LEARNING AFFRODANCES FOR MAXIMUM DISTANCE THROWS IN THE CONTEXT OF LEARNING TO THROW

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Submitted to the faculty of the University Graduate School in partial fulfillment
of the requirements
for the degree of
Doctor of Philosophy
in the School of Health, Physical Education, and Recreation
Indiana University
May, 2008

Accepted by the Graduate Faculty, Indiana University, in partial fulfillment of the requirements for the degree of Doctor of Philosophy

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Date of Oral Examination – March 28th, 2008

ACKNOWLEDGMENTS

I have been looking forward to this moment to write this part for many years. Truly, nothing could be accomplished without so many wonderful people in my life. As I am running across the finish line of my graduate career, I feel very grateful to those wonderful people who have been with me since the very start of this run.

Thanks are first extended to my family: my wife (Rui-Lin Chen), my parents (Yu-Fen Wang, Shao-Rong Zhu), my parents in-law (Xiu-Lian Liao, Xian-Hua Chen), and my aged grandfather (Zhao-Yuan Zhu) and grandmother (Mei-Ying Yang) as well. No matter where I am, home or far away, you have been always supportive to every decision I made and every step I took. Special thanks to my wife, you have not only taken care of me during my effort of working or study, but also helped me with recruiting participants and collecting data for this research project. The project was not possible to be completed without your assistance! I love you all, and I am writing this because of you!

I also want to express sincere appreciation to my research committee members: Dr. David M. Koceja and Dr. John S. Raglin for their scholarly advice and insightful comments to this research project. In addition, special thanks to Dr. Jesus Dapena for his offering of expertise and technical support to motion analysis of throwing, and Dr. Jerome R. Busemeyer for his valuable inputs to the theory of function learning. The project would not have gone successful without all of you!

Last but not least, tremendous thanks to my advisors: Dr. Geoffrey P. Bingham and Dr. John B. Shea. Both of you have been great friends and mentors for my entire time here at

IU. Geoff, you have been a great mentor to my research interest in the field of perception and action. You taught me not only the scientific thinking to the research questions, but also as a scientist how to tackle these questions in a scientific way. John, you have been a great mentor to my knowledge of the scholarship in kinesiology. You taught me that the research of motor behavior should be interdisciplinary, entailing both a broad knowledge of own field and a good collaboration with people in other fields. Your opinions have been always insightful. I feel lucky to have both of you, and I couldn’t ask for more!

ABSTRACT

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LEARNING AFFORDANCES FOR MAXIMUM DISTANCE THROWS IN THE CONTEXT OF LEARNING TO THROW

By hefting objects in the hand, people are able to judge the object affordance (the optimally weighted object at a given graspable size) for maximum distance throws (Bingham at al., 1989; Zhu & Bingham, in press). This affordance corresponds to a relation between object size and weight and distances of throws, that is, a single valued function (disance) in two variables (size and weight). The present study first explored whether this affordance could be learned with the acquisition of throwing skill, and second attempted to identify whether the acquisition of this affordance is a type of function learning (Busemeyer & McDaniel, 1997) or the acquisition of a smart perceptual mechanism (Bingham, et al., 1989). 24 unskilled adult throwers were asked to heft 48 objects of different sizes and weights, and to judge their affordances for the maximum distance throws. A month long intensive practice of throwing was then administered, for which participants were divided into 4 groups so that 3 groups practiced throwing with vision using 3 prescribed sets of 6 objects each (constant size, constant weight or constant density) but the 4th group without vision using the set in constant density. After practice, hefting judgments, throwing and then hefting judgments again were tested with the full set of 48 objects. The results showed that participants, were unable to perceive the affordance before practice, however, as throwing skill was acquired through practice and the visual perception of throwing distance was provided, their sensitivity to the affordance improved independently of the prescribed set of objects, and finally, accurate perception of the affordance was acquired. Study also confirmed that only object weight affected the dynamics of throwing to determine the release velocity although the throwing distance was determined jointly by object size and weight. The results indicated that the affordance was perceived using a smart perceptual mechanism that was also acquired as participants learned to throw.

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CHAPTER 1

General Introduction

Homo sapiens are unique in their ability to throw objects to significant distances (Young, 2003)[1]. This ability is known to have been of central importance to the evolution and survival of the species through the ice ages to the current time (Bingham, 1999; Darlington, 1975; Isaac, 1987; Young, 2003). Human throwing ability is also unique in the relative complexity of the action and in the exquisite relative timing that is required (Hore, Ritchie, & Watts, 1999; Hore, Watts, Martin & Miller, 1995; Joris, van Muyen, van Ingen Schenau & Kemper, 1985). The energy of a throw is developed in the slower motions of the more massive trunk of the body and then, is passed sequentially to less massful limb segments that move at proportionally faster speeds (e.g. Joris, et al., 1985) yielding finally high peak speed of the hand at the precisely timed moment of release (Hore, et al, 1995; 1999). Specific brain structure, and in particular, the cerebellar structure and organization, is known to be required for such precise relative timing of movements (Ivry, 1997; McNaughton, Timmann, Watts & Hore, 2004). It has been hypothesized that the evolution of much of this brain structure and organization was specifically to support this adaptively advantageous behavior (Calvin, 1982; 1983a & b; Stout & Chaminade, 2006; Stout, Toth & Schick, 2007; Weaver, 2007). Recently, it has been found that increases in brain size exhibited by homo sapiens compared to earlier species entailed increases in cerebellum size specifically, and furthermore, that the difference between homo sapiens and Neanderthal was that, while Neanderthal actually had a larger brain than homo sapiens, the cerebellum

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[1] Monkeys and primates are able to throw accurately to hit targets at short distances (≈1m), but only humans are able to throw to long distances (>30m) (Westergaard, Liv, Haynie, & Suomi, 2000; Westergaard & Suomi, 1994).

was smaller ! (Stout & Chaminade, 2006; Stout, Toth & Schick, 2007; Weaver, 2007). The inference is that homo sapiens won out because they are better at throwing.

As the research reported in this dissertation shows, human throwing ability is accompanied by the ability to perceive the affordance of objects for throwing and in particular, for maximum distance throwing. This affordance and its perception are particularly interesting and important for reasons beyond the relevance to human evolution. As we show, the affordance consists of a continuous functional relation between object size and weight. This relation determines objects that can be thrown to a maximum distance: for any given graspable size, there is a weight that yields maximum distance throws. This affordance is unique among affordance properties studied to date for two reasons. First, it is intrinsically dynamic, both because it is mass related and because it entails the dynamics of throwing and of projectile motion. Second, the affordance is more complex than any studied to date. It entails a continuous single valued function of two variables: maximum thrown distance is a function of both object size and weight.

This functional relation is peculiar because it happens to be the same as that corresponding to the classic size-weight illusion (Bingham, Schmidt & Rosenblum, 1989). This illusion has attracted much attention because it is among the most salient and robust in the literature of perceptual illusions. The illusion is a misperception of weight. Given two objects of different size, the larger object must weigh more to be perceived of equal weight to the smaller object. The function corresponding to equal perceived heaviness of different sized objects also describes the optimal weights and sizes for maximum distance throwing. But in the latter case, the affordance property is correctly and accurately perceived. Both the robustness of the illusion and the accuracy of the affordance perception suggest that these related phenomena provide a window on a fundamental human perceptual capability.

The complexity of the functional relation corresponding to the affordance is challenging because the perception of the affordance must be learned. Although, only humans can really throw, not all humans can throw. Throwing is a skill that is learned and so presumably is accompanying affordance. Function learning is an active area of research in psychology (McDaniel & Busmeyer, 2005; DeLosh, Buyemeyer & McDaniel, 1997), but research efforts have mainly thus far addressed functions that map a single variable to another. The learning of a functional relation that maps two variables to a third is an especial challenge in the understanding of function learning.

The original investigation of this affordance by Bingham et al. (1989) was inspired by a common childhood game played at the beach. The game is to throw stones to see who can achieve the farthest distance out on the water. Part of the game is to select among stones on the beach those that are optimal for being thrown to a maximum distance. Assuming a roughly spherical shape, stones are selected depending on their relative size and weight. Stones usually exhibit nearly constant density, so size and weight covary. This means the problem can be solved by merely picking the best graspable weight. According to Bingham et al.'s smart mechanism hypothesis, this experience would be enough for throwers subsequently to be able to pick the optimal weight for any size object. Otherwise, experience of throwing with more extensive variations of sizes and weights should be required to learn to perceive the affordance.

The affordance involves object weight. Weight is a mass dimensioned dynamic property. The majority of affordance studies have investigated the use of vision to perceive affordances (e.g. Bingham & Muchisky, 1993a; 1993b; 1993c; Marks, 1987; 1990; Warren, 1984; Warren & Wang, 1987), for instance, the visual perception of maximum seat height (Marks, 1990), of the maximum passable aperture (Warren & Wang, 1987), or of maximum climbable stair height (Warren, 1984). Exceptions are studies of dynamic touch (Turvey, 1996) where, for instance, observers have been shown to be able to perceive, by wielding (without vision), the distance reachable by a hand held rod. Nevertheless, all these affordance properties are essentially geometric. Stair height, seat height, aperture width and rod length are all length dimensioned properties. The perception by hefting of optimal throwing objects is different from these previously studied affordance properties because optimal throwability is inherently dynamic[2].

The optimality of throwing objects is determined by the dynamics of throwing and the dynamics of projectile motion. Thus, these dynamics must be confronted to understand the affordance. The variables that determine the distance of travel in the dynamics of projectile motion are size (that is, cross sectional area) and weight of the projectile as well as the initial speed and angle at release (Parker, 1977). However, given a particular release angle and velocity for an object of a given size, variation of the weight does not yield an optimum distance from projectile motion dynamics. The distance of travel only increases with increase of weight. It does not decrease. So, the determination of a weight for a given size that yields a maximum throwing distance necessarily entails the dynamics of throwing.

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[2] Strictly speaking, dynamics is relevant to all of these affordances. The dynamics of walking is relevant to the size of passable apertures as is the dynamics of stair climbing to the size of the maximum climbable stair. Nevertheless, geometric properties were featured in the respective studies because they capture most of the variance. In the context of throwing, the dynamics must be addressed to formulate any understanding of the problem.

Bingham et al. (1989) reviewed studies of the dynamics of throwing and found that throwing has two essential aspects. First, as already mentioned, energy is developed starting with more massful proximal body segments and then is passed in sequence from one segment to the next proceeding distally from the trunk to the hand. Second, during the final stage of a throw (that is, the last ≈ 100ms), the object actually stops moving for an instant as the wrist is cocked injecting energy into the long tendons of the wrist by stretching them. This allows those tendons to amplify the energy by returning it at higher shortening velocity as the elbow and wrist extend and flex respectively to launch the object. Bingham et al. hypothesized that larger objects affected throwing by changing the length, and thus the stiffness, of the wrist tendons. The reason is that the same tendons contribute to the control of finger flexion in grasping and wrist flexion in throwing. Grasping larger objects shortens the tendons at the wrist yielding stiffer tendons (because of their curvilinear length-tension relation). Bingham et al. (1989) performed an experiment to measure the effect of grasped object size on stiffness at the wrist and found increases in stiffness with increasing object size as expected. Accordingly, they hypothesized that greater mass is required for larger objects both to preserve the frequency of the motion and to load the spring so as to yield high shortening velocity. The frequency of motion at the wrist would be preserved to preserve the relative time among the joints (shoulder, elbow and wrist).

If optimal throwability is determined by the dynamics of throwing, how can hefting provide information about this affordance, that is, how can hefting provide information about an object's effect on throwing? One obvious hypothesis would be that past experience of throwing yields knowledge of the functional relation between object size and weight that yields maximum distance throws. Each time an object is thrown with a maximum effort, the distance of travel is noted (that is, knowledge of results or KR) and stored in memory together with the object size and weight. Eventually, after experience of sufficient variation in sizes and weights, this information is used to induce the function specifying optimal objects (McDaniel & Busmeyer, 2005; DeLosh, Buyemeyer & McDaniel, 1997). Because a different weight is optimal for each size, this function learning approach would require that the full range of throwable sizes and weights is each sampled adequately and independently. That is, optimal weights would have to be discovered for multiple sizes to induce the full functional relation.

There are two related problems with this idea. First, this entails the assumption that distances of throws can be accurately perceived and compared across occasions occurring in different environments and separated by significant amounts of time. Studies of distance perception have shown that absolute distances in the relevant range (up to 35 or 40 meters) are not perceived accurately (Todd et al., 1995). Distances are even less accurately compared when perceived over ground surfaces composed of different textures, that is, throws performed over water versus a grass covered field versus a sand or gravel covered beach (Hu et al., 2002). This need to compare across occasions in different environments at widely different times is introduced by a second assumption, already mentioned, which is that one would require experience of throwing a variety of different weights in each of different sizes. The size and weight would have to vary independently in throwing experience so that the optimal weight could be discovered in given sizes. The problem is that size and weight would covary in most contexts, for instance, heavier stones on the beach are simply the bigger ones. The same is true of apples in an orchard or wooden sticks in a forest or wads of paper in a classroom or rubber balls on a playground. Rarely, would objects of different materials but similar size be encountered on a single occasion in a given context. Rather, baseball sized stones would be encountered on the beach while baseball sized apples would be encountered in an orchard and actual baseballs on the playing field. So, throws with objects of common size but different weight would typically be compared across occasions occurring in different environments at distant times. Given these two connected problems, what is the likelihood that optimal weights in arbitrary sizes could be discovered through experience? Where would one get the experience that would allow one to pick the optimal weights for balls across the full range of graspable ball sizes?

A second hypothesis as to how hefting can provide information about optimal objects for throwing is that hefting acts as a kind of smart perceptual mechanism (Runeson, 1977; Bingham, et al., 1989). Runeson (1977) suggested that perception might be smart by taking advantage of particular circumstances in a task that simplify the perceptual problems. Bingham, et al.'s application of the smart mechanism idea was that the dynamics of hefting should be similar to the dynamics of throwing. This would be the "smartness" that would allow hefting to provide a window on the effect of object size and weight on throwing. Bingham et al. (1989) suggested that hefting would allow participants to detect the effect of object size on wrist stiffness and to find the optimal weight given that stiffness. The role of past experience in this case would be to enable throwers (1) to develop good throwing skills and (2) to develop good sensitivity to the information provided by hefting about throwing. Specific experience of a variety of weights in each of a number of different sizes would not be required as it would to learn the affordance using function learning through KR. Rather, acquiring the smart mechanism would only require that one become sensitive to the information provided by the smart mechanism. This, in turn, should only require experience of different weights in a single size or, more likely in natural settings, experience of a single constant density series of objects of co-varying sizes and weights. Once, one learns to pick the optimal stone on the beach, for instance, one should be able to pick the optimal weight for objects of any given size (and density) within the throwable range.

The smart mechanism hypothesis entails two assumptions as well. The first assumption is that hefting by hand would be required to provide specific information about throwing using the hand. The dynamics of throwing by hand is specific to the structure of the arm and hand. Seeing the object size and feeling the weight using the elbow or the foot would not be sufficient for predicting the hand throwing performance according to the smart mechanism hypothesis. The specific dynamics of hefting by hand would be required because it is similar to the dynamics of throwing by hand. The second assumption is that the optimal objects are uniquely determined by the dynamics of throwing, and not that of projectile motion. Thus, the effects of object size and weight on the dynamics of hefting must be similar to that on the dynamics of throwing, which induce the optimality of throwing objects. Zhu & Bingham (in press) had recently tested these two assumptions. In their first three experiments, skilled throwers were asked to heft objects and judge the optimality for throwing using either hand or foot. Distances of throws made by either hand or foot were measured afterwards. The results showed that the judgments made by hand were more consistent and accurate than those made by elbow or foot, which supported the first assumption suggesting that the perception of the affordance entailed using the skilled throwing limb. However, in their following experiment where projectile motion was simulated using object size, weight and the measured throwing distances, they found that the release velocity was as a function of only object weight, and the simulated throwing distances using the weight-determined velocities accounted for over 80% of the variance in the actual measured distances. This finding undermined the second assumption of smart mechanism hypothesis, suggesting that the optimal objects were determined by dynamics of both throwing and projectile motion. While object size and weight both affected the dynamics of projectile motion, only object weight affected the dynamics of throwing. The contradictory results from this study suggest that the smart mechanism hypothesis needs to be re-evaluated and probably to be evaluated in comparison with the alternative, namely, the function learning hypothesis.

The current study was completed with efforts to unveil the perception of the affordance for throwing. First, we wanted to examine whether the ability to perceive the affordance for throwing could be acquired with learning to throw. We recruited 24 unskilled throwers and tested their ability to judge among 48 objects the optimally weighted objects for maximum distance throws before, during and after their acquisition of throwing skill. Previous studies have shown that normal skilled throwers were sensitive to the affordance for throwing when hefting using the skilled throwing limb (Zhu & Bingham, in press). It remains unclear whether unskilled throwers are also sensitive to this affordance. Theories of both perceptual learning and function learning suggest that past experience plays important role in shaping people's perception to the world although the emphasis of each is different. While the perceptual learning theory welcomes the exploratory movement to discover and differentiate the invariant information between the environment and the perceiver (Stoffregen, 2005; Goldstone, 1998; E.J. Gibson, 2000), the function learning theory requires sampling sufficient input variables with knowledge of results to yield the accurate prediction to the outcome variable (DeLosh, Buyemeyer & McDaniel, 1997). Obviously, unskilled throws are lack of experience in throwing. Neither they have been involved with throwing activities, nor have they been engaged in exploring the relation between the throwing object and the throwing distance. Therefore, we expected their perception of the affordance for throwing would be as poor as their throwing performance. However, with practice of throwing, we expected their ability to perceive the affordance should be improved, because during learning to throw, throwers are usually encouraged not only to explore the objects by touching, grasping, hefting, wielding and throwing, but also to seek the efficient way to throw objects of different sizes and weights to the maximum distance which allows the functional relation between the throwing object and the throwing distance to be discovered.

More importantly, we wanted to investigate how the affordance might be perceived. The hypothesis we investigated is directly relevant to the means by which people might learn to perceive the affordance for throwing, specifically, whether the affordance was perceived using a smart perceptual mechanism or through function learning. Although both hypotheses suggest that the perception of the affordance for throwing strongly relies on the throwing experience, the roles of throwing experience are different. According to the hypothesis of smart perceptual mechanism, throwing experience allows throwers to extract the most relevant information between the throwing distance and the to-be-thrown object via the exploratory motions such as hefting and throwing, but once the information is acquired, the perceptual system needs no more exploration to detect the affordance. However, in accordance with the hypothesis of function learning, the extensive experience of throwing objects of different sizes and weights is needed to discover the functional relation between the throwing distance and object size and weight. The more sizes and weights are sampled, the better learning of the function. When the complete function is learned, the perceptual system is able to perceive the affordance in the manner of predicting the throwing distance by looking up the table value for both size and weight. We manipulated the throwing experience by constraining the throwing object properties (size and weight). 3 subsets of 6 objects each within the complete set of 48 objects was constructed so that one set of objects has constant size but variation of weight, the other set has constant weight but variation of size and the last set has constant density with variation of both size and weight. By asking participants to practice throwing with these constrained sets of objects, we were interested whether the perception of the affordance after practice would be acquired and if so whether there would be any difference. If the affordance was learned through function learning, we expected no acquisition of the affordance perception for all participants, because no practice condition allowed fully sampling of object size and weight to yield learning about the complete function with respect to the throwing distance. However, if the affordance was perceived using a smart perceptual mechanism, we expected the acquisition of the affordance perception for all participants given the throwing skill was acquired.

We were also interested in the potential role of knowledge of result (in the form of visual feedback) in the acquisition of both throwing skill and the ability to perceive the affordance. Although vision did not seem to be essential to the perception of the affordance, there is evidence showing that vision plays an important role in control of throwing motion (Lenoir, 2005; Krishnamoorthy et al, 2005; Collins & De Luca, 1995). Since we hypothesized that the affordance for throwing could be acquired with learning to throw, we wondered whether vision would affect acquisition of the throwing skill to affect the acquisition of the affordance. Presumably, vision provides visual feedback about throwing distance in the task of learning to throw. If the affordance for throwing was acquired through function learning, visual feedback about the outcome variable would be indispensible for learning the functional relation between the predicting variable (throwing distance) and the input variables (size and weight of the thrown object). Accordingly, we created an additional group of participants who were asked to practice throwing using the constant density objects without vision.

Finally, the understanding of the perception of the affordance for throwing entails identifying the roles of object size and weight in dynamics of hefting, throwing and projectile motion. The effects of object size and weight have been found in hefting (Bingham et al., 1989) and projectile motion (Parker, 1977), however, their respective roles in the dynamics of throwing has not yet been identified. Zhu and Bingham (in press) has proposed that only object weight affected the release velocity to determine the dynamics of throwing, however, the release angles and release velocities were not directly measured for each throw. The current study used 2-D motion analysis technique to directly measure the kinematics of throwing with the acquisition of throwing skill, trying to first track the kinematic changes occurred with learning to throw, and second identify the respective role of object size and weight in the kinematics of throwing.

The ultimate goal of the current study is to understand the perceptual mechanism underlying the ability to perceive the affordance for maximum distance throws, and how this perceptual ability develops with the ability to perform the throwing task. We hope our findings could contribute to the filed of affordances perception and inspire the future studies.

CHAPTER 2

Learning to Perceive Affordances for Maximum Distance Throwing with Acquisition of Throw Skill

Abstract

People have been shown to be sensitive to affordances that are based on geometric relationships between properties of the environment and the actor such as graspability, climbability and passability (Warren, 1984; Hallford, 1983; Warren & Whang, 1987). Zhu & Bingham (in press) recently found that people are also sensitive to affordances that depend on dynamic properties, namely, the throwability of the object. We now explore the possibility that the perception of this affordance is learned with the acquisition of throwing skill. 24 unskilled adult throwers were asked to heft 48 objects of different sizes and weights and judge the optimal object for throwing to a maximum distance. A month long intensive practice of throwing was then administered. To test whether the affordance was acquired through function learning or using a smart perceptual mechanism, participants were divided into 4 groups so that 3 groups practiced throwing with vision using 3 different sets of 6 objects each (constant size, constant weight or constant density) and the 4th group practiced throwing using objects of constant density but without vision. After practice, hefting judgments, throwing and then hefting judgments again were tested with the full set of 48 objects. The results showed that participants were unable to detect the throwability of objects before practice, however, as throwing skill was acquired and visual feedback about throwing distance was available, their sensitivity to the optimally throwable objects improved independently of the prescribed set of objects, and finally, accurate perception of the affordance was acquired. The results indicated that the affordance is perceived using a smart perceptual mechanism that was also acquired as participants learned to throw.

Introduction

A common scenario at the beach is that children compete in throwing to see who can throw stones to the farthest distance out on the water. Part of the game is to select the optimal stone for throwing to a maximum distance. Assuming a roughly spherical shape, stones are selected depending on their relative size and weight. Do objects actually exhibit such an affordance for throwing? If so, are people actually able to perceive this affordance property, that is, the optimal object for throwing to a maximum distance?

Affordances are dispositional properties of the environment that support potential actions for an animal (Gibson, 1979/1986). Extensive studies have attempted to reveal how affordances are perceived and used in the animal-environment system. To date, studies have shown that affordances can be perceived using information that scales environmental properties with respect to the human body. Scaling can entail a geometric relationship between the environment and the actor. For instance, optically scaled stairs are determined by the size of stair risers in comparison to the leg length of stair climbers (Warren, 1984), and the graspability of an object is determined in large part by the size of the object relative to the size of the grasper's hand (Hallford, 1984). Scaling also can be dynamic, which entails dynamic properties of the environment-actor system to be specified by kinematic or optical flow patterns (Bingham, 1987). Studies of tool use, for example, have found that the suitability of a stick for hammering or poking could be determined when the dynamic invariant (rotational inertia) was specified in wielding motion (Wagman & Carello, 2001). Similarly, the catchableness of a fly ball can be well judged when the kinematics of the fly ball (spatial position over time) is specified in the optical structure from the action initiated by moving catchers (Oudejans et al.,1996).

