Especial Skills

ESPECIAL SKILLS

By

KATHERINE M. KEETCH,

Hons.B.Kin., M.Sc.

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Doctor of Philosophy

McMaster University

DOCTOR OF PHILOSOPHY (2008) McMaster University

(Kinesiology) Hamilton, Ontario

TITLE: Especial Skills

AUTHOR: Katherine M. Keetch, Hons.B.Kin (McMaster University), M.Sc. (McMaster University)

SUPERVISOR: Dr. Timothy D. Lee, Ph.D.

NUMBER OF PAGES: xii, 131

Abstract

Considerable controversy exists about how motor skills come to be represented in memory as a product of practice. One line of research advocates specificity effects, whereby skills are considered highly specific to the conditions under which they are learned. An alternative view suggests that motor control is flexible and non-specific; that motor skills are represented in a more general manner, whereby the representation is an abstraction of the products of practice. Although experimental findings exist that support both specificity and generality of motor skills, such evidence has emerged from very different experimental conditions and paradigms, making direct comparisons difficult. An important and interesting question then is what would happen if both specificity and generality effects could be documented within a single paradigm? And what could be said about motor control theory if such effects co-exist?

The possibility that a single memory representation may be developed for an entire class of skills (i.e., generality), but that performance of one member of that class may be distinguished from the rest (i.e., showing specificity effects) was examined. The basketball set shot (characterized by the feet remaining planted on the floor during execution) performed by highly-skilled players represents such a class of skills. Skilled performers have massive numbers of practice attempts of the set shot, however taken predominantly at 15-ft. (free-throws from the foul-line), with only minimal practice at other locations (in front of and behind the foul-line or at different angles to the basket). The six experiments presented here examined the nature of learned memory representation of the basketball set shot in highly skilled players.

In an initial series of experiments, skilled basketball players were required to perform a series of shots from several target locations spanning 9- to 21-ft. in line with the basket, including the foul-line at 15-ft. This task was completed using two different types of basketball shots (set shots; Experiments 1 and 2, jump shots; Experiment 3). Results revealed that set shot performance at the 15-ft. location was significantly better than predicted by a regression equation based on the performance at the other locations in Experiment 1 and replicated in Experiment 2. However, the superior performance at the foul line was *not* found in novice players (Experiment 2b) or when individuals performed jump shots (in Experiment 3). Instead, performance was accurately predicted by the regression equation. We suggested that a massive amount of practice accrued over many years of basketball shooting establishes the free throw as an *especial* skill - one that represents a highly specific capability among the general class of set-shot skills.

In a follow-up series of experiments, we examined potential mechanisms underlying the emergence of the especial free throw skill with an attempt to reconcile our findings with theories of motor control. In Experiments 4 and 5 two possible explanations for the specificity effect were examined: the *visual-context* hypothesis (unique visual context including the visual distance and visual angle to the basket) vs. the *learned-parameters* hypothesis (overlearned specifications for the parameterizations of the set shot at 15 ft). In Experiment 4, skilled players performed set shots from the foul line (15 ft) and locations that were equidistant (15ft) but at different angles to the basket (15°, 30°, 45° to the left and right of the foul line). Performance of the set shot at the foul line was superior to the other locations, which is consistent with our previous specificity findings. In Experiment 5, players performed set shots and jump shots at the foul line and at player-chosen "favorite" locations on the court. A double dissociation was found: performance of the set shot was superior to the jump shot at the foul line but was inferior to jump shot performance at the players' favorite locations. These results are contrary to the learned-parameters hypothesis, but consistent with the visual-context hypothesis. In our last experiment, invariance in the timing structure of set shot execution of skilled players was examined to determine if the free throw was represented by the same or a distinct generalized motor program. Results revealed that the especial free throw is not represented in memory by a separate motor program compared to other set shot skills.

Overall, these experiments provided evidence that the free-throw is an *especial* skill, one which, as a result of massive amounts of practice, has a special status within a generalizable class of motor skills, and which is distinguished by its enhanced performance capability relative to the other members of the same class. The co-existence of skills represented by both specificity and generality effects have theoretical and practical implications which are discussed and warrant further investigation.

