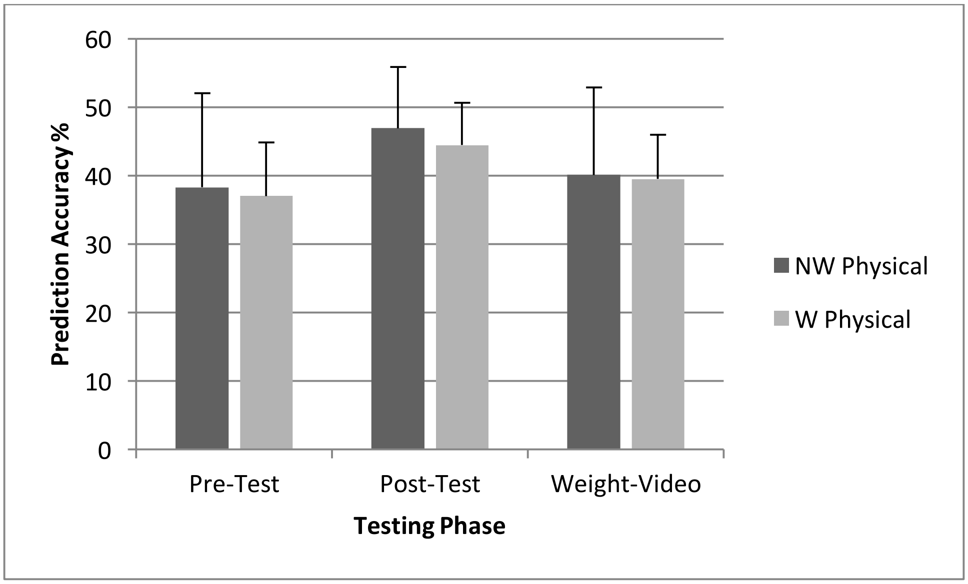

Figure 17. Prediction accuracy percentage data for the physical practice groups from the force condition as a function of group (weight/no weight) and testing phase. Error-bars show between-subject SDs.

Perceptual Practice, No-Weight and Weighted Groups: We did not expect interference from the force task in the perceptual practice groups (Figure 18). In support, there was an improvement in prediction accuracy from pre- to post-test; main effect of Test, $F(1,14) = 17.23$, $p < 0.001$, $\eta_p^2 = 0.55$. There was no Test X Weight Practice group interaction, $F(1,14) = 2.13$, $p = 0.17$, $\eta_p^2 = 0.13$. There were also no between-group differences ($F < 1$). From post-test to weight-videos, there is a trend for a main effect of Test, $F(1,14) = 3.29$, $p = 0.09$, $\eta_p^2 = 0.19$, and a trend for a Test X Weight Practice group interaction, $F(1,14) = 3.29$, $p = 0.09$, $\eta_p^2 = 0.19$, both of which just failed to reach the standard level of significance. There were no between-group differences ($F < 1$).

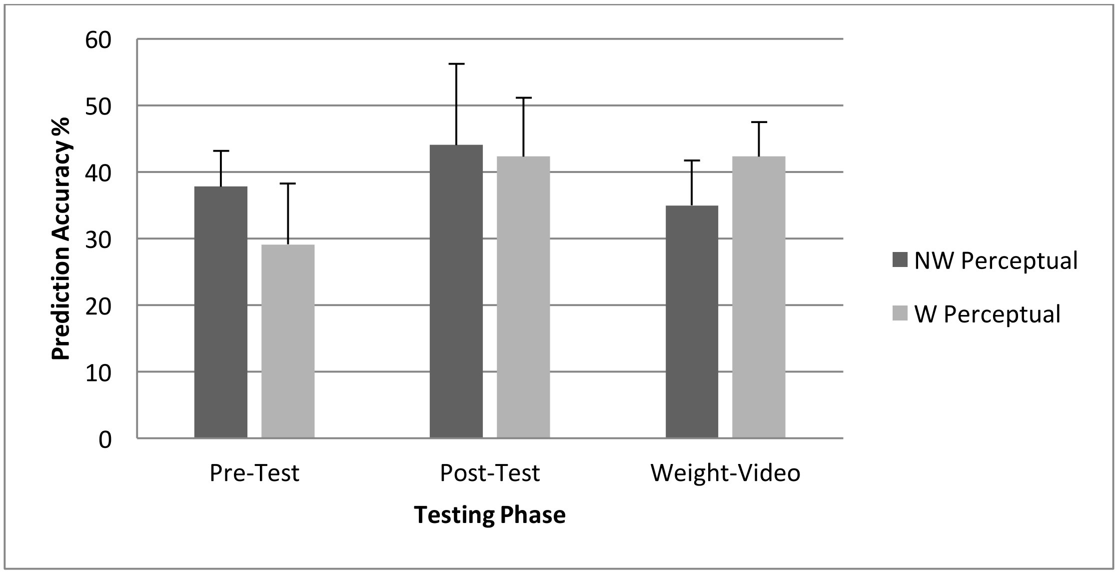

Figure 18. Prediction accuracy percentage data from the force condition as a function of perceptual group and testing phase. Error-bars show between-subject SDs.sw