The affordance property of our current interest is the affordance for maximum distance throwing, that is an optimal weighted object at a given graspable size that can be thrown to the farthest distance. This affordance property is notable among others to date (e.g. Bingham & Muchisky, 1993a; 1993b; 1993c; Mark, 1987, 1990; Turvey, 1996; Hove, 2006) for two reasons. First, it is intrinsically dynamic, both because it is about a dynamic rather than geometric property (namely, object mass) and it entails the dynamics of both throwing and projectile motion. Second, this affordance is more complex than any affordance studied to date. It entails a continuous single valued function of two variables: maximum thrown distance is a function of both object size and weight. Bingham et al. (1989) initiated the study of this affordance by asking participants to heft to select the optimal weighted object at a given size for maximum distance throwing. The results showed that people were quite sensitive to this affordance, and the selected objects by hefting did achieve the maximum throwing distances in throwing.

Is the ability to perceive the affordance for throwing acquired or intrinsic? The possibility is that it is acquired through learning to throw. Throwing is a unique skill that developed in human evolution (Bingham, 1999). The ability to throw objects to significant distances is known to be of central importance to the evolution and survival of the species through the ice ages to the current time, and distinguished human from other species (Calvin, 1982; Darlington, 1975; Isaac, 1987; Young, 2003; Westergaard et al., 2000). Studies have shown that throwing is relatively complex and requires extremely precise relative timing among joints of the throwing arm (Hore, Watts, Martin & Miller, 1995; Hore, Ritchie & Watts, 1999). Specific brain structure, and in particular, the cerebellar structure and organization is known to be required for such precise relative timing of movements (Ivry, 1997; McNaughton et al., 2004). Recently, it has been claimed that increases in brain size exhibited by homo sapiens compared to earlier species entailed increases in cerebellum size specifically, and the difference between homo sapiens and Neanderthal was that, while the latter had a larger brain than the former, the former's cerebellum was actually larger (Stout & Chaminade, 2006; Stout, Toth & Schick, 2007; Weaver, 2007). The indication is that homo sapiens won out because they are better at throwing. In this context, throwing seems to be intrinsic to modern humans. Most healthy people can throw and they start throwing from very early ages (Langendorfer & Roberton, 2002). The human body is structured well for throwing thanks to the anatomy of the throwing arm (Perry, 1983). However, not everyone can throw well, and people vary in their abilities to throw an object to a long distance. Studies in sports have shown that practice of throwing can yield consistent increases of throwing distance (Brose & Hanson, 1967; Zatsiorsky & Kraemer, 2006). Thus, the long distance throw has to be learned. Considering the ability to perform a long distance throw is acquired, we hypothesized that the ability to perceive the affordance for throwing should be acquired through learning to throw. Recently, Zhu & Bingham (in press) found that perceivers with a good amount of throwing experience were accurate in perceiving the affordance, but only when hefting objects using the skilled throwing limb, suggesting that the perception of the affordance for throwing might require the perceiver to possess throwing skill. To test the possibility that the affordance is acquired through learning to throw, the current study examined and monitored the perception of the affordance in the context of training unskilled throwers to acquire the skill for the maximum distance throwing.

The understanding of the affordance for throwing also entails identifying the perceptual information responsible for detecting the affordance. Bingham et al. (1989) proposed that this affordance was perceived via a smart perceptual mechanism. According to Runeson (1977), perception might be smart by taking advantage of particular circumstances in a task that simplify the perceptual problems. The application of this idea in perceiving the affordance for throwing is that hefting acts as a kind of smart perceptual mechanism to provide a window on the effect of object size and weight on throwing. The “smartness” entails two assumptions. First, the dynamics of hefting should be similar to the dynamics of throwing so that object size and weight would yield the same effects on both motions. Bingham et al. (1989) reviewed the dynamics of throwing and found that throwing entailed transfer of high energy from the trunk to the hand via the long tendons of the wrist, which were also used in the control of finger flexion during hefting. Hence, hefting motions involving the tendons at the wrist might provide perceptual information about throwing. They then performed an experiment to measure the effect of grasped object size on stiffness at the wrist and found increases in stiffness with increasing object size as expected. Accordingly, they hypothesized that greater mass was required for larger objects to preserve the frequency of the motion at the wrist to preserve the relative timing among the joints (shoulder, elbow and wrist) when throwing. Since objects selected by hefting increased in mass as size increased, hefting seemed to have provided kinematic information about the objects in the context of throwing. The second assumption that the “smartness” entails is that hefting by hand would provide specific information about throwing using the hand. Seeing the object size and perceiving the weight using other limbs or unskilled limbs would not be sufficient for predicting the overhand throwing performance. This assumption was recently tested by Zhu and Bingham (in press). In their experiments, participants were asked to judge the optimal weight for throwing by hefting using a limb different from the hand (elbow or foot). First, participants were asked to heft to judge for overhand throwing using either their elbow or foot. The results showed that significantly heavier weights were selected, and the selections were quite variable compared to those generated using the hand. Next, participants judged for foot throwing when hefting using their foot and their foot throwing distances were measured as well. The results showed that the foot throwing distances were much shorter than that of hand throwing, and the judgments using the foot were more variable and inaccurate compared to those generated using the hand. In fact, the judgments were not found to differ significantly from completely random selections. These results added to the previous findings suggesting that the ability to perceive optimal objects for throwing correctly was strongly dependent on the specific skill developed in use of the throwing device (throwing hand and arm). Hefting using a skilled throwing limb would provide better perceptual access to the throwability of objects.

However, the smart perceptual mechanism hypothesis was also recently challenged by Zhu and Bingham (in press). They investigated the affordance for throwing in the context of the dynamics of throwing and the dynamics of projectile motion. One can not ignore the effect of object size and weight on projectile motion in determining the projectile distance. If hefting serves as a smart perceptual device to provide information about throwing, object size and weight must affect the dynamics of hefting in a way similar to the effect on the dynamics of throwing. By testing skilled throwers and performing simulations of projectile motion, Zhu and Bingham found that release angles did not vary with either the weight or size of the objects being thrown, however, the release velocity, a critical variable that links the dynamics of throwing with projectile motion, significantly changed with object weight but not with object size. The functional relationship between the release velocity and object weight was then discovered and used to predict throwing distances. The simulated distances accounted for over 80% of the variance in the actual measured distances, indicating that object size and weight did not equally affect the dynamics of throwing and projectile motion: while object weight played an important role in both dynamics (to determine both release velocity and throwing distance), object size only played a role in the dynamics of projectile motion to affect the air resistance. Thus, the particular smart perceptual mechanism hypothesis proposed by Bingham et al (1989) was undermined.

Based on the functional relation between throwing distance and both object size and weight, Zhu and Bingham (in press) hypothesized that the affordance could alternatively be perceived through learning a single valued function (throwing distance) of two variables (object size and weight). Function learning is an active research area in psychology (McDaniel & Busemeyer, 2005; DeLosh, Busemeyer & McDaniel, 1997), according to which, people can learn a function by sampling inputs repetitively within a certain stimulus range when knowledge of results (KR) is given, and once the function is learned, people are able to predict the outcome of a given input that falls either within (Interpolation) or beyond (Extrapolation) the range of experienced stimuli. In this view, perception of the affordance would resemble the prediction of throwing distance based on the inputs of object size and weight according to the functional relation between them. The function serves as a kind of lookup table. However, learning this function would not be easy, because it entails learning a curve-linear function based on two independent inputs[3]. Busemeyer et al. (1993) explored the learning of a linear function y (t) based on two stimulus cues, x1(t) and x2(t), that are independent of each other. A cue competition effect was found. That is, learning a cue that is highly correlated with the function will decrease the effectiveness of learning the effect of the other cue on that function. The challenge in learning the affordance for throwing is that throwing distance is as a curve-linear function of both object size and weight, where object size and weight could vary either together or independently with the potential competition effect on throwing distance.

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[3] Zhu & Bingham (in press) found that throwing distance as a function of object size and weight displayed an inverted-U shape, and object size and weight independently determined throwing distance, thus, the function of throwing distance is curve-linear, in which the input variables, object size and weight, are independent of each other.

Consequently, learning this function is harder and requires an independent and adequate sampling of both input variables. In addition, learning the function to perceive the affordance would entail generally the distances of throws to be accurately perceived and compared across occasions occurring in different environments or separated by significant amounts of time. Studies of distance perception have shown that absolute distances in the relevant range (up to 35 or 40 meters) are not perceived accurately (Todd et al., 1995). Distances are even less accurately compared when perceived over ground surfaces composed of different textures, that is, throws performed over water versus a grass covered field versus a sand or gravel covered beach (Hu et al, 2002). With these challenges, it seems unlikely that optimal weights in arbitrary sizes could be discovered through experience. Nevertheless, we will investigate this possibility by manipulating object size and weight so that the function could be explored either by sampling weight variation in a given size or by sampling the size variation at a given weight level, or by sampling the simultaneous co-variation of size and weight.

Vision does not seem to be essential to the task of perceiving the affordance for throwing. People can perform hefting and throwing without seeing the object, and they can perceive the affordance for throwing well in this way. However, skilled throwing is associated with better control of throwing motion, and vision has been found to be important for this movement control. Lenoir (2005) found that providing the full and peripheral vision facilitated the control of trunk rotation in discus throwing. The advantage of having vision in motor control was considered to be relevant to maintaining of an arbitrary posture in a stable state so that the joint configuration variability during movement can be reduced (Krishnamoorthy et al, 2005; Collins & De Luca, 1995). According to our hypothesis, the affordance for throwing is acquired by learning to throw. So, if vision affects throwing performance while learning to throw, it could potentially affect the acquisition of the affordance for throwing too. In addition, the acquisition of the affordance might involve seeing the maximum throwing distance of a given object. Vision potentially provides knowledge of results about maximum throwing distance, and hence might be necessary for the acquisition of this perception. Especially, if the affordance is acquired through function learning, visual knowledge of results about throwing distance would be critical because it allows continuous mapping between the cues (object size and weight) and the criterion to be known (throwing distance), which in turn allows the learning of the complete function. Otherwise, if the affordance is acquires through obtaining a smart perceptual mechanism, visual knowledge of results about throwing distance would allow perceivers to tune their perception to those optimal weights that yielded the longest distances. To investigate the potential role of vision in acquisition of the affordance through learning to throw, we created a condition for thrower to practice throwing without vision.

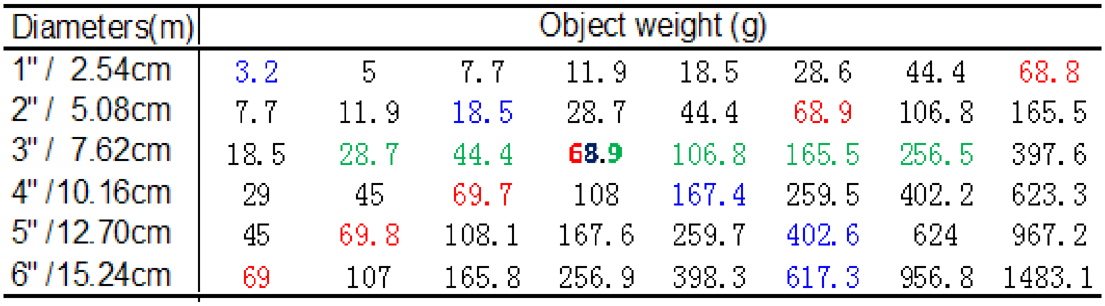
The current study was engaged to tackle three questions: first, whether the acquisition of the affordance for maximum distance throwing was coupled with the acquisition of skill for long distance throwing; second, whether the affordance was perceived via a smart perceptual mechanism or instead involved a lookup table involving a single valued function (throwing distance) of two variables (object size and weight); and third, whether visual perception of throwing is important for acquisition of both throwing skill and the ability to perceive the affordance for throwing. To answer the first question, we recruited and trained unskilled throwers to throw. Perceptual judgments of the optimal object were assessed before and after training. If perceptual judgments became accurate with improved throwing ability after practice, then the affordance must be acquired. To answer the second question, we manipulated the set of practice objects for throwing during training. Three configurations of size and weight were used: a set of objects of constant weight but varying in size; a set of objects of constant size but varying in weight; and a set of objects of constant density with co-variation of size and weight. If perception of the affordance was acquired through function learning, practice with different sets of objects should yield different learning about the function. Specifically, the constant size group should be able to pick the optimal weight in the experienced size, but not in other sizes, in which the optimal weight is different. The constant weight group should not be able to pick the optimal weight in any size, although they should be able to pick the optimal size, and the constant density group should be able to pick the optimal object in the constant density set, but not the optimal weight in any given size. However, if the smart perceptual mechanism hypothesis was correct, using any set of objects for practice would be sufficient to yield a generalized sensitivity to the information that specifies the optimally weighted object at any given size for maximum distance throwing, and presumably, using the constant density set of objects would be more effective because it simulates the way size and weight would vary in natural objects like stones found on a beach. Last, to answer the third question, we manipulated the availability of vision before, during and after practice. Using the same objects, one group of participants was asked to throw objects with vision during and after practice, and the other group to throw without vision during practice but with vision after practice. If visual perception of throwing distance was important for acquisition of both throwing skill and the ability to perceive the affordance, differences of throwing performance and the judgments should be expected between the two groups after practice, and the no-vision group should also throw and judge differently when vision was provided after practice.

Method

Apparatus

48 spherical objects were made with eight weights in each of six sizes. Objects varied in size with diameters as follows: .2.54cm (1”), .5.08cm (2”), 7.62cm (3”), 10.16cm (4”), 12.7cm (5”), 15.24cm (6”). These sizes correspond roughly to a small marble, a golf ball, a baseball, a soft ball, a playground ball, and a water polo ball. Weights in each size varied as a geometric progression: Wn+1 = Wn × 1.55. Eight weights were generated in each of the six sizes starting with the lightest weight that could be constructed in each size. The matrix of object size and weight was constructed so that three subsets of objects were residing in the matrix: a set of six objects at a constant weight of 69g (varying therefore only in size); a set of six objects at a constant density (0.3 g/cm3); and a set of six objects at a constant size of 7.62cm in diameter. For purpose of minimizing the possible function learning, only one object was shared by all three subsets (See Table 1).

TABLE 1: Configurations of Object Size and Weight



Diameters(m)	Object weight (g)							
1" / 2.54cm	3.2	5	7.7	11.9	18.5	28.6	44.4	68.8
2" / 5.08cm	7.7	11.9	18.5	28.7	44.4	68.9	106.8	165.5
3" / 7.62cm	18.5	28.7	44.4	**68.9**	106.8	165.5	256.5	397.6
4" /10.16cm	29	45	69.7	108	167.4	259.5	402.2	623.3
5" /12.70cm	45	69.8	108.1	167.6	259.7	402.6	624	967.2
6" /15.24cm	69	107	165.8	256.9	398.3	617.3	956.8	1483.1

Note: RED denotes Constant Weight subset
GREEN denotes Constant Size subset
BLUE denotes Constant Density subset

Spherical plastic shells in five of the sizes were available commercially. They were designed to float in water to insulate swimming pools. They consisted of a hard, durable hollow plastic shell. We manufactured like balls in the otherwise unavailable 12.7cm size. To do this, a 12.7cm diameter spherical steel mold was cut in half with hinges on each hemisphere for future closure, and then a fiberglass resin composite was put inside of the mold together with a balloon that was inflated to push the resin against the mold which was then heated to form the desired sphere. For some of the heaviest objects at both 2.54cm size and 15.24cm size, we used commercially available solid steel balls instead of plastic shells. Finally, some of the lightest objects were pure Styrofoam, such as the object at 12.7cm size with a weight of 45g and the object at 15.24cm size with a weight of 69g. All objects were tested to be durable enough to withstand impacts from maximum distance throws. The surface of each object was covered with a wrapping of thin, stretchable adhesive tape to produce good graspability and improved durability. To prevent objects from being remembered by participants in the later hefting and throwing task, each object was painted yellow to create identical appearance and surface texture, and then coded with a sign that was only recognizable to experimenters. The yellow look also increased the visibility of the ball in videos taped during throwing sessions.

To manipulate the weights, most of the objects were filled with a sprung brass wire that was injected into the object through a small hole. The wire spontaneously distributed itself homogeneously throughout the available interior perimeter of the shell. After this, foam insulation (a silica gel) was injected through the hole to fill the remaining space and rigidly stabilize the material inside the object. For the extremely heavy weights, lead shot was projected into the sphere together with the foam insulation to mix with the brass wires so as to achieve the desired weights with a homogeneous distribution of the interior mass. For the smallest sizes, layers of duct tape were used to coat the surface of the object so that the desired weights could be achieved.

To measure the throwing distances accurately, we used a measuring tape (100-M long) at distances shorter than ten meters, and a laser rangefinder (Simons Yardage Master 1000) at distances longer than ten meters.

Participants

24 Indiana University undergraduates were recruited for the experiments. They passed a screening session to participate in the experiment (see the screening procedure). Only one participant was male and the rest were all females. Participants were required to be capable of throwing objects and to have had little prior experience or skill at over-arm throwing, to have good (corrected) vision and to be free of motor impairments. They were paid at a rate of $9.00 per hour for participation in the testing of hefting judgment and throwing performance.

Experimental Procedure

Experiments involved assessing hefting judgments and throwing performance before, during and after practice (See Table 2).

TABLE 2: Experimental Testing Schedule

	Throwing Ability Test								10 min
Initial Test	Hefting Test w/ all objects								0.5 hr
	Throwing Test w/ all objects								1 hr
A Month Practice		Monday		Tuesday	Wednesday	Thursday	Friday	Saturday	Test ≈ 2.5 hr (35min X 4 days)
	Week 1	Test w/ subset	Instructional Practice	Rest	Instructional Practice	Rest	Instructional Practice	Rest	
	Week 2	Test w/ subset	Instructional Practice	Rest	Instructional Practice	Rest	Instructional Practice	Rest	
	Week 3	Test w/ subset	Instructional Practice	Rest	Instructional Practice	Rest	Instructional Practice	Rest	Practice = 12 hr (1 hr X 12 days)
	Week 4	Test w/ subset	Instructional Practice	Rest	Instructional Practice	Rest	Instructional Practice	Rest	
Final Test	Hefting Test w/ all objects								Test = 2 hr (0.5hr X 2tests + 1hr)
	Throwing Test w/ all objects								
	Hefting Test w/ all objects								

Screening Participants First, a screening procedure was used to select participants. Potential participants were asked to throw with their dominant hand three tennis balls to a maximum distance in an outdoor field. The mean throwing distance was calculated to determine the eligibility for participation. Only participants who met the criterion of being unskilled throwers were recruited. The criterion was defined as throwing a tennis ball to a distance equal to or less than two standard deviations (6.5m) below the mean of throwing distance (29m) achieved by normally skilled throwers (hence distance $\leqslant$ 16m, according to Zhu and Bingham, in press)[4]. Participants who did not meet the criterion were thanked for their interest and asked to withdraw from the experiment.

Initial Test of Hefting Judgment Subsequently, the recruited participants were tested in the hefting task. The anthropometric data such as gender, height, weight, arm length, and hand span were measured and recorded before hefting judgments were assessed. For the hefting task, participants were asked to sit in front of a table. An experimenter sat behind the table and placed a set of eight objects of a given size on the table. The objects were arranged in random weight order. Participants were asked to lift (using the dominant hand) each of the objects in turn to feel its weight and judge its throwability. After participants had lifted and felt all the objects of a given size, they were asked to choose the best objects for throwing to a maximum distance. Participants were asked to choose the best three objects in order, namely, best, next best, and third best, and indicate their choices by pointing. They were asked to judge six different sets (sizes) of objects, each including eight different weights.

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[4] It was found later that the mean throwing distance of three tennis ball throws from the recruited participants was 13.25 ± 2.99 meters.

Initial Test of Throwing Distance Following the hefting judgment, participants were led to a playing field where they were asked to throw each object from the entire set of objects to a maximum distance three times using their dominant hand. Objects from the entire set were all thrown in a random order and then the set was repeated twice more each time using a new random order. The distance of each throw was measured and recorded. Participants were blindfolded and were handed the objects for throwing. They were also encouraged to do some stretching and warm up throws before the throwing, and if fatigue was felt during the test, a rest was taken.

Practice of Throwing When initial tests of hefting and throwing were completed, participants were scheduled for a month long practice of throwing. They were randomly assigned to one of four groups[5]. Each of three groups practiced with a different subset of the objects (Constant size, Constant Weight or Constant Density). Three groups threw the given subsets of objects with vision, but a fourth group was asked to throw the constant density subset without vision during practice. According to Van Den Tillaar (2004), an effective training program for generating fast throws should incorporate training 3 times per week for 5 weeks using underweight balls or in combination with overweight balls. We trained participants 3 times a week for 4 weeks, and used two types of objects for practice: a subset of six objects with variation of size or/and weight, and a tennis ball[6]. During practice with the subset of objects, participants threw any given object in a random order to a maximum

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[5] To ensure that the groups were equivalent in skill, we performed an ANOVA on the previously obtained hefting and throwing data adding group as a between-subject factor. The results showed no group difference either in hefting ($F_{3,20} = 0.17$, $p>0.05$) or in throwing ($F_{3,20} = 0.37$, $p>0.05$), indicating participants were of equal abilities in each group.

[6] A tennis ball was selected for practice for three reasons: first, it was a spherical object that approximately the same configuration of size and weight as the object that was shared by the three subsets; second, according to Edwards Van Muijen et al, (1991), practice with a light ball promotes the neural adaptations of muscles to the fast speed, which later on could be carried over in throwing the heavier balls; Third, it had fibrous and elastic surface so it provided good graspability, durability, and safety for practice.

distance in a field four times, and they were encouraged to explore the relationship between the object and the throwing distance. This practice took place on Monday of each practice week, and it was video taped for later motion analysis. To motivate participants' effort for improvement, a competitive prize of $20 was offered to award the most improved thrower. The mean distances of throwing were calculated and ranked each week for the entire set of participants. By the end of practice, the participant whose mean throwing distance increased the most received the award. In addition to throwing objects, participants also threw a tennis ball in a gym for practice, during which a tennis ball was thrown against the wall first by throwers, and then thrown back and forth between a thrower and a throwing expert with the distance between them being increased gradually. Participants were given instructions on how to enhance the coordination of movement at the hip, shoulder, elbow and wrist by stepping forward with the contralateral foot, as well as on the time at which the ball should be released (when arm speed achieved maximal value). This practice lasted for an hour and took place on three separate days each week (Monday, Wednesday, and Friday), and participants were instructed to do no other throwing practice with other objects during the month. At the end of practice, participants were asked to judge the most throwable object from the subset of six objects in order by pointing out their best three choices.

Final Tests of Hefting and Throwing A week after the practice sessions, participants were tested again in the hefting task and throwing using the whole set of objects. They were first tested in the hefting, and then led to the outdoor field to do the throwing task. Different from the earlier test, all participants were allowed to see how far each object was thrown in the field. When throwing was finished, participants were asked to do the hefting task once again with all of the objects.

Results

Previously, we had shown that the affordance for a maximum distance throw could be well perceived by people with sufficient throwing experience, and perception of this affordance depended on the use of the skilled throwing limb (Bingham at al., 1989; Zhu and Bingham, in press). This suggested that the affordance for throwing could be learned from experience because the skill itself is acquired from experience of throwing. If this were true, unskilled throwers (people with less throwing experience) would be unable to perceive the affordance in the beginning, but they would be expected to learn the affordance as they acquired the skill for throwing. We tested this possibility by assessing hefting judgments and throwing performance for unskilled throwers before, during and after their throwing practice sessions.

In the pre-practice phase, we tested hefting judgments as well as throwing performance using the full set of 48 objects and compared the judgments with throwing performance to see whether the optimal objects were selected. The factors in analyses were object size and weight, as well as participants' choices.

Then, in the practice phase during which participants threw subsets of 6 objects, we monitored the throwing performance to see whether the acquisition of throwing occurred and whether it was affected by the prescribed sets of objects and the vision conditions, that is, the group factor. The group factor was used in two different ways. First, the three groups who practiced with different object sets and with vision were compared. Second, the two groups who threw with the same sets of object but either with or without vision were compared. Because different groups threw sets of objects of different mean weight and weight is known to affect distances of throws, we used throws of commonly weighted and sized objects to compare among the groups.