Acknowledgements

It took the generosity, love, and support of a multitude of people to get me to this point, and although saying a few kind remarks here won't truly express the gratitude I have in my heart - here goes. Tim – thank you for your understanding, insight, and kindness through the best and worst of times. You are an incredible man and friend. Dig – thank you, whole-heartedly, for your continued encouragement, guidance, and laughter. Jim – thanks for always getting a kick out of my strange humour and making me smile in return. Thank you, as well, to Don Dawson and Mike Khan for being a part of my defence committee. I would also like to thank my family for always being there for me, being proud of me, giving me strength, and loving me unconditionally. Hansen, Larry, Justin, Clare, Alicia, Kim, Mel, AJ, Thea, Kersten, Marty, Claudia, and Rako - thank you SO much for all the good times, quotes of the day, challenges, conversations, squash, phoenix fun, and genuine friendship over the last several years. A big *bop bop* goes out to all my friends outside the walls of Kinesiology: Kenzy, Jenn, Ian, Carissa, Sean, Dale, Lex, Natalie, Chris, Lynn, Tania, and Nikkers – you are all swapme (lol) and I'm extremely honoured, lucky and proud to have you in my life. Thank you for knowing everything about me and loving me just the same. Thank you to Elisa and you know why. Live love learn laugh and grow – that's what I've done because of all of you! Thank you, sincerely.

Table of Contents

Section **Page**

Chapter 2 (continued)

Section **Page**

List of Figures

Figure **Page**

List of Tables

Chapter 1

GENERAL INTRODUCTION

Specificity Effects in Motor Control

One of the oldest and most persistent findings in learning and memory research concerns *specificity* effects: performance in test is most likely to be optimized when the conditions under which the information or skills were practiced are identical to the conditions present in the test. This line of thinking was promoted early on in Thorndike's theory of "identical elements" (Thorndike, 1913; Thorndike & Woodworth, 1901), which claimed that performance in transfer is a function of the number of elements that are identical to those in the conditions of learning. This viewpoint received support during the middle of the 20th century when considerable work in the transfer of skills was being conducted (see Cormier & Hagman, 1987 and Schmidt & Young, 1987 for reviews); here, the general finding was that transfer was small unless the skills were essentially identical to one another.

Specificity effects are seen in experiments where the "conditions" in which motor skills had been acquired are altered in tests of retention and transfer. Variations of this basic experimental theme have been studied and many of them show a rather similar finding – more expert-like performance is demonstrated when the "conditions" remain the same in retention or transfer as they had been during the acquisition period, compared to situations when there had been a change in the conditions underlying practice and test (e.g., Davies & Thomson, 1988; Proteau, 1992; Elliott & Lyons, 1998; Khan & Franks, 2004). Of course, a key issue here is the definition of what a "condition" is, and how the effect of changing these conditions would impact the performance of motor skill. One attempt has classified these specificity effects as, context specificity, processing specificity, or sensory-motor specificity (Schmidt & Lee, 2005, chapter 11).

Context-specificity effects are represented by a class of experiments in which task-related information is altered at the time of test, perhaps with the participant being unaware of the change, and which results in degraded performance (e.g., Davies & Thomson, 1988; Smith & Vela, 2001; Wright & Shea, 1991, 1994). For example, Wright and Shea (1991) showed that switching the relation between intentional stimuli (e.g. positioning and numbering of keys in required sequences) and incidental stimuli (e.g., the colour and shape of the display) from that established in the original learning environment had a detrimental effect on the subsequent performance of keypress sequences in retention. Removing the intentional cues and requiring an individual to perform the keypress task in the presence of altered incidental stimuli alone resulted in a further decrement in retention performance. This finding indicates that motor skill learning is influenced by contextual dependencies that develop during task acquisition. Even though an individual can be directed to attend to particular event information (intentional stimuli) in order to aid task acquisition, a degree of dependency on other contextual information (incidental stimuli) can develop. So-called "state-dependent learning" is a similar notion, based on the learner's internal states (e.g., drug effects) during practice and test conditions (e.g., Eich, Weingartner, Stillman, & Gillen, 1975). Furthermore, some of the ubiquitous "home field" advantage in sport may be a consequence of context-specificity effects.