Finally, in the post-practice phase, participants throwing performance using the full set of 48 objects was again tested and used to evaluate the hefting judgments made at three different phases: before practice, after practice and after seeing the throws of all 48 objects in the end. We wanted to determine whether the ability to perceive the affordance was acquired after practice or after seeing all the objects thrown. The factors in these analyses were the object size and weight, as well as group with the addition of the chices from the three hefting judgment sessions.

Pre-practice Phase

Participants were tested on their abilities to throw all 48 objects to the maximum distances. The results showed that all participants were poor throwers (see Figure 8 before practice). Their mean throwing distances ranged from 6.95m to 9.06m, much shorter than the average distance (29m) that skilled throwers could have achieved (Zhu & Bingham, in press). The three-way repeated measures ANOVA (size × weight × throwing round) conducted on distances of throws revealed strong effects for object size ($F_{5,115} = 49.72$, $p < 0.001$), for object weight ($F_{7,161} = 39.90$, $p < 0.001$), and for throwing round ($F_{2,46} = 3.82$, $p < 0.05$), as well as for the interaction between size and weight level ($F_{35,805} = 18.01$, $p < 0.001$). The Tukey's post-hoc analysis was performed to examine the size effect. It was found that although the small objects in general were thrown farther than larger objects ($p < 0.05$), objects smaller than 7.62cm in diameter did not differ in distances of throws, indicating participants were not even good at throwing the small objects. Post-hoc analysis on throwing round further revealed that the mean throwing distance in the first round was farther than the following two rounds (p <

0.05), indicating that participants lacked the stamina to perform the throwing task even when they were allowed to rest between throws. Since the interaction between size and weight level was significant, we examined the effect of object weight at each given size. The results showed that a different weighted object was thrown to the farthest at each size ($F_{7, 966} \geqslant 10.73$, $p < 0.001$), suggesting that a optimal weight existed in each size for the maximum distance throwing even when the throwing performance was poor.

Then, we analyzed participants' hefting judgments. Just as in our previous study (Zhu and Bingham, in press), we computed the mean of the chosen weights for each size by weighting judgments according to preference: first chosen weight was multiplied by 0.5, second chosen weight by 0.33, and the third chosen by 0.17. Unskilled throwers exhibited a similar pattern of mean judgments as did skilled throwers in previous studies. The mean of chosen weights increased with increasing object size (see Figure 1).

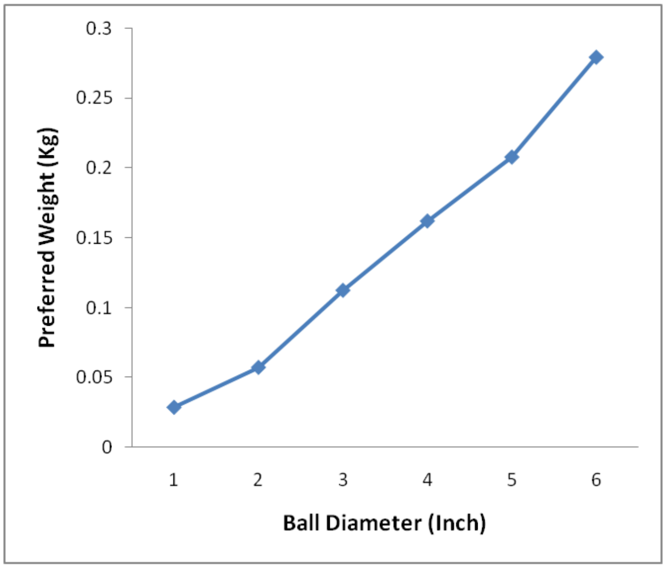

Figure 1 Mean weights selected by unskilled throwers as a function of object size in the initial test of hefting judgment

A repeated measure ANOVA on the chosen weights was performed with object size as a within-subject factor. The size effect was significant ($F_{5, 115} = 40.59$, $p < 0.001$). In previous studies (Bingham et al., 1989; Zhu & Bingham, in press), the pattern of mean judgments was the same as found here, although the mean chosen weights were larger than in the current study. The participants in the current study were somewhat smaller on average than participants in previous studies so we might have expected that they would choose lighter objects overall and they did (Mean in the current study = 140g with SD = 70 versus Mean in the previous study = 170g with SD = 60). Also, in the previous studies, the pattern of mean judgments was representative of the individual participant's choices. The chosen weight reliably increased with object size. In the current study, we examined the judgments to determine whether the choices were well ordered across object sizes, that is, whether individual participants selected increasingly heavy objects with increasing size. We computed the succeeding change of each mean chosen weight across sizes by subtracting each participant's mean chosen weight at a given size from that at the next larger size, yielding 120 (5 levels of size difference by 24 subjects) difference scores. We then computed the percentage of negative changes among the overall changes, which represents the cases where the chosen weight decreased with increasing size. The results showed that choices were not reliably well ordered. On average, 17.5% of the time participants chose a weight lighter than it was in next larger size (see Figure 11 before practice). The pattern of chosen weights was not as coherent as with the skilled participants in the previous studies (2.5%). Next, we compared choices with throwing performance to see if objects that were thrown to the farthest were chosen in advance in the hefting task.

A surface, that reflects the mean distances of throws as a function of both object size and weight, was computed to reveal the extent to which perception was accurate (See Figure 2). For each object size and participant, object weights were divided by the participant's mean chosen weight in the size. This displaced normed weight levels relative to one another across participants to align weights in respect to choices and for purposes of computing mean distances for given weight level in terms of the choices. Because weight levels were distributed according to a geometric series, the normed weight levels were log-transformed to achieve approximately equal intervals between levels. Next, the data was placed into bins whose size was selected to yield one data point for each participant in each bin. Then, mean distances for each bin were computed. Because weights were normalized by the mean chosen weights and then log-transformed, "0" on the log normed weight axis corresponded to the weight selected by hefting. The mean throw distances formed a surface in a Z (= distance) by X (= size), by Y (= log normed weight) space.

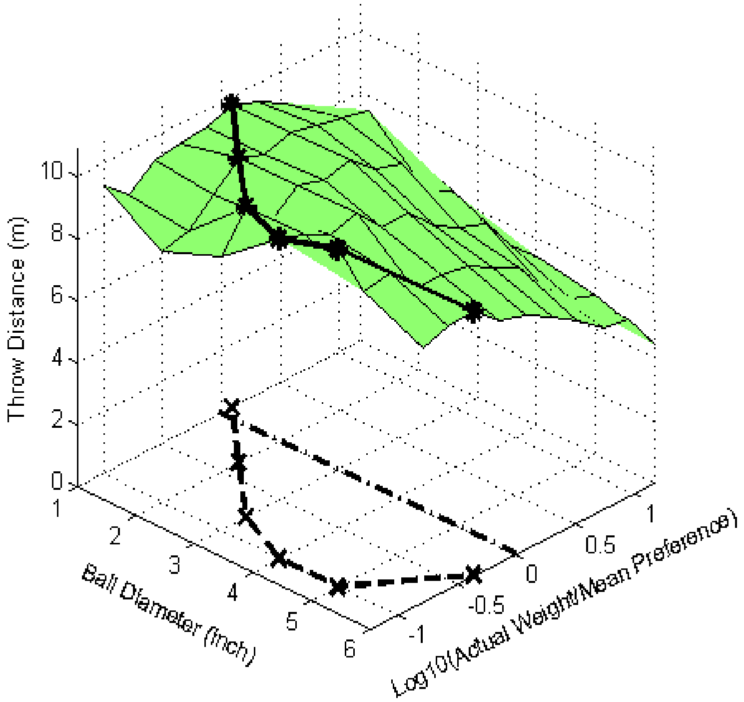

Figure 2 A surface representing mean throwing distances measured before practice as a function of object size and weight selected by hefting. The peak ridge (denoted by stars) of the surface is connected by a line and projected onto the size-weight plane describing the size-weight scaling relation for preferred objects. When the projected line aligns with the 0 value on log normed weight axis, the preferred weight was thrown to the farthest distance.

As we can see from Figure 2, the surface varied in two respects. First, distances exhibited an inverted-U pattern for each object size as a function of normed weight. Second, distances decreased with increasing size because of the increased air resistance in projectile motion. The peaks of the inverted-U curves were aligned to form a ridge line representing the mean maximum distance throws at each object size. We projected this ridge line onto the size by log normed weight plane, that is, the floor in the figure. If the ridge line projected directly onto the "0" axis of the log normed weight, then participants would have been perfectly accurate on average at selecting maximum throwable objects. The projected ridge line deviated from this axis and gradually shifted to the left as the object size increased, indicating that participants became worse in selecting the maximum throwable objects when object size increased, and they were actually overestimating the optimal weights.

Another way to examine whether the affordance was perceived is to compare the mean throwing distances between preferred and not-preferred objects. We calculated the mean throwing distances for the three preferred objects by weighting distances according to the preference: the distance of the first chosen object was multiplied by 0.5, the distance of the second chosen object by 0.33, and that of third chosen object by 0.17. Then, we calculated the mean throwing distances for the four not-preferred objects by averaging distances across the not-chosen objects (with the exclusion of the object that was thrown to the shortest distance to avoid a possible floor effect).

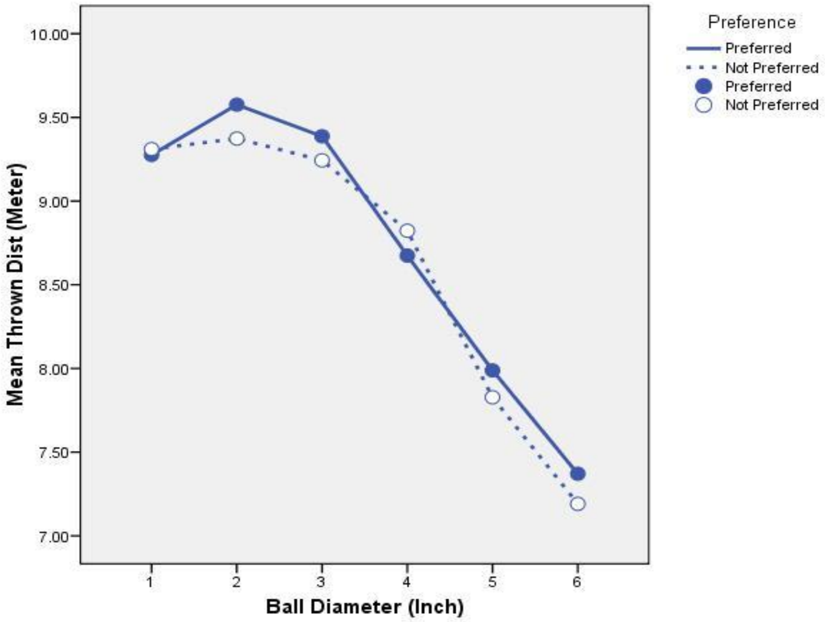

Figure 3 Mean throwing distances as a function of object size and preference. Dashed line with open circles represents mean throwing distances of the not-preferred objects. Solid line with filled circles represents mean throwing distances of the preferred objects.

As shown in Figure 3, the mean distances decreased as object size increased, and the distance curve of preferred objects overlapped with that of non-preferred objects. A repeated measures ANOVA was performed on the mean throwing distances treating object size and preference as two within-subject factors. Only a main effect for size was significant ($F_{5,\,115} = 43.97$, $p < 0.001$), neither preference ($p > 0.05$) nor size by preference interaction was significant ($p > 0.05$). These findings indicated that unskilled throwers did not select the optimal objects that could be thrown to the farthest at each size. They were poor in judging the affordance for throwing.

Practice Phase

One of our purposes for having a month long throwing practice was to enable unskilled throwers to acquire the necessary skills to perform good maximum distance throws. Throwing distance was the dependent variable that we monitored to measure the practice effect. We recorded the throwing distance every time each participant threw each object, yielding sixteen (four times on each of four Mondays) throwing rounds for each subset of objects. Results showed that practice of throwing yielded improved throwing distances for all participants.

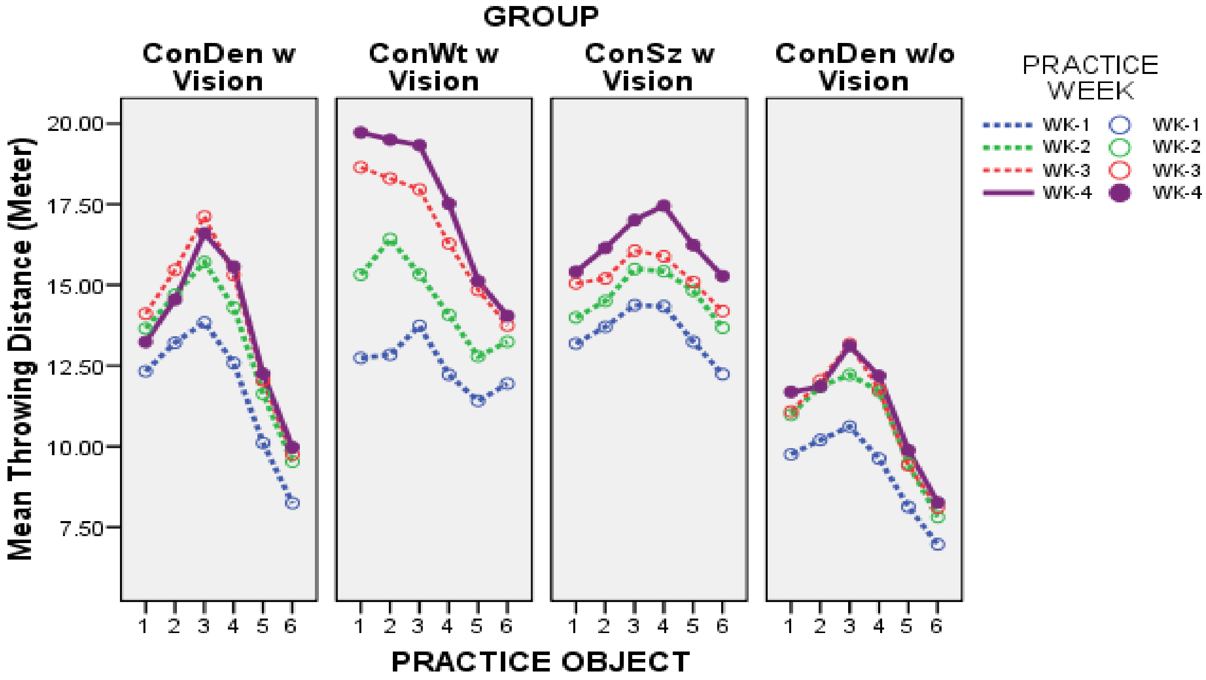

Figure 4 Mean throwing distances achieved by each group during practice as a function of throwing objects. Dashed lines with open circles represent the practice phase from week one to week three (blue, green, and red). Solid purple line with filled circles represents the performance in the last week of practice.

As can be seen from Figure 4, maximum distance throws changed in two respects: distances improved and differential performance was achieved with different objects. We averaged the four rounds in each week and performed a mixed design ANOVA on the throwing distances including group as a between-subject factor, and practice object and practice week as the two within-subject factors. The main effects for both practice object ($F_{5, 100} = 82.52$, $p < 0.001$) and practice week ($F_{3, 60} = 31.28$, $p < 0.001$) were significant, but not for group ($F_{3, 20} = 2.76$, $p > 0.05$), suggesting that all groups improved equally in throwing skill and their throwing distances were affected by the practice objects. In addition, there were significant group × practice object ($F_{15, 100} = 7.23$, $p < 0.001$), group × practice week ($F_{9, 60} = 2.38$, $p < 0.05$), and group × practice object × practice week ($F_{45, 300} = 2.24$, $p < 0.001$) interactions, indicating that each group improved the throwing distances differently depending on the practice objects. Post-hoc analyses further revealed that the group by object interaction was significant at each week ($F_{15, 400}$ = 3.09 at week one; 4.85 at week two; 5.64 at week three; and 6.61 at week four), so we tested the effect of object for each group at each week.

TABLE 3: ANOVA on throwing distances for effect of object at each practice week in each group

Object Effect ($F_{5, 460}$)	ConDen - V	ConWt - V	ConSz - V	ConDen - NV
Practice-WK1	13.39 ** # 1;2;3	1.94	1.94	5.73 ** # 1;2;3
Practice-WK2	15.39 ** # 2;3	5.78 ** # 2	1.64	8.69 ** # 2;3
Practice-WK3	17.08 ** # 3	12.04 ** # 1	1.35	9.30 ** # 2;3
Practice-WK4	21.07 ** # 3	17.78 ** # 1	2.20 * # 4	10.28 ** # 3

Note: * denotes $p<0.05$; ** denotes $p<0.001$;
# denotes the object(s) thrown to the farthest as indicated by the post-hoc analysis

As shown in Table 3, the F ratios for the object effect increased over practice and achieved significance for all groups by the end of practice. Additional Tukey's post-hoc analyses revealed that each group threw particular objects to the farthest distances each practice week, and eventually, object 3 was thrown the farthest by participants in the two constant density groups, object 1 was thrown the farthest in the constant weight group and object 4 in the constant size group.

During practice, three groups of participants practiced throwing with vision, each using a different set of objects. Averaging the weights across the subset of objects for each group, we found that the constant weight group threw an average weight of 0.069 kg, the constant size group threw an average of 0.112 kg, and the constant density groups threw an average of 0.212 kg. Given these differences in the overall average level of weight thrown by each group, the differences in throwing distances achieved by each group might simply be a reflection of these average weight levels. Thus, we picked the object of common weight thrown by all three groups, and examined the distances to which it was thrown during all testing sessions to better evaluate potential differences in performance among the groups. The results showed that the same amount of improvement was achieved in all groups when throwing the same object during practice (see Figure 5).

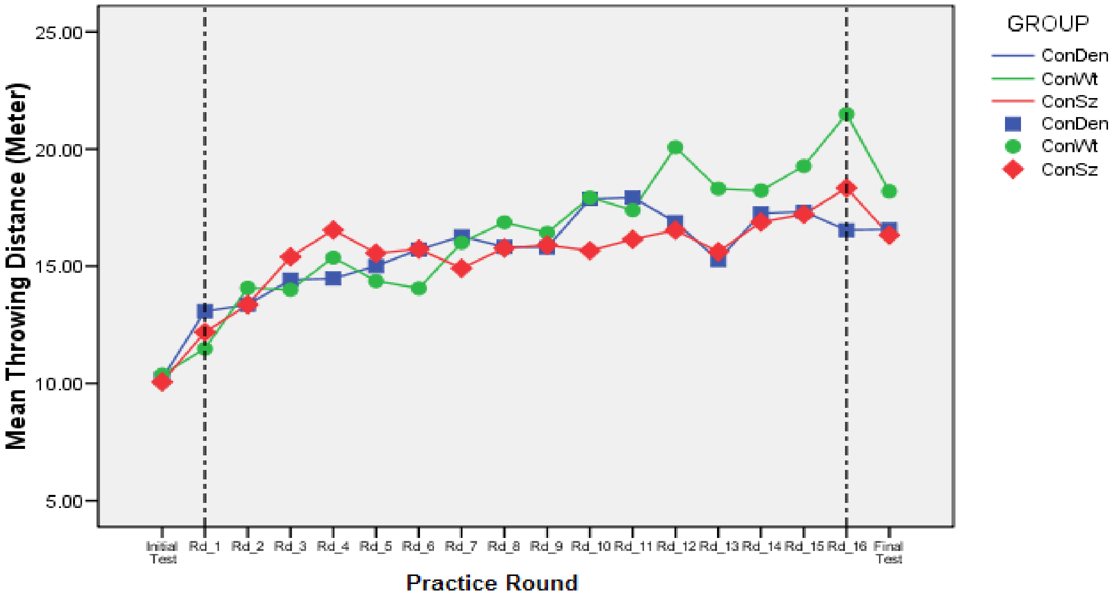

Figure 5 Mean throwing distances of the object of common weight (also the shared object) as a function of throwing round and the group membership in vision condition. Blue squares represent Constant Density group; Green circles represent Constant Weight group; and Red diamonds represent Constant Size group.

As shown in Figure 5, all groups increased throwing distances with practice, but more improvement was achieved at the beginning than near the end. A mixed design ANOVA was performed on throwing distances treating group as a between-subject factor and the practice round as a within-subject factor. Results showed only a main effect for practice round ($F_{17, 255} = 15.08$, $p < 0.001$). There was neither a group effect ($F_{2, 15} = 0.15$, $p > 0.05$) nor a group by practice round interaction ($F_{34, 255} = 1.22$, $p > 0.05$). A Tukey's post-Hoc analysis on practice round further showed a consistent improvement in throwing distance through the 10th round of practice ($p < 0.05$).

We also had two groups of participants who threw the same objects all the time but one group did it with vision and one without vision during practice. To examine the effect of vision on learning to throw, we picked the six objects that were prescribed to both groups for practice, and compared their throwing distances between the two groups across all testing sessions. The performance of both groups was parallel, and a consistent increasing pattern of throwing distance was noted over practice round (See Figure 6).

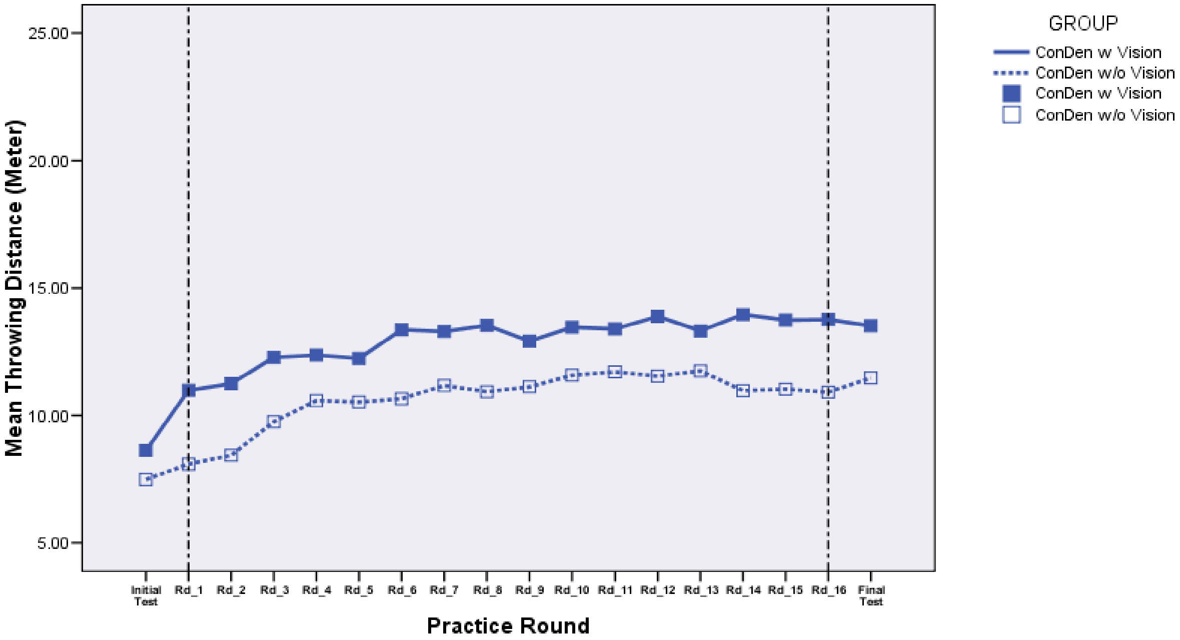

Figure 6 Mean throwing distances of the six objects of constant density as a function of throwing round and the vision condition. Filled squares connected with the blue solid line represent the throwing with vision. Unfilled squares connected with the blue dashed line represent the throwing without vision.

Since the vision condition for throwing was same (absent) for both groups before practice, but different during practice (present vs. absent), and same (present) after practice, three separate mixed design ANOVAs (group × practice round) were conducted on throwing distances to evaluate the effects of both practice and vision in these three practice phases. First, before practice (from the initial test to the practice round 1), the results showed the significant effects for practice round ($F_{1, 10} = 25.34$, $p < 0.001$) and the group × practice round interaction ($F_{1, 10} = 8.99$, $p < 0.05$), indicating that throwing performance was significantly improved for both groups even in the first round of practice. However, the vision group improved more than their no-vision counterparts during practice, suggesting that the acquisition of vision during practice yielded a better throwing performance. Next, during practice (from practice round 1 to practice round 16), the results only showed a significant effect on practice round ($F_{15, 150} = 3.38$, $p < 0.001$) and there was a marginal group effect ($F_{1, 10} = 4.35$, $p = 0.06$), suggesting that although there was a trend for people to throw better with vision, practice yielded equal amounts of improvement on throwing performance for both groups during the entire period of training. Last, after practice (from practice round 16 to the final test), none of effects was significant, suggesting that learning achieved asymptote for both groups, and their throwing performance exhibited no differences in the final test. The presence or absence of vision had no effect on learning to throw, however, it did have an effect on throwing performance which was worse without vision.

At the end of practice, we tested whether participants would be able to judge the optimal object among the set of objects that they used for practice. Participants were asked to select the best three objects that they could throw to the farthest distance. We counted the frequency for each object judged to be the first choice, second choice or third choice, and weighted the frequency by multiplying the first choice by 0.5, second choice by 0.33 and third choice by 0.17. Last, we summed those weighted frequencies to yield the cumulative frequency for each object. The results are shown in Figure 7.

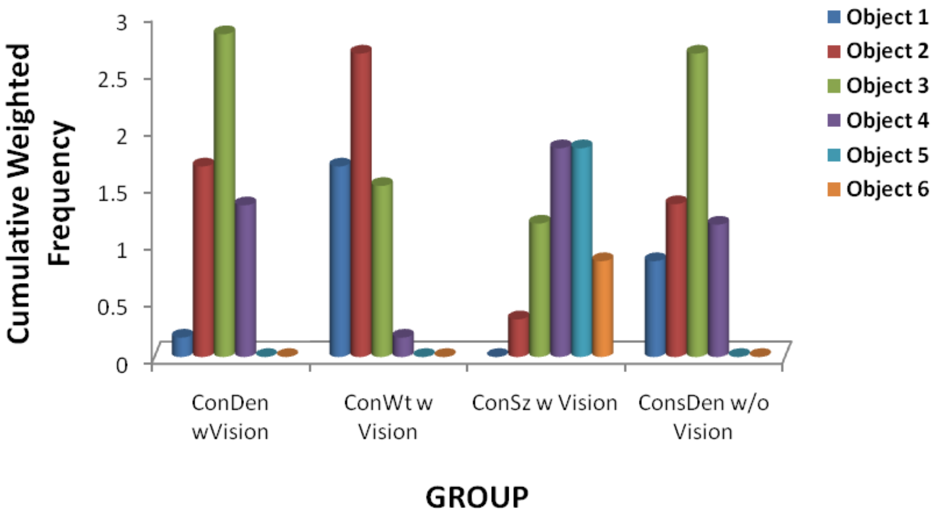

Figure 7 Cumulative weighted frequency for objects in subset being selected as the optimal in each group. Each object is represented by a color ranging from Blue to Orange. In constant weight and constant density groups, the color range represents size range (small to large); in constant size group, the color range represents the weight range (light to heavy).

As one can see, object 3 was the most preferred for both constant density groups, object 2 for the constant weight group, and object 4 for the constant size group. These objects with high cumulative weighted frequency corresponded to the ones that were thrown to the farthest on average at the end of practice[7], indicating participants became sensitive to the maximum throwable objects after practice. However, we are more interested in whether acquisition of throwing skill would allow this sensitivity to generalize across the whole set of objects.

Post-practice Phase

Our results supported the hypothesis that unskilled throwers would not be able to perceive the affordance for throwing. We also found that unskilled throwers were able to

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[7] For the constant weight group, object 2 was thrown to about same distance as object 1 as indicated by the post-hoc analysis, and it was also the second choice object at the end of practice.

acquire the skill for the maximum distance throwing through intensive practice. The key question that remains is whether the ability to perceive the affordance was acquired after practice, and if it was acquired, whether and how it depended on the practice sets or the vision conditions. To answer these questions, we performed a series of analyses on the hefting and throwing data acquired after practice.

First, we compared throwing distances before and after practice to see whether the practice effect was preserved in the final throwing session where the whole set of objects was used (see Figure 8 after practice). The results showed that participants significantly improved the maximum throwing distance of each object after practice.

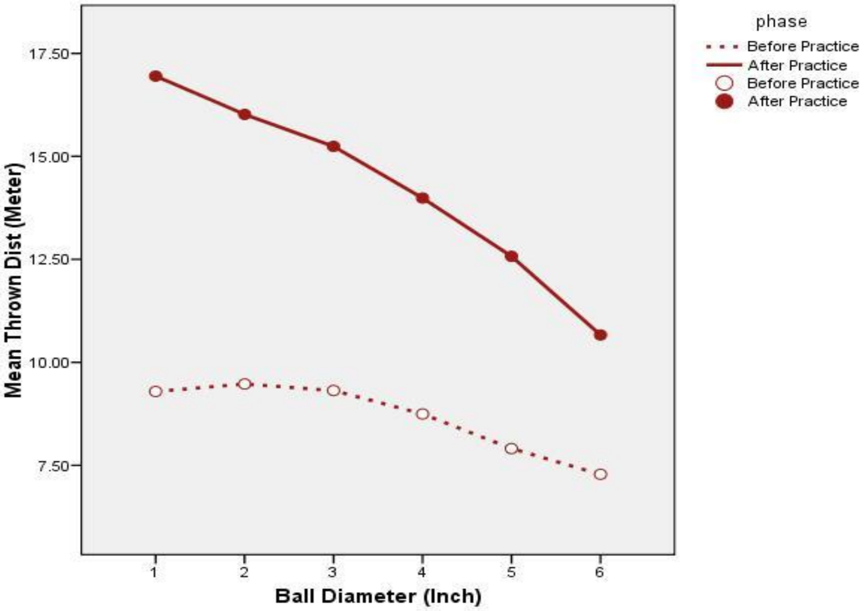

Figure 8 Mean throwing distances achieved before and after practice as a function of object size. The dashed line with open circles represents the distances achieved before practice; the solid line with filled circles represents the distances achieved after practice.

A size × practice (pre or post) × throwing round repeated measure ANOVA was performed on throwing distances. Size and practice were significant ($F_{5, 115} = 143.01$; $F_{1, 23} = 127.88$, $p < 0.001$), as was their interaction ($F_{5, 115} = 60.61$, $p < 0.001$). The Tukey's post-hoc analysis on size indicated that while the large objects continued to be thrown to shorter distances than small ones after practice, the throwing distances were different among small objects ($p < 0.05$) as well as among large objects as before, suggesting that participants became more skilled at throwing all sizes of objects. Throwing round was not significant, suggesting that participants did not fatigue perhaps because of their throwing skill.

Next, we performed analyses to determine whether participants acquired the ability to perceive the affordance after practice, and if so, whether the perceptual ability depended on the objects used for practice or the presence of vision during practice. We examined participants hefting judgments first to determine whether their judgments changed as a function of practice. Then, we analyzed distances of throws to see whether the selected objects were actually thrown to the farthest distance.

Participants' judgments were weighted according to their preference in each of the different judgment phases, that is, before or after practice or after throwing with vision. As shown in Figure 9, the mean chosen weights systematically decreased across phases as a function of practice and throwing experience. This occurred for all groups except the no-vision group, which chose heavier objects after practice but then returned to their original mean choices after throwing.

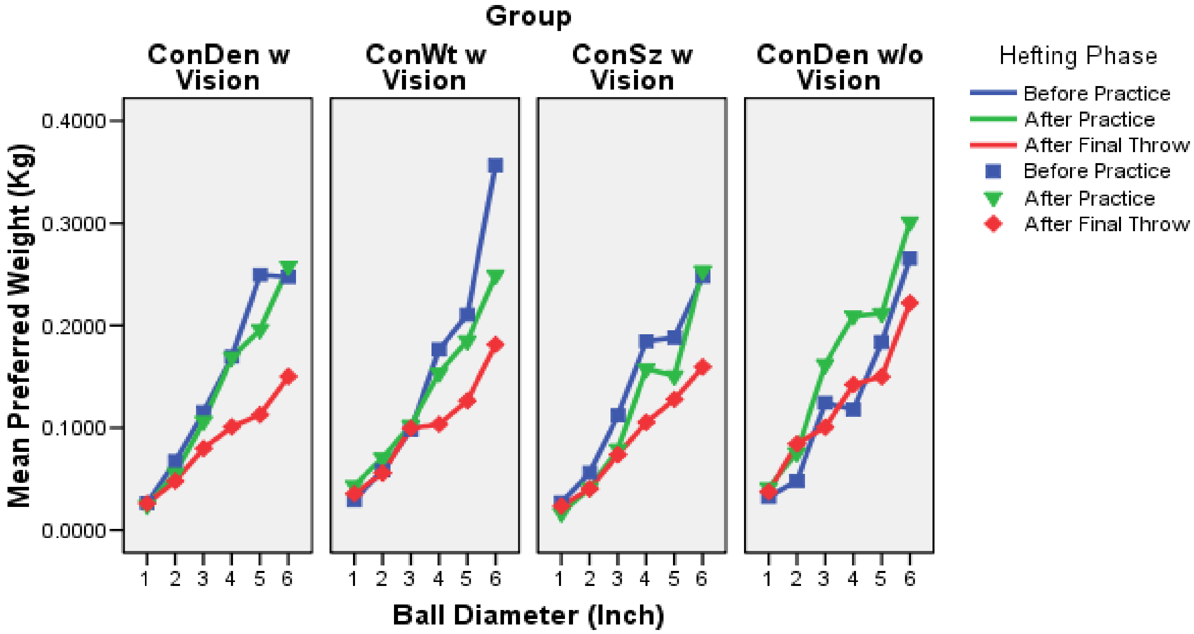

Figure 9 Mean weights selected by unskilled throwers (separated by group) throughout the hefting judgment phases. Blue squares represent the selection made before practice; Green triangles represent the selection made after practice; and Red diamonds represent the selection made after seeing final throws.

Although the mean judgments did change before and after practice they did not change a lot and did not really seem to change at all for the smallest objects. However, this need not mean that participants were not changing their choices before and after practice. One participant might select a heavier object and another select a lighter one, so the two changes cancelled one another out in the mean. To reveal whether participants were altering their choices before and after practice, and again after having thrown all the objects with vision, we computed changes of chosen weights before as compared to after practice, that is, between phases. For each size, the mean weight chosen by each participant in the succeeding phase was subtracted from that in the previous phase, and then divided by the previous weight, yielding the percentage of change in judged weight between phases. We then compared this change of judgment for each group, and the results showed that all participants changed their judgments of all the different sizes of objects across phases.

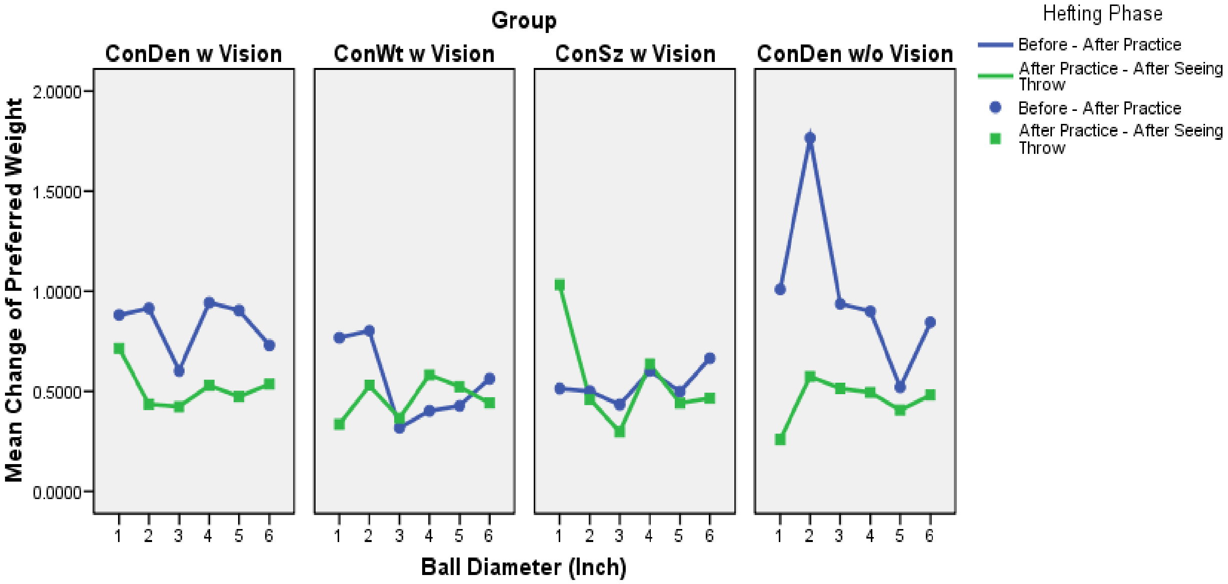

Figure 10 Mean change of weights selected by unskilled throwers (separated by group) between hefting judgment phases as a function of object size. Blue circles represent the change of judgment between before and after practice; Green squares represent the change of judgment between after practice and after seeing final throws.

As shown in Figure 10, the preferred weights changed by at least 50% in all sizes and groups. We performed a 3-way ANOVA on the changes of mean preferred weights for groups with vision treating group as a between-subject factor and size and phase difference as within-subject factors. Only a size effect was significant ($F_{5,75} = 2.73$, $p < 0.05$), and there was no effect for group, phase difference or the interaction between the two ($p > 0.05$). Tukey's post-hoc analysis on size showed that the change of mean chosen weights was significantly higher ($p < 0.05$) for the smallest object (2.54cm diameter), and relatively lower ($p < 0.05$) for the medium size object (7.62cm diameter). A separate ANOVA was then performed on the no-vision group treating size and phase difference again as within-subject factors. Only a phase difference effect was found ($F_{1, 5} = 7.97$, $p < 0.05$), indicating that the no-vision group made greater changes in judgments between the first two phases than between the last two.

So, the weights being selected in each size were clearly changing, but the next question was whether the choices were becoming better ordered and more accurate. We computed the succeeding change of mean chosen weights as sizes increased just as we did for the initial hefting session to address the question of ordering, that is, whether participants reliably selected increasingly heavy objects with increasing size. The percentage of negative changes in mean chosen weights was calculated for each group, that is, how often participants selected a lighter weight for the next biggest size (see Figure 11). Only vision groups decreased the proportion of negative changes. There was no change in the coherence of the judgments for the no-vision group after practice. The no vision group only improved in this respect after they got to see themselves throwing all of the objects.

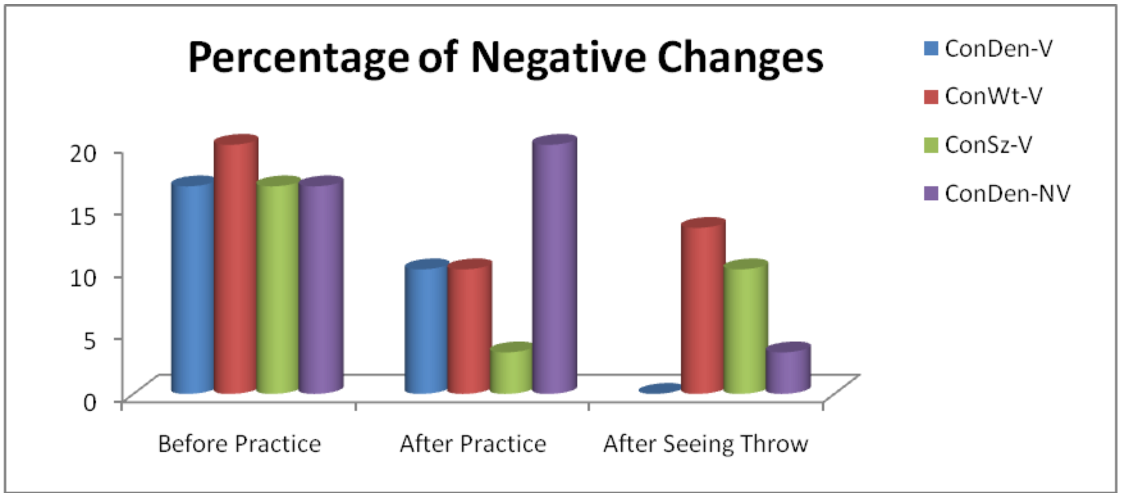

Figure 11 Percentage of negative change of preferred weight (selecting a lighter weight as size increased) across the hefting judgment phases. Green bar represent Constant Density group; Red bar represent Constant Weight group; Green bar represent Constant Size group; and Purple bar represent Constant Density without vision group.

As shown in Figure 11, vision groups exhibited a higher percentage of negative changes before practice (17.7%) than after practice (7.7%) and after seeing throws (7.7%), indicating that their judgments of weight became more ordered to increase with increasing size after practice. The no-vision group exhibited a high percentage both before (17%) and after practice (20%), and improved only after seeing their throws (3%).

To reveal the extent to which the hefting judgments varied with increasing size, we calculated the mean coefficient of variability (STD/MEAN) of mean chosen weights for every succeeding change in size for each group and at each judgment phase. The consistent decrease of the coefficient of variability was only exhibited by the vision groups.

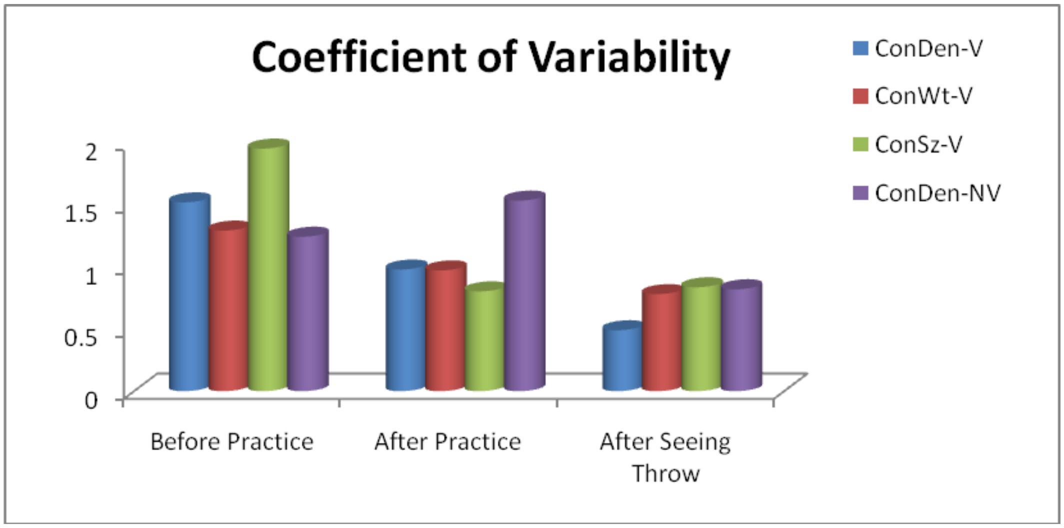

Figure 12 Coefficient of Variability for judgments across sizes at each judgment phase. Green bar represent Constant Density group; Red bar represent Constant Weight group; Green bar represent Constant Size group; and Purple bar represent Constant Density without vision group.

As illustrated by Figure 12, while the coefficients of variability progressively dropped across hefting judgment phases in all vision groups (1.6 to 0.9 to 0.7), it did not decrease in the no-vision group until after seeing the throws (1.2 to 1.5 to 0.8), suggesting again that hefting judgments became more reliable in terms of ordering with increasing sizes when throwing skill was acquired with vision.

It is evident that hefting judgments varied across phases to become more reliable in vision groups. The question remained whether participants became accurate in perceiving the affordance. To address this question, we analyzed the throwing distances as a function of participants' hefting judgments. The throwing distances of the full set of 48 objects achieved after practice were used to examine the accuracy of the hefting judgments made before practice, after practice and after seeing the throws in terms of predicting the throwability of objects[8]. We compared the mean throwing distances between the preferred and not-preferred objects for each set of the judgments, and found that the perception of the affordance was only acquired by the vision groups after practice as well as after seeing the throws, but not by the no-vision group at any phase (see Figure 13).

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[8] Previously, we had tested the hefting judgments made before practice using the throws performed before practice. Part of the problem is that throwing was poor before practice. So now we tested these same judgments using the superior throws after practice.

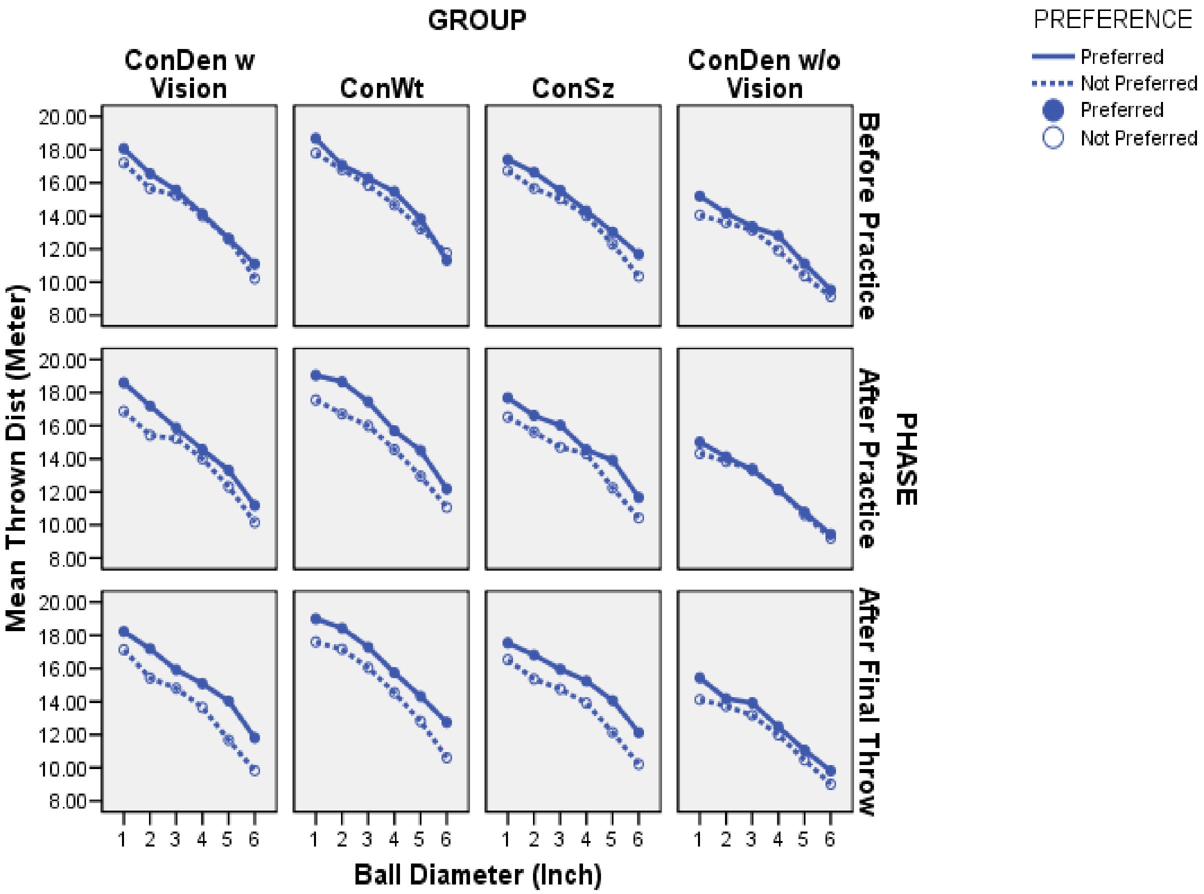

Figure 13 Mean throwing distances achieved by unskilled throwers after practice (separated for each group) as a function of size and preference across the hefting judgment phases. Filled circles connected with a solid line represent the preferred objects. Unfilled circles connected with a dashed line represent the un-preferred objects.

As illustrated in Figure 13, the preference curves differentiated in vision groups after practice and then more so after all the objects had been thrown with vision. However, the no-vision group did not exhibit any difference as a function of preference in any phase. Two mixed design ANOVAs were performed on the mean throwing distances to evaluate both the effect of the practice object sets and the effect of visual perception during practice. Group was treated as a between-subject factor, and object size, preference and phase as within-subject factors. For the three groups that practiced throwing with vision, each using a different set of objects, main effects for size ($F_{5, 75} = 94.61$, $p < 0.001$), preference ($F_{1, 15} = 41.98$, $p < 0.001$), and phase ($F_{2, 30} = 3.60$, $p < 0.05$) were significant. Phase was significant, suggesting that the throwing distances of the selected objects varied across phases. Since the same throwing data was used, the change of mean throwing distances would only reflect change of judgments. A 2-way interaction between preference and phase ($F_{2, 30} = 5.74$, $p < 0.01$) was also significant. So, the preference effect was tested at each phase. Results showed that the preference effect did not become significant until participants had acquired the throwing skill ($F_{1, 45} = 33.75$ after practice & $F_{1, 45} = 52.17$ after seeing throws, $p < 0.001$), indicating that participants became sensitive to the optimal objects only after practice when the throwing skill was acquired, and they became even better after seeing the throws as shown by the increase in the proportion of variability accounted for by the preference effect (partial omega square increased from 0.07 to 0.47 to 0.58). Neither group nor interactions between group and any other factors reached significance, indicating that all groups behaved similarly in choosing the optimal object for different sizes at different phases.

For two groups that practiced throwing using constant density objects either with or without vision, a significant main effect was found for size ($F_{5, 50} = 69.55$, $p < 0.001$) and for preference ($F_{1, 10} = 20.30$, $p < 0.001$). However, significant interactions were also found between preference and phase ($F_{2, 20} = 3.53$, $p < 0.05$), and most importantly, between group, preference and phase ($F_{2, 20} = 3.91$, $p < 0.05$), indicating that the two groups behaved differently in choosing the optimal objects at different phases. A separate ANOVA was performed to examine the preference effect at each phase and in each group. The vision group demonstrated no preference difference before practice ($F_{1, 30} = 2.51$, $p > 0.05$), but a significant preference effect after practice ($F_{1, 30} = 11.71$, $p < 0.001$) and after seeing throws ($F_{1, 30} = 24.77$, $p < 0.001$). The no-vision group only demonstrated a trend for a preference effect after seeing throws ($F_{1, 30} = 4.14$, $p = 0.052$), indicating that the blindfolded throwers did not begin to acquire the ability to perceive the affordance until the visual perception of the throwing was provided.

To better illustrate the difference between the vision and no-vision groups in acquisition of the affordance, we plotted the surfaces representing mean throwing distances as a function of size and preferred weight for the two groups after practice and after seeing the throws (See Figure 14).

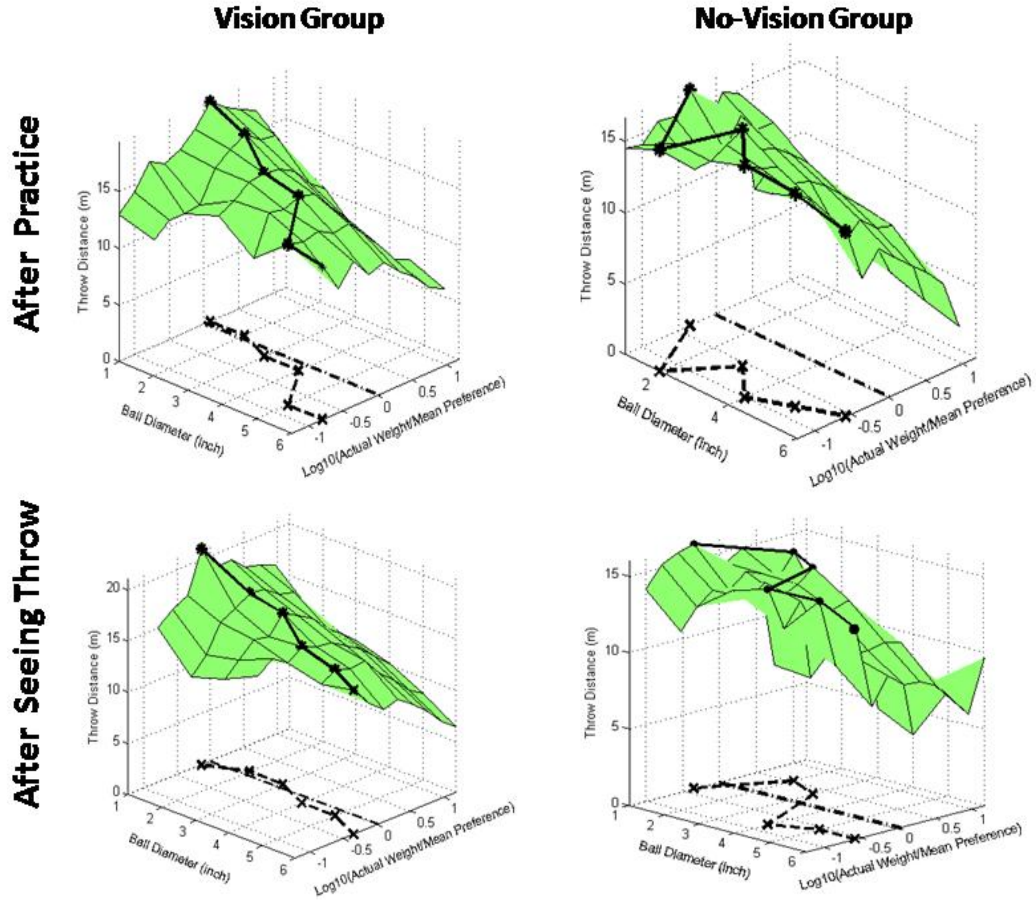

Figure 14 Surfaces representing mean throwing distances measured after practice as a function of object size and weight selected by hefting for the two groups who practiced throwing with versus without vision. The peak ridge (denoted by stars) of the surface is connected by a line and projected onto the size-weight plane describing the size-weight scaling relation for preferred objects. When the projected line aligns with the 0 value on weight axis, the preferred weight was thrown to the farthest distance.

It was apparent that both groups tended to overestimate the optimal weight (the preferred weights are heavier than the actual optimal weights) after practice, however, the vision group were very accurate in judging smaller to medium sized objects, while the no-vision group consistently overestimated the optimal weight in all sizes. When visual perception of throwing was provided, both groups demonstrated better judgment of the optimal objects. However, the vision group corrected their overestimation of the large objects, while the no-vision group was still not very accurate, exhibiting large variation in their judgment (the oscillation of the projected line relative to the optimal judgment line).

The results of the hefting judgments and throwing after practice indicated that all unskilled throwers acquired the skill for maximum distance throwing, and their judgment of the optimal objects for throwing changed each time it was assessed. However, only throwers who practiced throwing with vision became sensitive to the optimality of objects, and this was independent of the objects that were experienced during practice. Throwers who practiced throwing without vision did not acquire the sensitivity to the optimal objects.

Discussion

Previous studies (Bingham et al., 1989; Zhu & Bingham, in press) showed that people with sufficient throwing experience were able to heft and judge the optimal weight of different sized objects for maximum distance throwing, exhibiting an accurate perception of this affordance property. The current study assessed the perception of this affordance by unskilled throwers (people with less throwing experience) in the context of their learning to throw.

We hypothesized that the perception of the affordance must be learned because the ability to perform long distance throws has to be acquired. This hypothesis was supported by the present results. Initially, unskilled throwers were found to be poor at judging the affordance for throwing before practice. They were on average overestimating the optimal weight and increasingly so as object size increased. Their hefting judgments were variable and not well ordered with size, that is, they failed to choose increasing weights with increasing size. Both results indicated that the perception of the affordance for maximum distance throwing was poor when the throwing skill was poor. However, after throwing practice and acquisition of better throwing skill, most unskilled throwers (those who practiced with vision) acquired the ability to perceive the affordance. They became sensitive to the optimal objects not only within the subset with which they practiced but also among the entire set of objects, and their judgments were consistent and well ordered with size, indicating that the acquisition of the skill for long distance throwing enabled the affordance for throwing to be well perceived. Therefore, learning the affordance for throwing is a perceptual-motor task that entails the coupling of perceptual learning with the motor learning.

According to the ecological approach to perception and action (Gibson, 1979/1986), information has to be acquired to both detect the useful structure of the environment and assemble actions used to explore the environment. So, the next question we addressed was about how information is acquired through hefting and used for detecting the affordance for throwing. Two hypotheses were contrasted in the current study. The first was the smart perceptual mechanism hypothesis, which is that hefting acts as a smart perceptual device to detect information about optimal objects for throwing. The alternative was the function learning hypothesis, which is that hefting reads both object size and weight and uses them to predict the possible throwing distance based on a function learned in previous experience. Our results rejected the latter and supported the former.

These two hypotheses were tested using the functional relation between throwing distance and object size and weight, which is a single valued function (distance) of two variables (size and weight). A surface representing this function can be seen in Figure 2. Acquiring the complete function through function learning would require sampling variations in both size and weight, that is, cutting through the surface respectively in two different ways: one is to cut parallel to the weight axis so that weight variation would be sampled at different sizes; the other is to cut parallel to size axis so that size variation would be sampled at different weights. The cuts need not be perpendicular to one another or parallel to the size and weight axes, but two cuts in sufficiently different directions would be required. No single cut through the surface could be sufficient for learning the entire space. To test this, three sets of objects were constructed and prescribed for practice. The practice with each set of objects would represent a single cut through the surface that would be insufficient for learning the complete function, although interpolation or extrapolation could occur within each cut. If the perception of the affordance requires learning a single valued function of two variables, we would expect that participants who practiced with the constant size set would only learn distance as a function of weight but not size. Participants who practiced with the constant weight set would only learn distance as a function of size but not weight, and those who practiced with the constant density set only learn distance as a function of the particular co-variation of both size and weight that yields constant density, but not about the variation with all sizes and weights. Hence, none of conditions would allow learning of the complete function that takes inputs of arbitrary size and weight (within the relevant range). However, the results showed that participants in all three vision groups demonstrated acquisition of the affordance after practice independently of the prescribed set of objects with which they practiced throwing. The perceptual ability generalized to the entire space of objects. Thus, perception of the affordance can not be a result of function learning, and participants did not acquire a lookup table through associative learning.

According to the smart perceptual mechanism hypothesis, learning the affordance for throwing is to acquire sensitivity to the information made available by hefting with a skilled throwing limb. This requires sufficient variation of the information variable to make it salient together with feedback that reveals the mapping between the information and throwing distance. Once the information was acquired, it generalized to the entire space. Our results showed that all constrained learning conditions yielded a generalized learning of the complete space, suggesting that learning the effect of either size or weight, or both on throwing was sufficient for acquisition of the affordance for throwing. The perceptual system was able to take advantage of the available information to simplify the problem for judging the affordance. However, the acquisition of this sensitivity to the information made available by hefting requires vision to provide knowledge of results about throwing distance. Our results showed that people who practiced throwing without vision did not acquire the affordance after practice although they did acquire skill for maximum distance throwing, indicating that learning to throw itself did not guarantee the acquisition of the affordance. To learn the affordance, the throwing distances had to be seen as well. This was further supported by the results showing that all groups became more sensitive to the optimal objects when they were allowed to see how far each object was thrown in the final test.

Our study has confirmed that the perception of the affordance for throwing was acquired through learning to throw, and it was actualized by a smart perceptual mechanism that mapped information available in hefting to throwing distance. However, the investigation of perceptual mechanism for the affordance entails the perceptual information to be identified. Based on the smart perceptual mechanism hypothesis, Bingham et al. (1989)

advocated that the dynamics of hefting served as a window on the dynamics of throwing. Thus the effects of object size and weight should be similar on both hefting and throwing tasks. However, this assumption was undermined later by the results of Zhu & Bingham (in press) who found that only object weight, not object size, affected the release velocity to determine the contribution of the dynamics of throwing to throwing distance. We tested this assumption again in the present study. We first manipulated the properties of the to-be-thrown objects in respect to size and weight. Then, we asked participants to practice throwing using these objects, during which a motion analysis technique was used to both digitize each throwing motion for each participant and acquire the kinematic variables such as release velocity and release angle. Last, a series of analyses was performed on release velocities and release angles with respect to object size and weight (see "Learning Maximum Distant Throws: Kinematic Changes in Throwing as a Function of Object Size and Weight"). The results replicated our previous findings showing that the release velocity was only a function of object weight, which determined the contribution of the dynamics of throwing to throwing distance. Release angle did not vary systematically with either object size or weight and only became less variable with increasing throwing skill. Object size only affected the throwing distance through projectile motion by determining the air resistance. Since an object size effect was present in the dynamics of hefting (larger objects yielded a stiffer tendon at the wrist) but absent in the dynamics of throwing (release velocity did not vary with object size), the idea that hefting is a smart mechanism because of the symmetry in the dynamics of hefting and throwing was not supported. Nevertheless, the smart mechanism hypothesis was supported by our results in this study. So, the question is how did this work? The answer lies in the finding by Bingham et al. (1989) that the relation between optimal weights and object size was as that of the classic size-weight illusion, in which objects of increasing size must weigh more to be perceived of equal heaviness. The optimal objects for throwing in different sizes should be all felt of the same heaviness. This presumably is the invariant information for the affordance. When objects of different sizes and weights were hefted in hand, they were perceived of different heaviness, however, only one particular perceived heaviness was optimal for throwing. Thus, the perception of the affordance entails discriminating the invariant perceived heaviness that corresponds to maximum throwing distances. Because the optima only appear in throwing distances (as a function of both size and weight) not in the release velocities (as a function of only weight), the only way for perceivers to relate their perceived heaviness to the throwing distances is to see how far each felt heaviness can be thrown, by which the optimal perceived heaviness can be revealed. Once the optimal perceived heaviness is identified, the affordance can be perceived, and the perception of the affordance can be generalized to any situation where the optimal perceived heaviness can be detected.

Why optimal objects for long distance throwing are perceived to have equal heaviness remains to be determined. A number of different accounts of the size-weight illusion have been proposed, but none have been convincingly verified. The most current hypothesis is that proposed by Amazeen & Turvey (1996), which is that perceived heaviness is a function of an object's rotational inertia. The problem with this is that the objects created in Bingham et al. (1989) all had nearly equal rotational inertias because the weights of Styrofoam objects of different sizes were varied by packing them with lead at their centers. So the mass distributions and thus rotational inertias varied little. Another common account is in terms of expectations of experienced heaviness when an object is lifted. However, Mon-Williams et al. (2000) have shown that the "illusion" persists after an object has been lifted and its weight has been thoroughly tested. The bottom line is that perceived heaviness is a function of both size and weight and that function covaries with the affordance for long distance throwing.

CHAPTER 3

Learning to Perform Maximum Distance Throws: Kinematic Changes in Throwing as a Function of Object Size and Weight

Abstract

Zhu & Bingham (in press) discovered how maximum throwing distances are constrained by the dynamics of both throwing and projectile motion. They found that object weights affected both types of dynamics while object sizes only affected the latter. We now examine this issue in the context of learning to throw. 18 unskilled adult throwers practiced throwing for a month. They were divided into 3 groups that practiced throwing using 3 different sets of objects (constant size, constant weight or constant density). Throwing distances were recorded, and a 2-D motion analysis technique was used to record and analyze the kinematics of throwing to evaluate the effects of object size and weight on throwing. Motion analysis revealed that both release velocity and release angle became more reliable as throwing distances improved with practice, but only release velocities exhibited mean changes over practice. They increased. Furthermore, when throwing skill was acquired, object weight, not size, determined the release velocity to affect the dynamics of throwing. When it was greater than 50 g, the relation between weight and release velocity followed a power function. Surprisingly, skill level only affected the coefficient, not the exponent of weight in the power function determining the speed of throwing. The results confirmed those of Zhu & Bingham (in press) and Cross (2004).

Introduction

People learn to throw objects with fast speed to achieve a maximum throwing distance. This ability has been recognized as a key skill in sports like baseball, water polo, team handball, and javelin as well as in tennis serves or badminton smashes (Van Den Tillaar, 2005). To achieve maximum distance throws, two dynamics are relevant: the dynamics of throwing and the dynamics of projectile motion (Zhu & Bingham, in press). In projectile motion, both object size and weight played roles to determine projectile distance, however, the roles of object size and weight in the dynamics of throwing remained unclear, especially in the acquisition of throwing skill.

Studies of throwing dynamics are abundant in biomechanics (Yan, Payne & Thomas, 2000; Yang & Scholz, 2005; Gray, Watts & Hore, 2006; Marques-Bruna & Grimshaw, 1997). Researchers have used kinematic or neuromuscular measures to characterize fast or maximum distance throws. Action components such as forearm action, arm swing, trunk rotation and foot stepping have been found to contribute substantially to the generation of fast release velocity (Stodden et al., 2006a & 2006b; Dapena & Mcdonald, 1989; Feltner & Dapena, 1986), and these throws exhibit a sequential pattern of muscle contraction starting from the proximal segments such as the trunk and proceeding to the distal segments such as the arm and wrist (Hirshima et al., 2002). In addition, Linthorne & Everett (2006) found that the optimum projection angles for achieving maximum horizontal range in throwing or jumping events were considerably less than 45°. All these studies recorded and studied a single kinematic measure (either velocity or angle) to identify the components responsible for fast throws. They failed to consider possible interactions between different kinematic variables and the changes of these variables with the acquisition of throwing skill.

Another factor that affects the dynamics of throwing to determine throwing performance is the physical properties (size and weight) of thrown objects. Van Den Tillaar (2005) has proposed that 'the differences in kinematics during the throw are generally caused by the difference of weight or size of the object thrown'. There are only a couple of studies on the effects of object size and weight on throwing performance and these have only investigated either size and weight alone. Burton, Greer and Weise-Bjornstal (1992) examined the influence of ball size on throwing performance. Six different-sized (4.8 to 29.5 cm in diameter) Styrofoam balls were used. They reported a change of throwing pattern with increasing ball size, namely, a transition from one-handed to two-handed throwing, but they did not examine the influence of ball size on the dynamics of throwing or changes in release velocity or angle. Cross (2004) investigated the effect of object weight on release velocities. He measured release velocities directly and modeled the resulting relation between velocity and weight using a power law. The results indicated that for object weights greater than 50 g, the release velocity followed a power function of weight with an exponent of – 0.15. However projectile weights below 50 g did not affect release velocities, which were constant at about 20 m/s.

Zhu & Bingham (in press) tested the role of both object size and weight in the dynamics of throwing and projectile motion. They first asked throwers to throw, with maximum effort, each of a set of objects that varied both in size and weight, and measured the throwing distances. Next, they tested four skilled throwers to measure the release angles as they performed maximum distance throws of the objects. They used the mean measured release angles together with the mean measured thrown distances as well as object sizes and weights in simulations of the dynamics of projectile motion to derive the release velocities. They found that the resulting release velocities followed the same function of object weight as reported by Cross (2004). Using this velocity-weight function to generate release velocities and combining them with the mean measured release angles and object sizes, they simulated projectile motion to predict the mean throwing distances. The resulting mean throwing distances replicated the measured mean throwing distances, accounting for 82% of the variance. These results suggested that object size has no effect on throwing itself, and only affects projectile motion. However, the release angles and release velocities were not directly measured for each throw in that study.

In the current study, we addressed two related questions. We studied the acquisition by adults of throwing skill through training and practice. We focused on the interface between the dynamics of throwing and the dynamics of projectile motion, namely, release velocity and release angle. We investigated first how these two properties of throwing dynamics changed with the acquisition of the ability to throw long distance. Second, we investigated the effects of variations in projectile size and/or weight on throwing in respect to changes in release velocity or release angle. To isolate the effects of object weight, we had a group of participants practice throwing with a set of objects that varied in weight but not in size. Another group practiced with objects that varied in size but not in weight. A third group practiced with objects of constant density that varied in both size and weight. This last set of objects simulated the way size and weight would vary in natural objects like stones found on a beach.

Methods

Apparatus

The same objects used in the previous study (Chapter 2) were used in the current study, which consisted of 48 spherical objects varying in size and weight. There were 6 object sizes determined by the diameters of objects, and 8 weights generated in each of the six sizes starting with the lightest weight that could be constructed in each size. Object weights increased according to a geometric progression: $W_{n+1} = W_n \times 1.55$. The matrix of object size and weight was constructed so that three configurations could be found: a set of six objects at a constant weight of 69g (varying therefore only in size); a set of six objects at a constant size of 7.62cm in diameter (varying therefore only in weight); and a set of six objects at a constant density (0.3 g/cm^3, varying in both size and weight). However, one object was shared by all three configurations.

To measure the throwing distances accurately, we used a measuring tape (100-M long) at distances shorter than ten meters, and a laser rangefinder (Simons Yardage Master 1000) at distances longer than ten meters.

To acquire the kinematic data such as release angle and release velocity during throw, 2-D motion analysis technique was adopted, which required a video camera with a high speed shutter and a gravitational reference system. We used a commercially available Panasonic PV-GS500 MiniDV Camcorder (shutter speed range: 1/60 - 1/8,000 seconds), and made a reference system that consists of a pole with a tripod at the bottom, and a meter stick that could stand on the ground both horizontally and vertically. A string was tied to the pole with two marking balls in the middle and a plumb at the bottom.

Participants

18 Indiana University undergraduates were recruited for the experiments. They were the same participants recruited in the previous study (Chapter 2) who practiced throwing with vision. They were paid at a rate of $9.00 per hour for participation in both practice and testing sessions of throwing.

Experimental procedure

Since the same participants were used, participants in the current study met the criterion to be the unskilled throwers. They practiced throwing with the prescribed schedule and with the prescribed objects (3 subsets of objects and a tennis ball), and they were tested the throwing performance before, during and after practice. Two types of variables were measured in the current study.

Throwing Distances Throwing distances measured before, during and after practice for the constant density, constant weight and constant size groups in the previous study (Chapter 2) were used in the current study. To ensure the dividing of the group was even, we performed ANOVA on the throwing distances measured before practice by adding group as a between-subject factor, the results showed no group difference in throwing distance ($F_{2,15} = 0.06$, $p > 0.5$), indicating that participants were equally assigned to each group.

Kinematic Variables In order to acquire the kinematic data such as release angles and release velocities, we videotaped each maximum distance throw made by participants during practice. A digital camcorder with a tripod was set up 9.5 meter away from the standing point of the thrower facing perpendicular to the throwing direction in the field. The shutter speed of the camcorder was set at 1/3000 second. The zoom was adjusted to show both the gravitational reference system and the thrower on the left side of the screen and the projectile motion to the right side. The position and the zoom of the camcorder were fixed once the video for the reference system was recorded. The recorded video was digitized for each throw using the 2-D tracking procedure embedded in SIMI motion analysis software (Version 6). First, the video clip for the reference system was digitized to yield both horizontal and vertical coordinates; next, a calibration was applied to correct errors so that the reference coordinates became orthogonal to each other; then, video clips for each throw were digitized from the release of the projectile (the instant when object was barely off the tip of the hand) to either the landing of the object or the frame at which the object went out of view. Consequently, the positional coordinates (both horizontal and vertical) for airborne objects at each frame were obtained. We then programmed a projectile motion simulator that read both camera frame rate and the positional coordinates to generate the best fitted release angles and velocities (using air drag coefficient of 0.45).

The 2-D motion analysis required the projectile to be thrown in a plane perpendicular to the camcorder so that the projectile motion could be tracked in two dimensions (horizontal and vertical). To ensure the quality of 2-D tracking, a measuring tape was attached to the standing point of the thrower and extended towards the throwing direction perpendicular to the camcorder. Participants then were told to throw objects to the direction as indicated by the measuring tape. Meanwhile, an auditory signal for initiation of the throw was given by an experimenter who stood on the measuring tape at the far end. Due to the availability of both visual and auditory cues, participants were able to direct their throws toward the demanded direction.

Results

Three dependent variables were used for data analysis: throwing distance, release angle and release velocity. We first studied these dependent measures to determine whether throwing improved with practice. A mixed design ANOVA was performed on throwing distances treating group as a between subject factor, and thrown object and testing phase (before, during or after practice) as two within-subject factors. The same ANOVA was performed on release angles and on release velocities, and their variability was examined as well. In addition, we used linear regression to examine the relationship of throwing distance to the release angle and release velocity in the context of skill development. Finally, we were interested in the effects of object size and weight on the interface between the dynamics of throwing and the dynamics of projectile motion. We used the measured data from the last week of practice, and performed linear regressions to examine the relationship between the measured release velocities and the available object sizes and weights. The slopes of the regression lines were also compared using multiple regressions.

Kinematic changes of throwing with acquisition of throwing skill

Throwing Distance We measured throwing distances for all objects before and after practice, and for the subset of 6 objects for each group during practice. To examine the practice effect, we computed mean throwing distances measured for the subset of 6 objects according to the group membership before, during and after practice, and plotted them against both testing phases and thrown objects. As shown in Figure 15, the mean throwing distances yielded different curves for each group but all increased with practice.

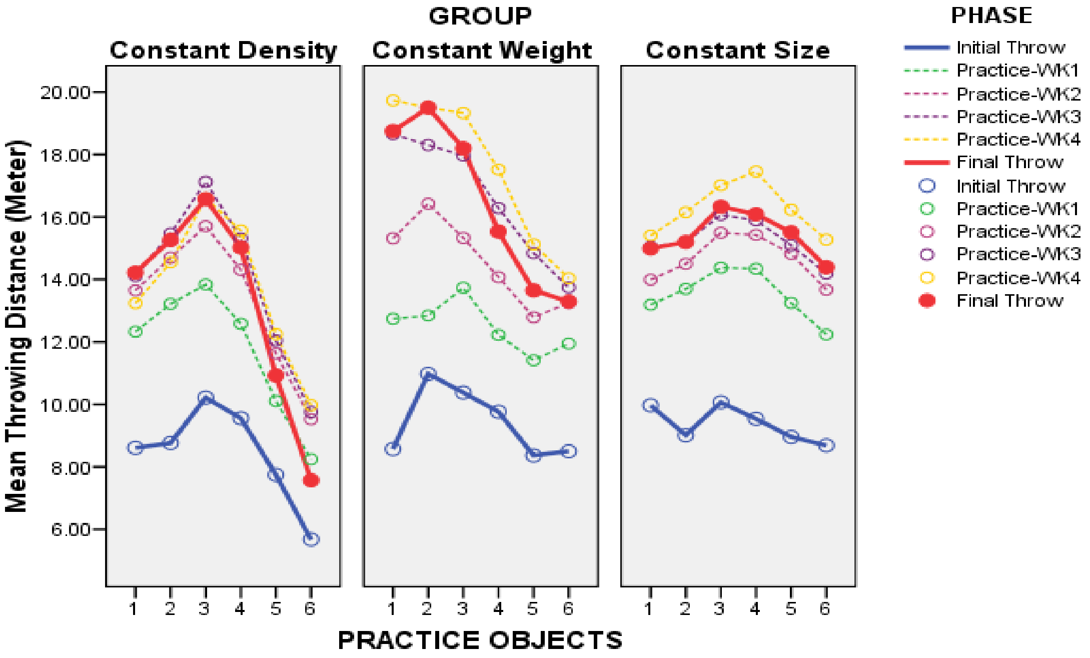

Figure 15 The mean throwing distances achieved by three groups as a function of thrown object and testing phase. X-axis represents the subset of 6 objects used for practice by each group: for the constant density group, both object size and weight increase from 1 to 6; for the constant weight group, object size increases from 1 to 6 but object weight was constant at about 69 g; for the constant size group, object weight increases from 1 to 6 but object size was constant in diameter of 7.62 cm. The solid line with open circles represents the mean throwing distances achieve in initial throws; the solid line with filled circles represents the mean throwing distances achieved in final throws; all other dash lines represent the mean throwing distances achieved during practice weeks.

A 3-way mixed design ANOVA (group × testing phase × thrown object) was performed on throwing distances. We found significant effects for the testing phase ($F_{5, 75} = 52.35$, $p < 0.001$) and for the thrown objects ($F_{5, 75} = 77.37$, $p < 0.001$), but no effect for group ($F_{2, 15} = 1.03$, $p > 0.05$), indicating that all groups increased throwing distances, and that throwing distances were affected by the thrown objects. However, the 3-way interaction (group x testing phase x thrown object) was also significant ($F_{50, 375} = 3.16$, $p < 0.001$), suggesting that each group behaved differently in their improvement of throwing. Accordingly, we performed separate

ANOVAs to reveal how throwing distances were determined by the thrown objects in each group and at each testing phase.

Table 4: ANOVAs on throwing distances for effect of object at each practice week for each group

Object Effect ($F_{5, 360}$)	ConDen		ConWt		ConSz	
Initial Throw	9.25 (3;4)	**	3.92 (2;3)	**	1.13	
Practice WK1	14.09 (3;2;4)	**	2.42 (3;2;1)	*	2.68 (3;4)	*
Practice WK2	13.05 (3;2;4)	**	6.68 (3;1;2)	**	2.79 (3;4)	*
Practice WK3	19.73 (3;2;4)	**	7.50 (1;2;3)	**	2.25 (3;4)	*
Practice WK4	15.24 (3)	**	12.97 (1;2)	**	3.71 (4;3)	**
Final Throw	33.35 (3)	**	15.21 (2;1)	**	2.17 (3;4)	*

Note: 1. "*" denotes $p<0.05$; "**" denotes $p<0.01$;
2. Number(s) in "( )" denotes the object(s) that have been thrown to the farthest after Tukey Post-Hoc analysis ($p<0.05$)

As shown in Table 4, the F ratios for the object effect increased across testing phases for all groups. The Tukey HSD post-hoc analyses then revealed that particular objects were thrown to the farthest in each group at each testing phase, and eventually, object 3 was thrown to the farthest in the constant density group, object 1 and 2 (the smallest objects) in the constant weight group, and object 3 and 4 in the constant size group. With practice, the throwing distances not only increased, but also were increasingly affected by the objects in the practice set, indicating that the physical properties (size and weight) of the thrown objects played an important role in determining the distances of skilled throwing.

Release Angle The release angles were also analyzed in the context of learning to throw. We found that throwing practice did not yield significant mean changes in the release angles. As shown in Figure 16, the mean release angles remained unchanged in all groups over practice weeks and for all thrown objects.

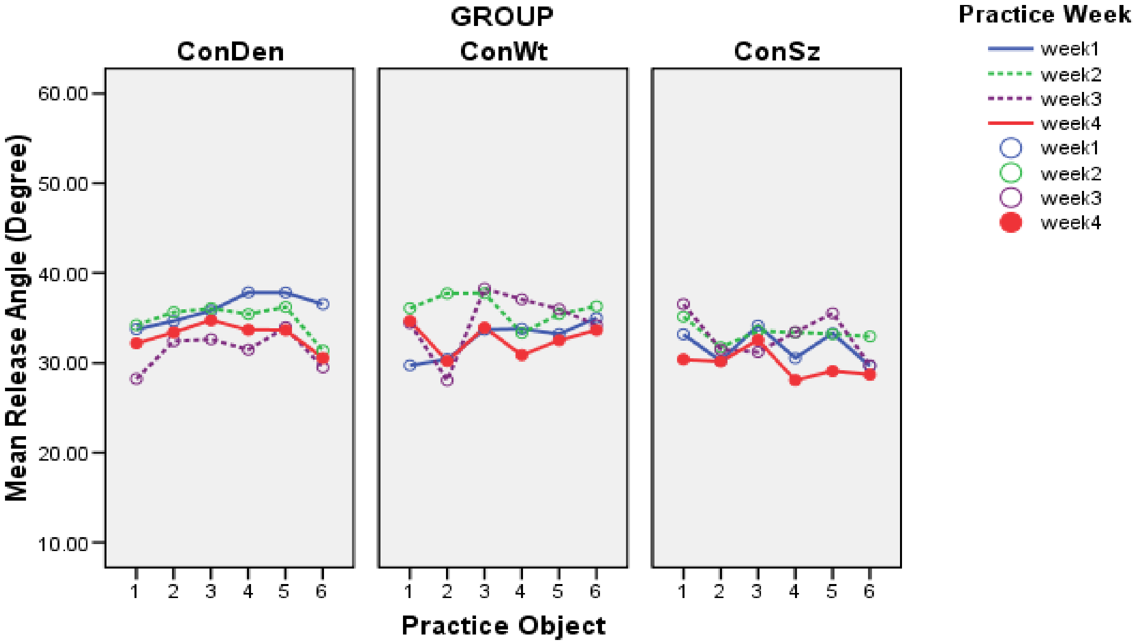

Figure 16 The mean release angles achieved by three groups as a function of thrown object and testing phase. X-axis represents the subset of 6 objects used for practice by each group: for the constant density group, both object size and weight increase from 1 to 6; for the constant weight group, object size increases from 1 to 6 but object weight was constant at about 69 g; for the constant size group, object weight increases from 1 to 6 but object size was constant in diameter of 7.62 cm. The solid line with open circles represents the mean throwing distances achieve in the first week of practice; the solid line with filled circles represents the mean throwing distances achieved in the last week of practice; all other dash lines represent the mean throwing distances achieved during other practice weeks.

A 3-way mixed design ANOVA (group × practice week × thrown object) was performed on release angles. None of the effects reached significance, indicating that the mean release angle varied neither with practice week nor with the thrown objects in any group.

However, examination of the variability indicated that release angle did become more reliable with practice and that the variability varied depending on the physical properties of thrown objects. We calculated the standard deviations of release angles for each object and for each participant during the first and last week of practice.

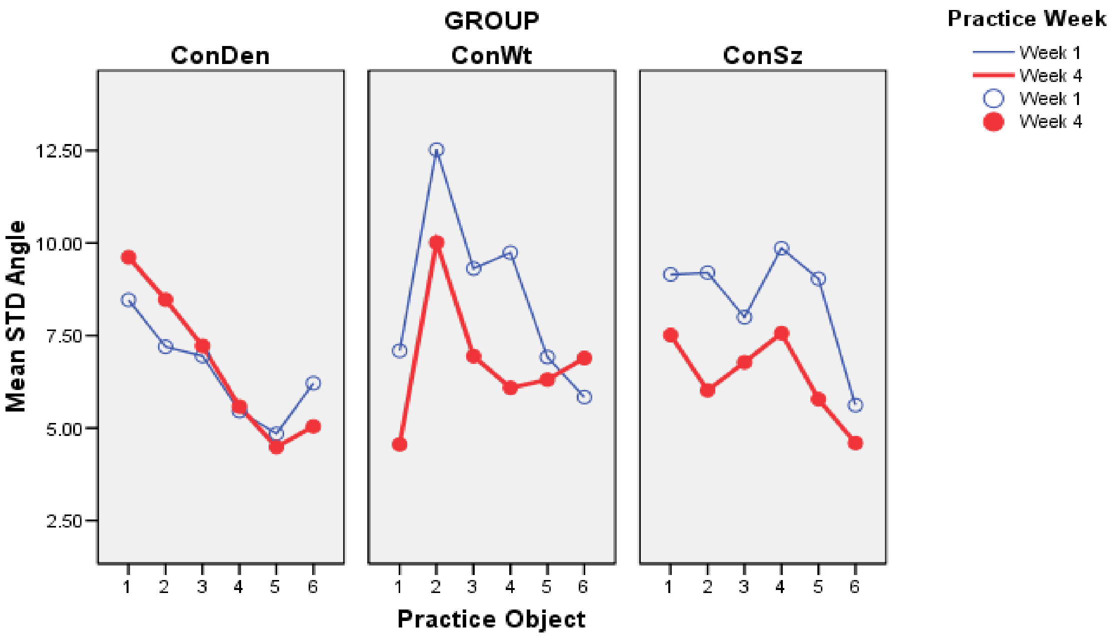

Figure 17 The standard deviation of release angles in three groups as a function of thrown objects and practice week. The thin solid line with open circles represents the mean standard deviations of release angles during the fist week of practice. The thick solid line with filled circles represents the mean standard deviations of release angles during the last week of practice.

As shown in Figure 17, the standard deviations of release angles were high in the first practice week and lower in the last practice week in both constant weight and constant size groups, but remained unchanged in the constant density group. A 3-way mixed design ANOVA (group × practice week × thrown object) was performed on these standard deviations. The results showed a significant main effect for practice week ($F_{1, 15} = 5.49$, $p < 0.05$), suggesting that practice yielded a general reduction of the variability of the release angle although it did not consequently cause the mean change of release angle. We also found a significant main effect for thrown object ($F_{5, 75} = 3.88$, $p < 0.01$), as well as its interaction with group ($F_{10, 75} = 2.13$, p

< 0.05), suggesting that the variability of the release angles was affected by thrown objects differently in each group. Accordingly, the effect of thrown object was examined for each group. The results showed the significant effect only in constant density ($F_{5, 90} = 2.27$, $p < 0.05$) and constant weight ($F_{5, 90} = 3.11$, $p < 0.05$) groups. The following Tukey's HSD post-hoc analyses further revealed that the object effect was different in the two groups. While the mean standard deviation of the second smallest object was singular (significantly higher than others among which no difference was found, $p < 0.05$) in the constant weight group, the mean standard deviations in the constant density group decreased gradually (significant every other level, $p < 0.05$) with increases in both size and weight of the thrown object. Thus, the effect of thrown object was mainly reflected in the constant density group, which suggested that the release angle varied less when participants threw larger and heavier objects.

Release Velocity We examined the release velocities as well for all groups in the context of learning to throw. The results showed that the release velocities increased directly with practice. As shown in Figure 18, the mean release velocity curves elevated from early practice to the late practice, however, they exhibited different patterns in each group.

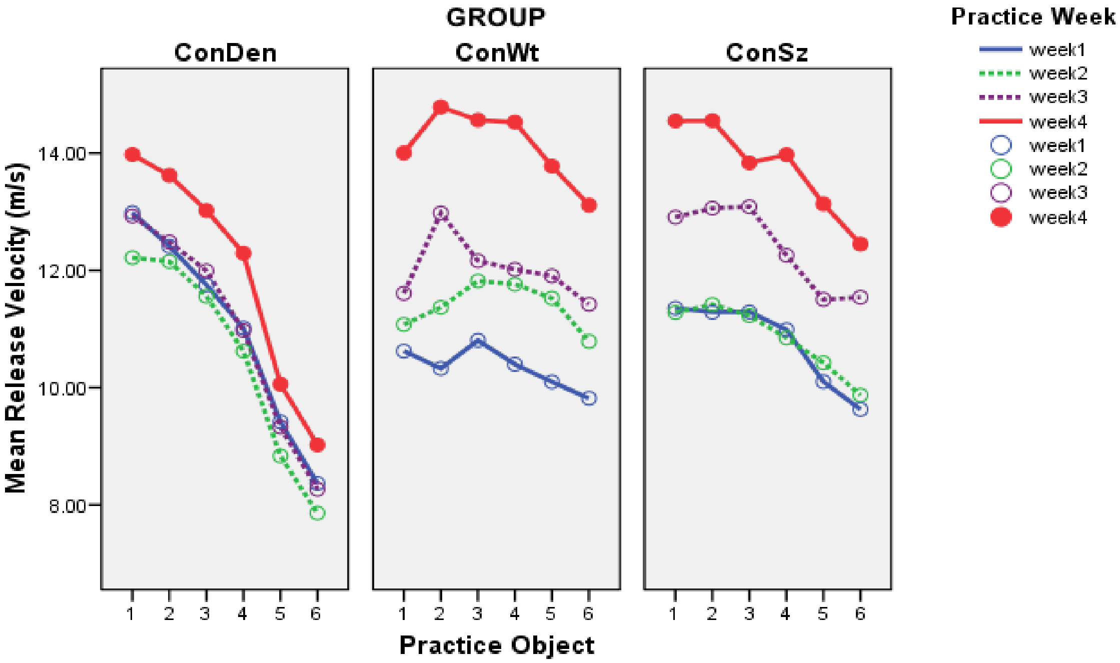

Figure 18 The mean release velocities achieved by three groups as a function of thrown object and testing phase. X-axis represents the subset of 6 objects used for practice by each group: for the constant density group, both object size and weight increase from 1 to 6; for the constant weight group, object size increases from 1 to 6 but object weight was constant at about 69 g; for the constant size group, object weight increases from 1 to 6 but object size was constant in diameter of 7.62 cm. The solid line with open circles represents the mean throwing distances achieve in the first week of practice; the solid line with filled circles represents the mean throwing distances achieved in the last week of practice; all other dash lines represent the mean throwing distances achieved during other practice weeks.

A 3-way mixed design ANOVA (group × practice week × thrown object) was performed on release velocities. The results showed significant main effects for practice week ($F_{3, 45} = 27.07$, $p < 0.001$) and thrown object ($F_{5, 75} = 88.35$, $p < 0 .001$), as well as for their interaction ($F_{15, 225} = 2.20$, $p < 0.01$), suggesting that release velocities not only increased with practice but also varied with the thrown objects. The 2-way interactions between group and thrown object ($F_{10, 75} = 21.29$, $p < 0.001$) and between group and practice week ($F_{6, 45} = 2.60$, $p < 0.05$) were also significant, indicating that groups did not equally increase release velocities with practice and their release velocities varied depending on the thrown objects. Therefore, we performed separate ANOVAs to reveal the effect of thrown objects on release velocities in each group and at each practice week.

Table 5: ANOVAs on release velocities for effect of object at each practice week for each group

Object Effect (F5,300)	**ConDen**	**ConWt**	**ConSz**
Practice WK1	38.42 ** (1;2;3)	1.86	6.78 ** (1;2;3;4)
Practice WK2	41.99 ** (1;2)	1.79	4.45 ** (1;2;3;4)
Practice WK3	44.14 ** (1)	3.81 ** (2)	8.03 ** (1;2;3)
Practice WK4	50.82 ** (1)	5.64 ** (1;2;3;4)	8.53 ** (1)

Note: 1. "**" denotes $p<0.01$;
2. Number(s) in "( )" denotes the object(s) thrown with max release velocity in order after Tukey Post-Hoc analysis ($p<0.05$)

As shown in Table 5, the F ratios increased over practice week for all groups, indicating that with practice, the release velocities were affected by thrown objects more and more for all groups. The Tukey HSD post-hoc analyses revealed that both constant density and constant size groups consistently threw the lighter objects with greater release velocities, and eventually the lightest object was released with the largest velocity. However, in the constant weight group, the release velocity increased with practice regardless of the size of the objects , implying that release velocity varied with object weight but not with object size.

Next, we evaluated the variability of the release velocity by computing the standard deviations of release velocities for each object and for each participant during the first and last week of practice. The results showed that the variability of the release velocity was much lower than that of the release angle although it remained to be affected by practice and thrown object.

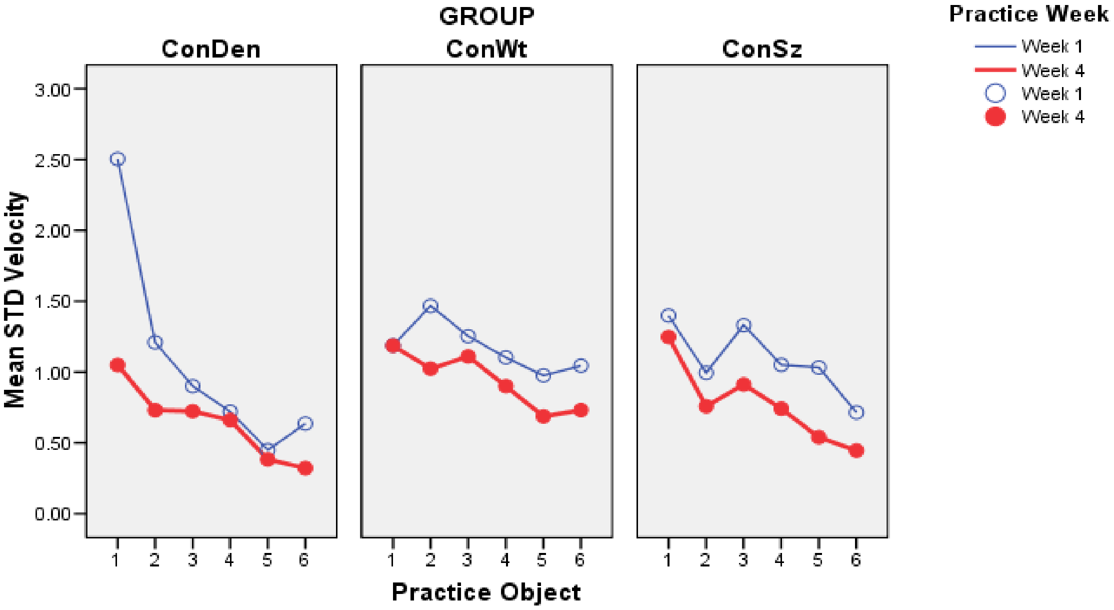

Figure 19 The standard deviation of release velocities in three groups as a function of thrown objects and practice week. The thin solid line with open circles represents the mean standard deviations of release angles during the fist week of practice. The thick solid line with filled circles represents the mean standard deviations of release angles during the last week of practice.

As shown in Figure 19, the standard deviations of the release velocities varied in two respects for all groups: they decreased with both practice and the thrown object. A 3-way (group × thrown object × practice week) ANOVA conducted on these standard deviations revealed significant main effects for both practice week ($F_{1, 15} = 10.05$, $p < 0.001$) and thrown object ($F_{5, 75} = 10.40$, $p < 0.001$) with no interactions, indicating that the variability of the release velocities significantly decreased with practice, and was strongly dependent on the physical properties of the thrown object. As revealed by the Tukey's post-hoc analyses, the release velocity varied less when participants threw larger or/and heavier objects.

Throwing distance versus release angle and release velocity We performed linear regressions on throwing distances using either release angles or release velocities to predict distances. Release angle was not significant ($R^2 = 0$, $F_{1, 1721} = 0.05$, $p > 0.05$), indicating that the increase of throwing distance could not be attributed to the change of release angles. However, we found that release angles became less variable with increase of throwing distance.

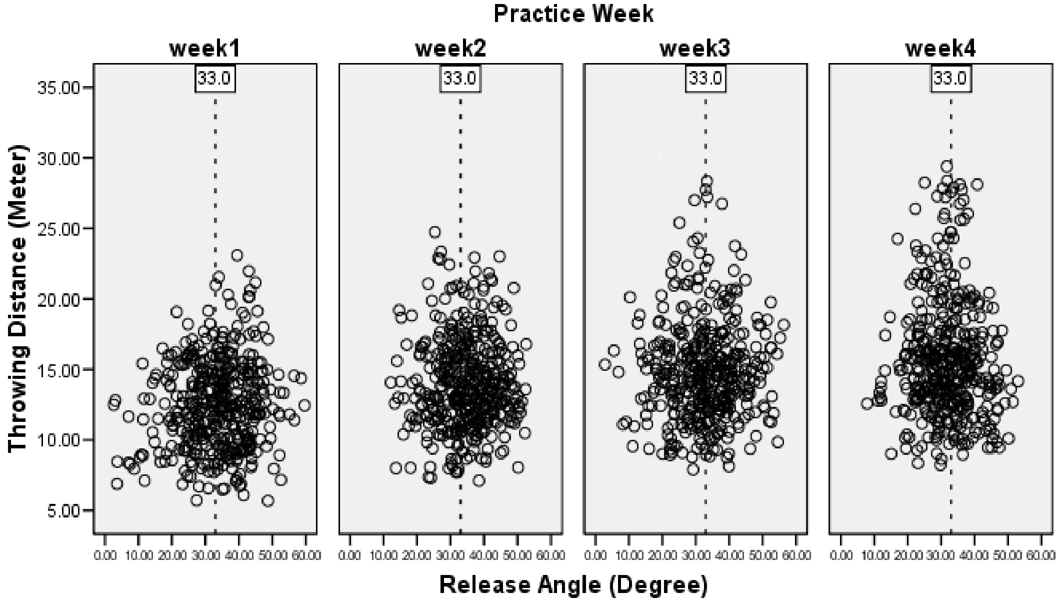

Figure 20 The linear regressions on throwing distances using release angles separated for each practice week. The dash line refers to an angle of 33° at release.

As shown in Figure 20, the variability of the release angle (around a mean of 33°) was shrinking across practice weeks, and at the end of practice, most long distance throws exhibited a release angle close to 33°. We binned the throwing distances by 5 meters increments within the distance range (5 to 30 meters), and calculated the standard deviations of the corresponding release angles in each distance bin during the first and last week of practice.

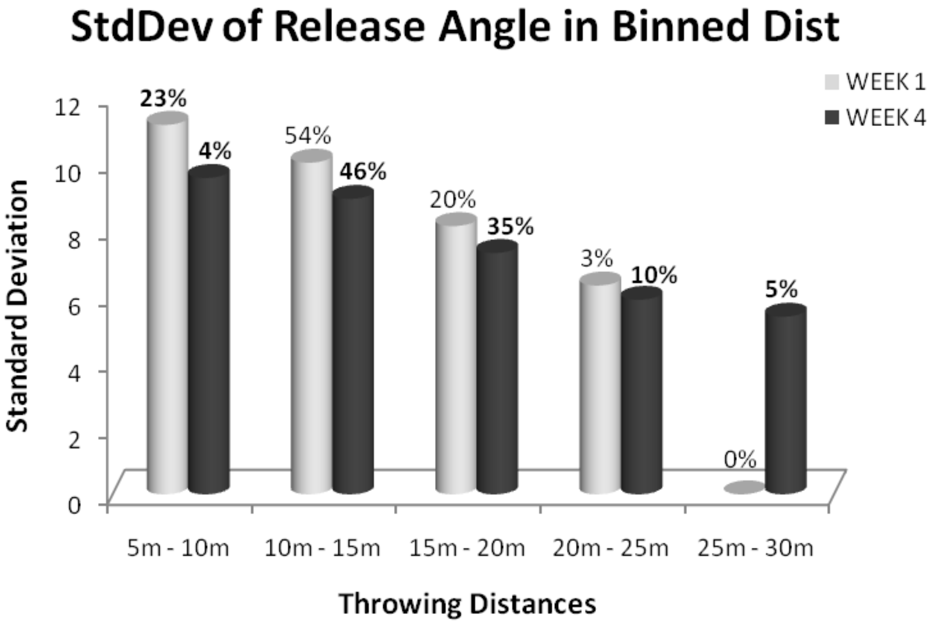

Figure 21 The standard deviation of release angles as a function of binned throwing distance. The light grey bar represents the standard deviation of release angles during the first week of practice. The dark grey bar represents the standard deviation of release angles during the last week of practice. The percentage labeled above each bar represents the proportion of the corresponding release angles in each distance bin.

As shown in Figure 21, the variability of the release angles consistently decreased as the distance of the bin increased, and comparing to the first week of practice, the variability of the release angle in the last week of practice decreased. Furthermore, the proportion of throws in the largest distance bin (25-30m) increased, indicating that a long distance throwing is associated with a less variable release angle. We calculated the proportion of the corresponding release angles in each distance bin for each of the two weeks. As seen in Figure 21, comparing to the first week of practice, the proportion of the release angles decreased in the shorter distance bins (5-10m & 10-15m) but increased in the longer distance bins (15-20m, 20-25m & 25-30m) in the last week of practice, suggesting that with practice, more reliable release angles of 33° were responsible for the long distance throwing. Both the reduction of the variability and the increase of proportion of the release angles for the long distance throwing indicated that a reliable release angle was developed by throwers through practice for a maximum distance throw.

The release velocity was found to be significantly correlated with the throwing distance ($R^2 = 0.51$, $F_{1, 1721} = 1759.62$, $p < 0.001$). A positive correlation indicated that a long throwing distance was associated with a high release velocity. To investigate how release velocity changed to determine the throwing distance with the acquisition of throwing skill, we performed separate linear regressions of throwing distances using release velocities at each practice week.

As shown in Figure 22, not only did the R square increase from 0.40 to 0.68, but also the slope increased from 0.91 to 1.39, indicating that throwing distances varied more strongly with release velocities with practice.

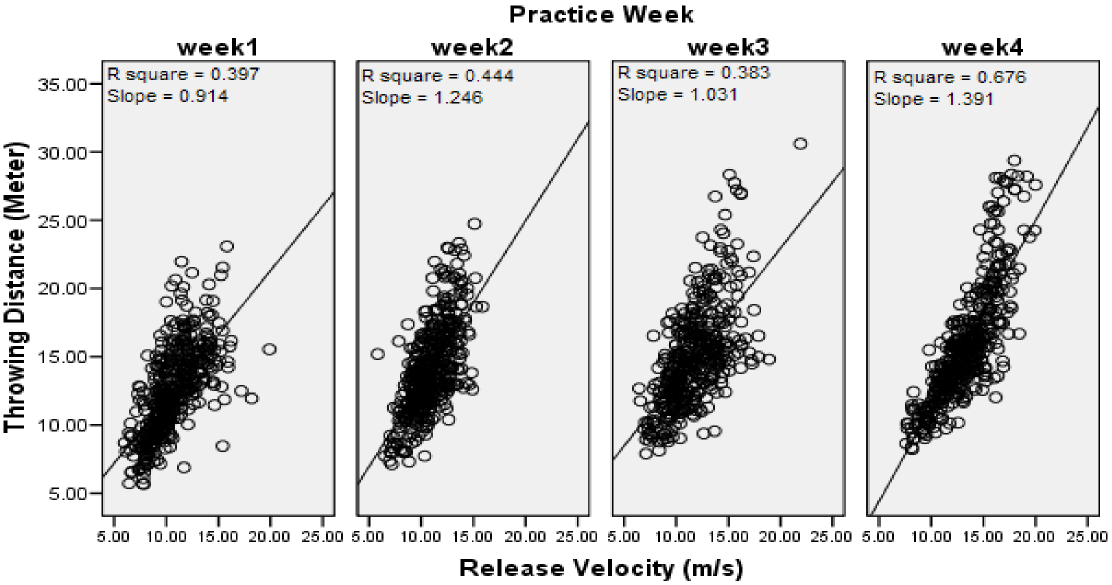

Figure 22 The linear regressions on throwing distances using release velocities separated for each practice week with R squares and slopes of regression lines.

The effects of object size and weight on the dynamics of throwing

The dynamics of maximum distance throwing consists of the dynamics of both throwing and projectile motion. Release velocity and release angle are two variables that result from the dynamics of throwing and provide input to projectile motion. Since we have found that the mean release angle did not vary significantly with the properties of thrown objects, while the mean release velocity did, the investigation of the effects of object size and weight on release velocity will reveal the specific impact of physical constraints from thrown objects on the dynamics of throwing. We were able to do so due to our manipulation of object size and weight in each practice condition. In our manipulation, the constant density group threw objects with variation of both size and weight, the constant weight group threw objects with no variation of weight but only variation of size, and the constant size group threw objects with no variation of size but a variation of weight[9].Consequently, the effects of object size and weight can be examined by performing linear regressions on the release velocity using either concurrent or isolated variations of object size and weight depending on the practice condition. Since the results have shown that properties of thrown objects affected both throwing distances and release velocities more at the end of practice, we used the release velocities measured in the last week of practice for this analysis.

The regression analysis revealed that the release velocity was more susceptible to the weight variation than to the size variation. We first performed a linear regression on release velocities using the variation of object size in the constant weight group. The regression was not significant ($R^2 = 0.02$, $F_{1, 142} = 2.99$, $p > 0.05$), suggesting that the size variation did not affect the release velocity when object weight was kept constant. This finding was consistent

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[9] The weight varied from 28.7g to 256.5g in the constant size group with a mean weight increase of 45.6g between objects; the weight varied from 3.2g to 617.3g in the constant density group with a mean weight increase of 122.8g between objects.

with our earlier results showing that there was no object effect on the release velocity in the constant weight group. Next, we performed a linear regression for the constant size group using the variation of object weight. Since object weight varied as a geometric progression, we log transformed weight for the linear regression. The regression was significant ($R^2 = 0.12$, $F_{1,\ 142} = 19.02$, $p < 0.001$) with a significant slope ($\beta = -\ 2.19$, $t = -\ 4.36$, $p < 0.001$), suggesting that the weight variation affected the release velocity when object size was kept constant. These results showed that the weight variation was more significant than the size variation in its effect on release velocity. To examine the extent to which the variance of release velocity can be accounted for by the weight variation when size and weight covaried, we performed a linear regression on release velocities for the constant density group using just the weight variation (log transformed again).

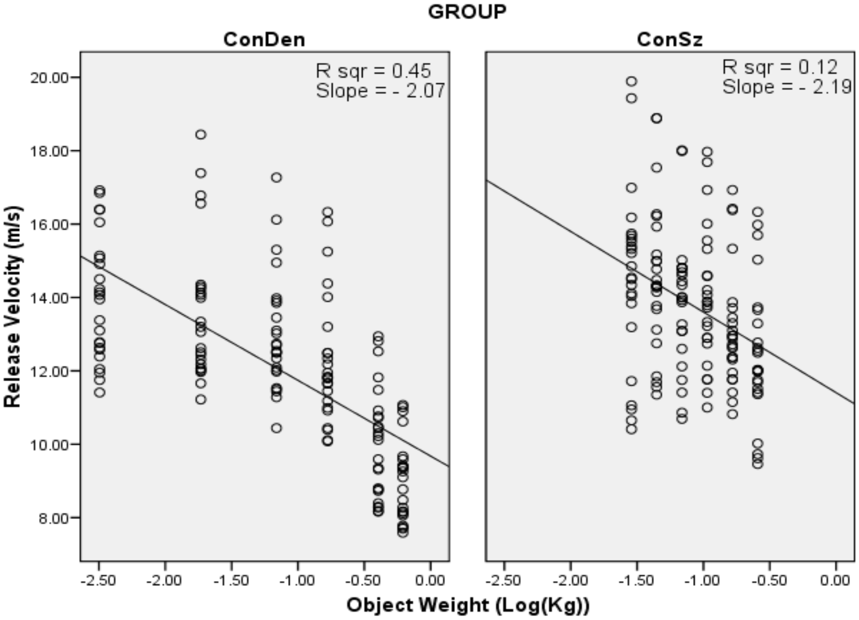

Figure 23 The linear regression on the release velocities using the log-transformed object weight with R squares and slopes depicted for the regression lines conducted for the constant density and constant size groups.

As seen in Figure 23, the regression line in the constant density group was the same and therefore parallel to that in the constant size group. The regression was significant ($R^2 = 0.45$, $F_{1, 142} = 116.12$, $p < 0.001$) with a significant slope ($\beta = - 2.07$, $t = - 10.77$, $p < 0.001$), suggesting that only weight variation affected release velocity. A multiple regression contrasting the slopes of the two regressions revealed no difference between the slopes ($t = - 0.25$, $p > 0.05$), which convinced that the release velocity was affected only by the weight variation, not size. Either a small (as in the constant size group) or a large (as in the constant density group) variation of object weight was sufficient to yield the change of release velocity, and faster throws were exhibited when participants threw the lighter objects.

Previously, Cross (2004) found that for object weights greater than 50 g, the release velocity followed a power function of weight with an exponent of – 0.15. Zhu & Bingham (in press) simulated the release velocities in projectile motion for skilled throwing using the measured throwing distances together with object size and weight and release angle. The power function between the release velocity and weight (greater than 50 g) for skilled throwing was: $\text{Velocity} = 14.8 \times (\text{Weight})^{-0.15}$. Since a relation between the release velocity and the weight was found in the current study, we investigated whether the same power law was followed. We selected both constant density and constant size groups (because both had variation of object weight), and performed a linear regression on the log transformed release velocities using the log transformed object weights[10] to reveal the power function. Since the power function only obtains for weights greater than 50 g, we used object weights greater than 50 g. The regression was significant ($R^2 = 0.45$, $F_{1, 188} = 152.98$, $p < 0.001$) with a significant slope ($\beta_0 = - 0.17$, $t = - 12.37$, $p < 0.001$) and a significant intercept ($\beta_1 = 0.95$, $t =$

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[10] A log-log linear regression is transformable to a power function.

80.32, $p < 0.001$). The transformed power function, Velocity = 8.9 × $(\text{Weight})^{-0.17}$, yielded a similar exponent (- 0.17 vs. - 0.15) but a smaller coefficient (8.51 vs. 14.8) of weight than in skilled throwing, indicating that the acquisition of throwing skill might have only affected the coefficient of weight in the power function. To test this possibility, we performed regressions for each practice week to see whether the coefficients and exponents of weight changed in the power functions. First, all regressions were significant ($p < 0.001$). The value of R^2 increased from 0.33 at the first week to 0.45 at the last week. The slopes of the regression lines varied from – 0.13 to – 0.17, while the intercepts of the regression lines varied from 0.88 to 0.95. Second, multiple regressions performed to contrast all regression slopes and intercepts between weeks (coding the two to-be-contrasted weeks as 1 and -1) revealed no differences between slopes ($p > 0.05$), but a significant increase of intercept from the early practice to the late practice ($t \geq -2.38$, $p < 0.001$), both of which suggested that the exponent in the power function did not vary with practice, but the coefficient corresponding to the intercept did. The increase of the intercept yielded the corresponding increase of release velocity for the lightest object (weight = 50 g) by 2.04 m/s. We also performed regressions on release velocities using object weights less than 50 g. The regression was only significant in the first two weeks with a very small R^2 value ($R^2 = 0.07$, $F_{1, 94} = 7.06$, $p < 0.05$ at week one; $R^2 = 0.05$, $F_{1, 94} = 5.62$, $p < 0.05$ at week two), and the regression became insignificant at week three and after, suggesting that after practice the release velocity was not affected by object weight at all. This finding confirmed that the power law would only take effect on the release velocity when object weights are greater than 50 g.

Discussion

Throwing, together with other movements such as reaching, grasping, and kicking, is a fundamental type of motor skill that is commonly referred to as an object-control skill (Payne & Issacs, 2004). These movements can be performed by children in their early ages, and thus are considered as the early start of human-environment interaction. In an ecological view, the movement performance is determined by the interaction of constraints from task, performer, and environment (Newell, 1986). Given the goal of the task in the current study was to throw objects to a maximum distance. The throwing performance mainly depended on how skilled the thrower was and how the environment constrained the throwing. The current study addressed first the kinematic changes of throwing with the skill acquisition, and second, the impact of the environmental constraints from thrown objects, namely, object size and weight, on the throwing dynamics.

The acquisition of throwing skill results in the ability to throw objects farther. We found significant improvement of throwing distances with practice for all participants, indicating that participants acquired some skill to perform long distance throws through training. Throwing contributes to a determination of the distance of projectile motion of a thrown object in two ways, namely by determining the release velocity and the release angle. We investigated how these two properties changed with the acquisition of throwing skill. We found that although practice did not yield a significant mean change of the release angles, it did affect their variability. Practice yielded a general reduction of variability of the release angles around a mean of 33°. On the other hand, the release velocity increased directly with the increase in throwing skill, and faster throws produced longer throwing distances. Both mean values and the variability of the release velocity improved with practice. As a result, more reliable faster throws were generated. However, due to the physical constraint of the thrown object, throwing generally exhibited less variability in both release angles and velocities for larger or/and heavier objects.

The second factor that we investigated was how the physical properties (size and weight) of thrown object would constrain the throwing performance when throwing skill was acquired. In the present study, we found that thrown objects yielded a significant effect on the mean change of both throwing distance and release velocity after practice, indicating that the dynamics of both throwing and projectile motion was constrained by the physical properties of thrown object. The post-hoc analyses further revealed that there were different objects being thrown either with the maximum velocity or to the maximum distance in each practice condition. In the constant density condition where object size and weight covaried, an object of moderate size and weight was thrown to the farthest, but the maximum release velocity was consistently developed with the lightest and smallest object. In the constant weight condition where only object size varied, the same release velocity was used to throw all objects although the smallest one always travelled to the farthest. Last, in the constant size condition where only object weight varied, an object of moderate weight reached the farthest distance although the lightest object was thrown fastest. The indication was that while both object size and weight played roles in projectile motion to determine the throwing distance, only object weight determined the release velocity to affect the dynamics of throwing. To determine the respective role of object size or object weight in the dynamics of throwing, we performed linear regressions on release velocities using either the size variation in the constant weight group or the weight variation in the constant size group. The results showed a strong effect for weight, but not for size. Furthermore, the weight effect found in the constant size group was equivalent to that in the constant density group (sharing the same slope of regression), suggesting that weight, rather than size, determined the release velocity.

Consequently, we examined the power law relation between the release velocity and object weight. The results replicated those of Zhu & Bingham (in press) and Cross (2004), showing that release velocity followed a power function of object weight with an exponent of – 0.15 when objects weighted greater than 50 g, otherwise, it was independent of the object weight.

According to Cross's (2004) account of the power law relation between the release velocity and object weight, when the thrown object weighed less than 50 g, the acceleration of throwing would mainly depend on the ability of muscles to generate force to overcome the moment of inertia of the throwing hand and forearm, however, when the thrown object weighed more than 50 g, fast throws could be regarded as a relatively straightforward physics problem, because the acceleration of throwing would only follow the power law to decrease with increasing weight of thrown object, independently of the accelerative ability of muscles. Our results extended the understanding of this power law relation, showing that the exponent of weight in the power function was invariant, and practice of throwing could only yield the increase of the coefficient of weight in the power function which consequently increased the release velocity. Figure 24 illustrated the practice effect on the functional relationship between the release velocity and the object weight.

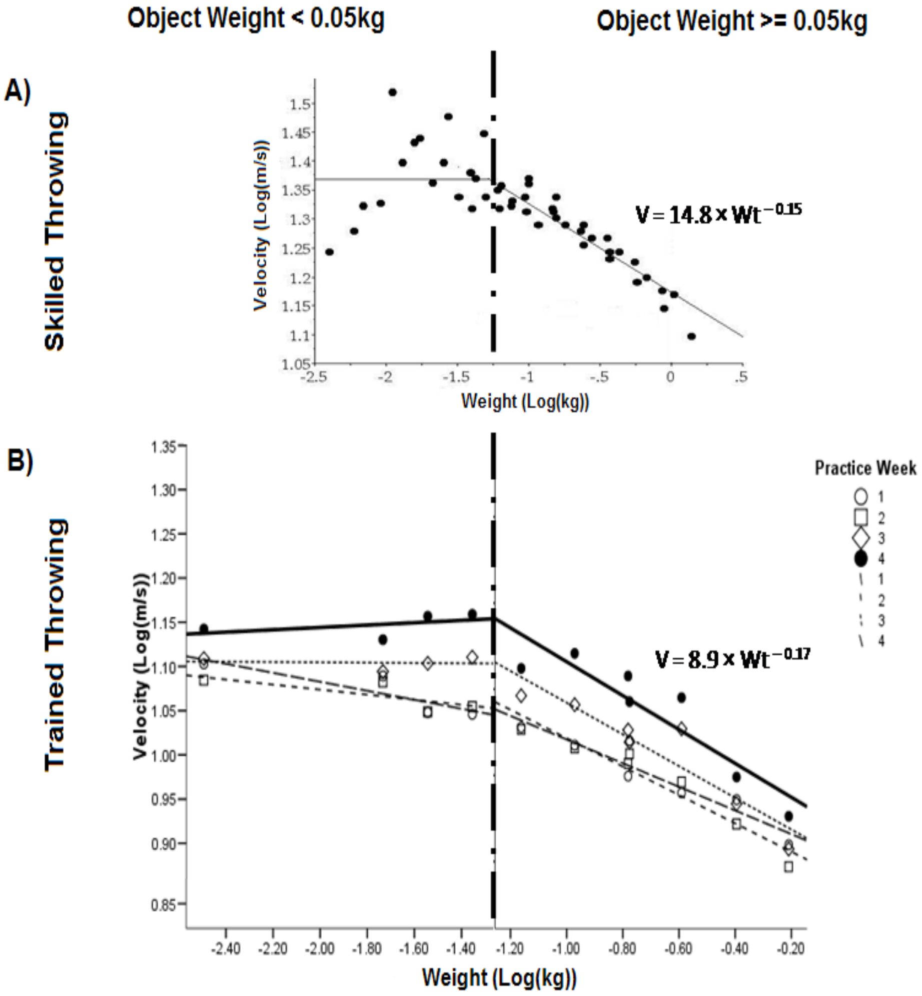

Figure 24 The functional relationship between the mean release velocity (log-transformed) and the object weight (log-transformed) for both trained throwing and skilled throwing. Panel A represents the skilled throwing, and Panel B represents the trained throwing, both separated by a vertical line that represents object weight = 0.05 kg. The power functions transformed from the linear regressions were provided for both types of throwing when object weights greater than 0.05 kg. The dashed line with open circles represents the regression in the first week of practice; the dashed line with open squares represents the regression in the second week of practice; the dashed line with open diamonds represents the regression in the third week of practice; the solid line with filled circles represents the regression in the last week of practice.

We regressed the mean release velocities (log transformed) in each practice week using object weights (log transformed) existed in both constant density and constant size groups, and compared them with the results found in skilled throwing (Zhu & Bingham, in press). First, the release velocity was constrained in the same pattern by object weight for both types of throwing, that is, object weight became to affect the release velocity (decrease with increasing weight) only when weight reached 50g and beyond. Secondly, the release velocities generated in skilled throwing were much higher than those in the current trained throwing. The maximum release velocity achieved by our participants after practice was just about same as the release velocity used by skilled throwers to throw the heaviest object, which suggested that our training yielded a better but not skilled throwing, and our participants were far more than expert throwers. Thirdly, the regression line in the trained throwing elevated in parallel from the first to the last week of practice, suggesting that practice only yielded the increase of the intercept, not the change of slope for the regression. Correspondingly, only the coefficient, not the exponent of weight in the power function increased. To be mentioned, 94% of participants who met the criterion for the current study were females, while participants in the skilled throwing were mainly males. Thus, factors such as gender, skill level, and deliberate practice could potentially make difference of the ability to generate fast throws, but they can only make difference by changing the coefficient, not the exponent of weight in the power function of release velocity.

Bingham et al. (1989) and Zhu & Bingham (in press) found that skilled throwers identified objects of an optimal weight in each size that they were then able to throw to a maximum distance. The question raised by this finding was whether these optima were determined by the interaction of object size and weight in the effects on throwing dynamics. The results of the current study confirmed these of Zhu & Bingham (in press) showing that only object weight affected throwing itself. The effect of size is only on the projectile motion dynamics. Distances of throw are determined by the effect of object weight on throwing to yield a given release velocity together with the effects of object weight and size on projectile motion given the initial angle and velocity at release.

CHAPTER 4

General Discussion

Human perceptual system often demonstrates being sensitive to the relation between the environment and the perceiver. It informs the perceiver of what possible action could be taken and what consequence that action would yield to the environment-actor system. We particularly studied people's ability to perceive the affordance for maximum distance throws. Our results revealed that this ability was acquired through learning to throw where the knowledge of result about throwing distance was available, and the affordance was perceived using a smart perceptual mechanism which allowed the perceiver to associate the perceived heaviness with the seen maximum throwing distances. The kinematic analysis of throwing further revealed that the contribution of the dynamics of throwing to the determination of the maximum throwing distance was mainly exhibited in the release velocity, which follows a power function of only object weight, not size. Thus, the idea that hefting is a smart mechanism because of the symmetry between the dynamics of hefting and throwing was rejected.

Discussion on "Learning to Perceive the Affordance"

We argued that the ability to perceive the affordance for throwing was acquired rather than intrinsic. The results supported this proposition showing that unskilled throwers were poor at judging the optimal objects for throwing before practice, but the majority of them (those threw with vision) became sensitive to the optimal objects for throwing after practice. Indeed, throwing experience, in the manner of learning throwing skill, exploring object size and weight and seeing the distance of throw, allowed throwers to tune their perception to the information relevant to the affordance. However, it seems that the experience of seeing the distance of throws is critical to the acquisition of the affordance perception. Participants who practiced throwing without vision acquired the throwing skill as much as their vision counterparts, but they did not acquire the sensitivity to the optimal objects, indicating that the perception of the affordance for throwing involved visual elements although it is mainly a haptic task.

We also examined whether the perception of the affordance for throwing was acquired through function learning or using a smart perceptual mechanism. The results showed that practice with objects constrained in either size variation (constant size) or weight variation (constant weight) or both (constant density) yielded equal acquisition of the affordance perception. Since a single sampling of one variable (size or weight) yielded a generalized learning to the complete function with respect to the throwing distance, the function learning hypothesis has to be rejected. Learning the affordance does not involve acquiring a lookup table for a single valued function (distance) of two variables (size and weight). The smart perceptual mechanism hypothesis was supported on the other hand. Through practice and throwing objects constrained in size or/and weight property, the perceptual system began to differentiate the information about the functional relation between the throwing distance and both object size and weight, and once the information was attuned through vision (seeing the distance of throw), the registration of either size or weight was sufficient to bring about the perception of the affordance for throwing. The perceptual system was able to take advantage of the available information to simplify the perceptual problem, exhibiting the "smartness".

Discussion on “Learning to Perform Maximum Distance Throws”

By measuring the release velocity and release angle during practice of throwing different sized and weighted objects, we were able to examine the developing changes of kinematics with acquisition of throwing skill, as well as the potential roles of object size and weight in the dynamics of throwing. We found both throwing distance and release velocity increased with practice and they became more and more dependent on the thrown object, indicating that practice yielded a positive effect on throwing, and how far and fast an object can be thrown depended on the size and weight of the thrown object. Although practice yielded the general reduction of the variability on the release angles, the mean release angles neither changed with the improved throwing distances, nor systematically varied with object size or weight, indicating that release angle contributed less to the dynamics of throwing in determining the maximum throwing distance. Consequently, the effects of object size and weight were examined on the release velocity to reveal how object size and weight would affect the dynamics of throwing. The results was in agreement with the previous study (Zhu & Bingham, in press) showing that only object weight, not object size, affected the release velocity to determine the contribution of throwing dynamics to a determination of throwing distance. Furthermore, the functional relation between the release velocity and the object weight was determined. Release velocity followed the power function of object weight with an invariant exponent and a changeable coefficient, suggesting again that the dynamics of throwing was constrained naturally by the object weight.

Implications & Question Remained

The current study clearly supported the smart perceptual mechanism hypothesis, because the affordance was perceived after acquisition of the throwing skill independently of the experience of throwing objects with constrained variations of either size or weight or both. There must be a single informational variable detected by hefting to elicit the affordance. However, the smart perceptual mechanism supported here is different from what was supposed before. According to Bingham et al. (1989), hefting provided a perceptual access to the affordance for throwing because similar dynamics was shared by both hefting and throwing. This hypothesis assumed first that the perception of the affordance was actualized mainly through a haptic task (hefting) with few role of vision. Perceiver could judge the optimal objects without seeing objects being hefted in hand. Second, the impact of object size and weight on both hefting and throwing should be similar. Conversely, we found that learning the affordance for throwing required vision to provide perceptual access to the functional relation between the throwing distance and both object size and weight. In addition, object size and weight did not both affect the throwing dynamics, only object weight did. The implication is that the smart perceptual mechanism should not be actualized through the symmetry in the dynamics of hefting and throwing.

Nevertheless, the smart mechanism hypothesis was supported by our results in current study. So, the question is how did this work? The answer lies in the finding by Bingham et al. (1989) that the relation between optimal weights and object size was as that of the classic size-weight illusion, in which objects of increasing size must weigh more to be perceived of equal heaviness. The optimal objects for throwing in different sizes should be all felt of the same heaviness. This presumably is the invariant information for the affordance. When objects of different sizes and weights were hefted in hand, they were perceived of different heaviness, however, only one particular perceived heaviness was optimal for throwing. Thus, the perception of the affordance entails discriminating the invariant perceived heaviness that corresponds to maximum throwing distances. Because the optima only appear in throwing distances (as a function of both size and weight) not in the release velocities (as a function of only weight), the only way for perceivers to relate their perceived heaviness to the throwing distances is to see how far each felt heaviness can be thrown, by which the optimal perceived heaviness can be revealed. Once the optimal perceived heaviness is identified, the affordance can be perceived, and the perception of the affordance can be generalized to any situation where the optimal perceived heaviness can be detected.

Why optimal objects for long distance throwing are perceived to have equal heaviness remains to be determined. A number of different accounts of the size-weight illusion have been proposed, but none have been convincingly verified. The most current hypothesis is that proposed by Amazeen & Turvey (1996), which is that perceived heaviness is a function of an object's rotational inertia. The problem with this is that the objects created in Bingham et al. (1989) all had nearly equal rotational inertias because the weights of Styrofoam objects of different sizes were varied by packing them with lead at their centers. So the mass distributions and thus rotational inertias varied little. Another common account is in terms of expectations of experienced heaviness when an object is lifted. However, Mon-Williams et al. (2000) have shown that the "illusion" persists after an object has been lifted and its weight has been thoroughly tested. The bottom line is that perceived heaviness is a function of both size and weight and that function covaries with the affordance for long distance throwing.

Conclusion

The present study suggests that learning the affordance for throwing not only requires the throwing skill to be learned, but also requires the throwing distance to be seen. However, once the affordance is learned, the perception of the affordance does not require either throwing the object or seeing how far the object can be thrown. All it takes is to heft an object using the skilled throwing limb, exhibiting the smartness of the perceptual system.

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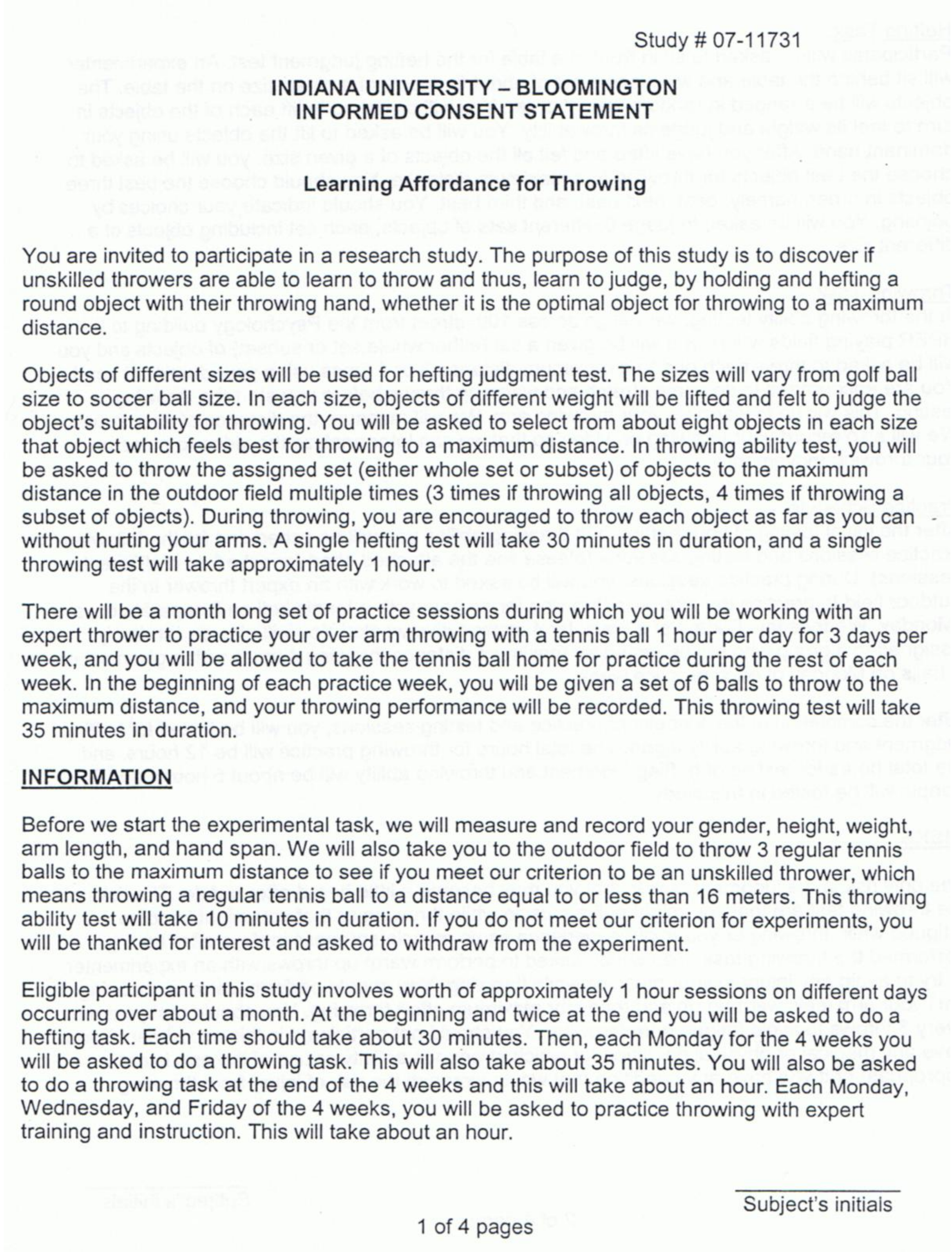
APPENDIX A: HUMAN SUBJECT CONSENT FORM



Study # 07-11731

INDIANA UNIVERSITY – BLOOMINGTON
INFORMED CONSENT STATEMENT

Learning Affordance for Throwing

You are invited to participate in a research study. The purpose of this study is to discover if unskilled throwers are able to learn to throw and thus, learn to judge, by holding and hefting a round object with their throwing hand, whether it is the optimal object for throwing to a maximum distance.

Objects of different sizes will be used for hefting judgment test. The sizes will vary from golf ball size to soccer ball size. In each size, objects of different weight will be lifted and felt to judge the object's suitability for throwing. You will be asked to select from about eight objects in each size that object which feels best for throwing to a maximum distance. In throwing ability test, you will be asked to throw the assigned set (either whole set or subset) of objects to the maximum distance in the outdoor field multiple times (3 times if throwing all objects, 4 times if throwing a subset of objects). During throwing, you are encouraged to throw each object as far as you can without hurting your arms. A single hefting test will take 30 minutes in duration, and a single throwing test will take approximately 1 hour.

There will be a month long set of practice sessions during which you will be working with an expert thrower to practice your over arm throwing with a tennis ball 1 hour per day for 3 days per week, and you will be allowed to take the tennis ball home for practice during the rest of each week. In the beginning of each practice week, you will be given a set of 6 balls to throw to the maximum distance, and your throwing performance will be recorded. This throwing test will take 35 minutes in duration.

INFORMATION

Before we start the experimental task, we will measure and record your gender, height, weight, arm length, and hand span. We will also take you to the outdoor field to throw 3 regular tennis balls to the maximum distance to see if you meet our criterion to be an unskilled thrower, which means throwing a regular tennis ball to a distance equal to or less than 16 meters. This throwing ability test will take 10 minutes in duration. If you do not meet our criterion for experiments, you will be thanked for interest and asked to withdraw from the experiment.

Eligible participant in this study involves worth of approximately 1 hour sessions on different days occurring over about a month. At the beginning and twice at the end you will be asked to do a hefting task. Each time should take about 30 minutes. Then, each Monday for the 4 weeks you will be asked to do a throwing task. This will also take about 35 minutes. You will also be asked to do a throwing task at the end of the 4 weeks and this will take about an hour. Each Monday, Wednesday, and Friday of the 4 weeks, you will be asked to practice throwing with expert training and instruction. This will take about an hour.

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Subject's initials

1 of 4 pages

Hefting Task.

Participants will be asked to sit in front of a table for the hefting judgment test. An experimenter will sit behind the table and will place a set of about 8 objects of a given size on the table. The objects will be arranged in random weight order. You will be asked to lift each of the objects in turn to feel its weight and judge its throwability. You will be asked to lift the objects using your dominant hand. After you have lifted and felt all the objects of a given size, you will be asked to choose the best objects for throwing to a maximum distance. You should choose the best three objects in order, namely, best, next best, and third best. You should indicate your choices by pointing. You will be asked to judge 6 different sets of objects, each set including objects of a different size.

Throwing Task.

In the throwing ability testing, we will go across 10th street from the Psychology building to the HPER playing fields where you will be given a set (either whole set or subset) of objects and you will be asked to throw each one to a maximum distance 3 or 4 times using your dominant hand. You are encouraged to do some stretch and warm up throws before you start the throwing testing. This will be to warm up your throwing arm. We will measure the distance of your throws. We will also record your throwing on video so that we can later analyze the video to measure your throwing movements.

Practice Schedule.

After the initial testing of your hefting and throwing ability, you will be scheduled for the following practice sessions and testing sessions (please see the attached chart for schedule of different sessions). During practice sessions, you will be asked to work with an expert thrower in the outdoor field to practice the over arm throwing for an hour with a tennis ball on 3 separate days (Monday, Wednesday, Friday) of a week for 4 consecutive weeks. You will also be randomly assigned to a group who will be tested for maximum distance throwing 4 times with a given set of 6 balls on Monday of each practice week.

After the completion of the 4 weeks of practice and testing sessions, you will be tested for hefting judgment and throwing ability again. The total hours for throwing practice will be 12 hours, and the total hours for testing of hefting judgment and throwing ability will be about 5 hours, and 24 people will be tested in this study.

RISKS

The only risk in the judgment task is that you may become a little bored after awhile. The risks of the throwing test are that you might pull a muscle while throwing or that you might become fatigued while throwing or you might experience some muscle soreness in days after having performed the throwing task. You will be asked to perform warm up throws with an experimenter to try to avoid any injury to your muscles while throwing. You should perform warm up throwing until your arm feels warmed up and ready for maximum effort throwing. You should rest your arm every 3 throws to avoid fatigue from throwing. You should not participate in this experiment if you have any medical or physical condition for which strenuous activity or use of the arm is not appropriate or if you have any condition that would increase the risk of injury from throwing.

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Subject's initials

EMERGENCY MEDICAL TREATMENT

In the unlikely event of physical injury resulting from your participation in this research, emergency medical treatment will be provided at no cost to you. Be certain that you immediately notify the researcher if you are injured. If you require additional medical treatment you will be responsible for the cost. No other compensation will be provided if you are injured in this research.

BENEFITS

The benefit anticipated from this study is to discover whether and how unskilled throwers are able to perceive and select optimal objects for throwing with hefting using their throwing hands and potentially how the perceptual act of feeling and testing objects might be related to the act of throwing those objects. The potential benefit to you personally is to gain skill of throwing by practice with an expert thrower and potentially to have some fun if happen to enjoy this task.

CONFIDENTIALITY

We will assign you a number for identification purposes. Your data will be recorded only with this number to allow us to keep the body measurements, judgments and throwing data together. The recorded video tapes will be only used for data analysis and will be destroyed after that by 2010.

COMPENSATION

A check will be issued and mailed to your provided address after participation of the experiment. The value of the check will be $9 per hour for the time you spent in the hefting judgment and throwing ability testing experiments rounded up to the nearest half hour. If you withdraw from the study prior to its completion, you will receive $9 per hour for the time you spent in the study rounded up to the nearest half hour. Since expert instruction will be given, you will not get compensated for the hours spent in the instructional practice that is total of 12 hours spreading in 4 weeks.

CONTACT

If you have questions at any time about the study or the procedures, (or you experience adverse effects as a result of participating in this study), you may contact the researcher, Qin Zhu at Room 322 in the Psychology Building at Indiana University, 1101 E. 10th Street, Bloomington, IN 47405tel. 812 855 4322, and qizhu@indiana.edu .

If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact the office for the Indiana University Bloomington Human Subjects Committee, Carmichael Center L03, 530 E. Kirkwood Ave., Bloomington, IN 47408, 812/855-3067, by e-mail at iub_hsc@indiana.edu

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Subject's initials

PARTICIPATION

Your participation in this study is voluntary; you may refuse to participate without penalty. If you decide to participate, you may withdraw from the study at any time without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed.

CONSENT

I have read this form and received a copy of it. I have had all my questions answered to my satisfaction. I agree to take part in this study.

Subject's signature_____________________________Date ________________

Consent form date: February 12, 2007

See Attachment for Chart for Schedule of Experimental Sessions

IRB Approved
Approval Date: FEB 15 2007
Expires: FEB 14 2008

APPENDIX B: CURRICULUM VITAE

Curriculum Vitae of Qin “Arthur” Zhu

Address:

800 N UNION ST APT 515	Telephone: 812-857-9413
BLOOMINGTON, IN 47408	Email: qizhu@indiana.edu

Department of Kinesiology
Indiana University

Career Objective:

- A successful scholar in teaching and research with specialization in human movement science
- A knowledgeable educator promoting the active and healthy life

Education Background:

- PhD candidate in ***Human Performance***, minor in ***Psychology*** (2006)
  Department of Kinesiology, Indiana University
  Dissertation expected to be final defended by Nov. 2007
  Advisors: Dr. John B. Shea & Dr. Geoffrey P. Bingham
- M.Ed in ***Exercise Science*** (2002)
  Graduate School, Shanghai University of Sports
  Advisor: Dr. Jian-Cheng Zhang
- BS in ***Physical Education*** (1999)
  Department of Coaching and Physical Education, Shanghai University of Sports
  Advisor: Dr. Jin-Biao Dai

Academic Positions:

- 2007 – Present: Adjunct Faculty, Department of Kinesiology, Indiana University
    - *Motor Learning*, *Badminton, Tennis* (Independent Teaching)
    - *Experimental Analysis and Design* (Teaching Assistant)
- 2002 – 2006: Associate Instructor, Department of Kinesiology, Indiana University
    - *Motor Learning, Badminton, Tennis* (Independent & Assistant Teaching)
- 2000 – 2002: Research Associate & Instructor, Department of Coaching and Physical Education, Shanghai University of Sports
    - *Sport Psychology*, *Motor Skill Acquisition* (Teaching Assistant)

Research Lab Experience:

- 2002 – Present: IU ***Motor Control and Learning*** Laboratory
  Department of Kinesiology, Indiana University, Director: John B. Shea.
- 2003 – Present: IU ***Perception and Action*** Laboratory
  Department of Psychology, Indiana University, Director: Geoffrey P. Bingham.
- 2004 – Present: IU ***Ergonomics*** Laboratory
  Department of Kinesiology, Indiana University, Director: John B. Shea

Professional Affiliations:

- Student Member of North American Society for the Psychology of Sport and Physical Activity
- Student Member of American Alliance for Health, Physical Education, Recreation and Dance
- Member of USA Badminton Coaching Education Department
- Member of USA Badminton Court Official Committee, National Umpire of Badminton

Other Appointments & Services:

- 2003 – present: Coordinator for IU-SUS academic exchange program, Indiana University, IN, USA
- June. 2004: Director & Coach of IU Badminton Camp
- 2002 – 2003: President of IU Badminton Club, Indiana University, IN, USA
- 2001 – 2002: Administrative Assistant, China Badminton Association, China
- Nov.2000: Assistant Investigator, China Office of Census, China
- 1983 – 1995: Professional badminton player serving Junior National Team of China, China

Awards & Grants:

- Title: School of HPER Research Fund for Dissertation
  Funding Agency: School of HPER
  Duration: 2006-2007
  Amount: $1100
- Title: School of HPER University Fellowship
  Funding Agency: Indiana University
  Duration: 2002–2005 (Annually)
  Amount: $1100
- Title: School of HPER Travel-Grant-in-Aid Award
  Funding Agency: School of HPER
  Duration: 2002–2006 (Annually)
  Amount: $250
- Title: Department of Kinesiology Travel-Grant-in-Aid
  Funding Agency: Department of Kinesiology
  Duration: 2002–2006 (Annually)
  Amount: $250

Honors:

- 2002 ~ 2005: School of HPER University Fellowship Award
- 2003/04/11: School of HPER Gallahue-Morris Graduate Research Award
- 2002/06/25: Best Graduate Thesis in Shanghai University of Sports
- 1995 ~ 1999: Outstanding student in Department of Coaching and PE at SUS
- 2006/10/05: Reported in the article “Badminton phenom has Olympic dreams” on Herald-Times newspaper, http://www.heraldtimesonline.com/
- 2005/08/25: Reported in the article “A champion of and for his sport” on Herald-Times newspaper, http://www.heraldtimesonline.com/
- 2004 ~ present: Student Spotlight on Homepage of IU Athletics and Sports
- 2003 ~ 2004: Male Athlete of the Year, Club Sports, Division of IU Recreational Sports
- 2003 ~ 2004: Most Improved Club Sport, Club Sports, Division of IU Recreational Sports

Conference Presentations:

1. *The Effect of Practice Order on Learning Three Simple Motor Tasks*, Poster in NASPSPA in junction of ACSM, Denver CO, June 2006
2. *The Grouping Effect on Simple Motor Task Switching*, Motor Learning & Control Verbal Presentation: “Switching Effects on Action” in NASPSPA Conference, St. Pete’s Beach FL, June 2005
3. *The Effect of Switch Practice and Amount of Pre-switch Trials On Task Switching Performance,* Research Consortium 12-minute oral presentation at the 2005 AAHPERD National Convention in Chicago, Illinois, April 2005
4. *The Effect of Practice on Task Switching Performance*, Poster in NASPSPA, Vancouver, Canada, June 2004
5. *The 3rd Asian Conference on Sports Science*, Beijing, China, May. 2004
6. *10th Measurement and Evaluation Conference*, Urbana-Champaign IL, Oct. 2003
7. *Research on Selective Attention in Modern Badminton Competition with the Technique of Spatial Occlusion*, Poster in NASPSPA, Savannah GA, June 2003

Academic Publications:

Published Journal Article:

1. **Zhu, Q.** & Bingham, G.P. (in press). Is hefting to perceive the affordance for throwing a smart perceptual mechanism. *Journal of Experimental Psychology: Human Performance and Perception*.

Published Journal Abstracts:

1. **Zhu, Q.** & Shea, J.B. (2006). The effect of practice order on learning three simple motor tasks. *Journal of Sport & Exercise Psychology, 28S*, 197.
2. **Zhu, Q.** & Shea, J.B. (2005). The grouping effect on simple motor task switching. *Journal of Sport & Exercise Psychology, 27S*, 164.
3. Parry, T.E., Shea, J.B. & **Zhu, Q.** (2005). Task Switching effects of a single-segment stimulus on the performance of a multi-segment motor task. *Journal of Sport & Exercise Psychology, 27S*, 121.
4. **Zhu, Q.** & Shea, J.B. (2004). The effect of practice on task switching performance. *Journal of Sport & Exercise Psychology, 26S*, 205.

Other Publications

1. **Zhu, Q.** & Chen, D.P. (2002). The research on selective attention in badminton competition with the technique of Spatial Occlusion. *Unpublished Thesis for Master Degree in Shanghai University of Sport.*
2. Ren, J., Zhang, J.C., Jin, Y.H. & **Zhu, Q.** (2001). The implicit learning and distractive practice in motor skill learning: coping with the stress. *Journal of Sports Science,* Volume 3, Beijing, China.
3. **Zhu, Q.** & Zhang, J.C. (2000). Status Quo of researches on selective attention in contemporary sports. *Academic Journal of Shanghai Institute of Physical Education,* Volume 4, Shanghai, China.
4. **Zhu, Q.** & Dai, J.B. (1999). Study of the speed in movement of Badminton, *China Badminton Coach,* Shanghai, China

Special Skills:

- ***Computer techniques***:
  - Hardware repair
  - Familiar with using following Software:
    - Microsoft Office Package
    - JavaScript
    - Macromedia Flash
    - Adobe Premiere & Photoshop
    - Qualisys Track Motion Capture System
  - Statistics and Programming:
    - Matlab
    - SPSS
    - E-Prime
- ***Language***: English and Chinese, proficiency in speaking and writing
- ***Badminton***: Expert level in playing, coaching, and officiating; can help to establish a badminton program at the academic level
- ***Communication:*** Good at team working with colleagues in a cross-culture and multi-disciplinary environment