Processing specificity effects are seen when practice engenders a particular type of cognitive processing, which then facilitates later test performance when the same processing operations are promoted by the "conditions" of the test. Contextual interference effects, in which the advantage of random practice conditions remain strong despite similar (random) or changing (blocked) conditions at test, are thought to be due mainly to enhanced cognitive operations that support retention (Shea & Morgan, 1979). Observational learning paradigms (e.g., McCullagh & Caird, 1990) have shown that watching demonstrations of a *learning* model compared to an *expert* model enhances learning in novice performers. Processing specificity explains this result as it is thought that the observer and the learning model undergo similar problem-solving processes during learning (e.g., trial and error, strategies for adjustments in performance). This is contrary to the type of processing that watching expert models might elicit (whose performance is consistent and accurate from trial to trial) and so may not be beneficial for optimal learning. In these examples, it is the similarity of cognitive processing that supports the specificity effects.

In terms of *sensory-motor specificity*, an example of altered sensory-motor conditions is seen in experiments in which sensory information (e.g., vision) is systematically added or removed at the time of test (e.g., Proteau, Marteniuk, Girouard, & Dugas, 1987; Proteau, 1992; Proteau, Marteniuk, & Lévesque, 1992). For example, Proteau, et al. (1987) had individuals learn a manual aiming movement under full vision (of limb and target) or no vision (target only) for either 200 or 2000 trials. Participants were then transferred to a no vision test. Although all groups improved over acquisition, the key finding was that in transfer the full vision groups (i.e., 200 and 2000) performed markedly worse than the target only groups, with the latter showing further decrement than the former. Therefore, not only was it detrimental to performance to remove vision in transfer, but the degrading effect increased as the number of practice trials increased. Because of findings like this, Proteau (1992) proposed the *specificity of learning* hypothesis, which states that what is learned is specific to the conditions of practice, with an increasingly stronger effect as practice increases. Indeed, complimentary designs have revealed that the degrading effect with change in sensory conditions is *more* pronounced as the number of practice trials increased (see also Jordan, 1995; Park & Shea, 2005). It was also shown by Proteau et al. (1992) (also see Elliott & Jaeger, 1988) that a performance decrement in transfer could occur when a source of sensory information was *added* that was not present in acquisition. Specifically, adding vision in transfer caused a decrement to performance after individuals had been trained in a no vision condition. All these results, Proteau theorized, were in support of specific sensorimotor representations developing with extended practice where decrements could be predicted if the sensory information did not match the expected sensory consequences. Overall, these experiments have shown that either removing or adding sensory information, and thereby changing the information that had been available during the learning trials, or the "conditions" of practice, had a degrading effect on the performance of the test trials.

Of note, some these effects of specificity are not mutually exclusive. For example, unlike Proteau's representational position on specificity, work by Elliott and colleagues (e.g., Elliott, Chua, Pollock, & Lyons, 1995; Elliott, Lyons, & Dyson, 1997) has been used to support a "processing specificity" explanation of "sensory-motor specificity" (e.g., there will be positive transfer between sensory conditions only to the extent that processes are similar).

Despite the frequent demonstration of specificity in motor control and learning, there have been few attempts to model these effects in theories. One exception was Adams (1971) closed-loop theory, in which he represented the accumulation of skill as the learning of a specific representation in memory. According to Adams' theory, the learning of a blindfolded positioning movement resulted from the strengthening in memory of a specific underlying neural representation, which he called the *perceptual trace*. Figure 1 illustrates this aspect of Adams' theory. Early in learning (top panel), trace strength is generalized across many representations, both correct and incorrect. With continued practice and learning, the optimal or *correct* representation is selectively strengthened, thereby weakening the relative strength of competing representations (middle panel). The correct movement (bottom panel) is represented as a highly specific representation that has been strengthened to an extreme level, compared to competing (incorrect) perceptual traces. Although limitations in Adams (1971) theory have been noted over the years (see Schmidt & Lee, 2005, chapter 13), it is one of few, and perhaps the only motor control theory that provides an explanation for sensory-motor specificity effects.

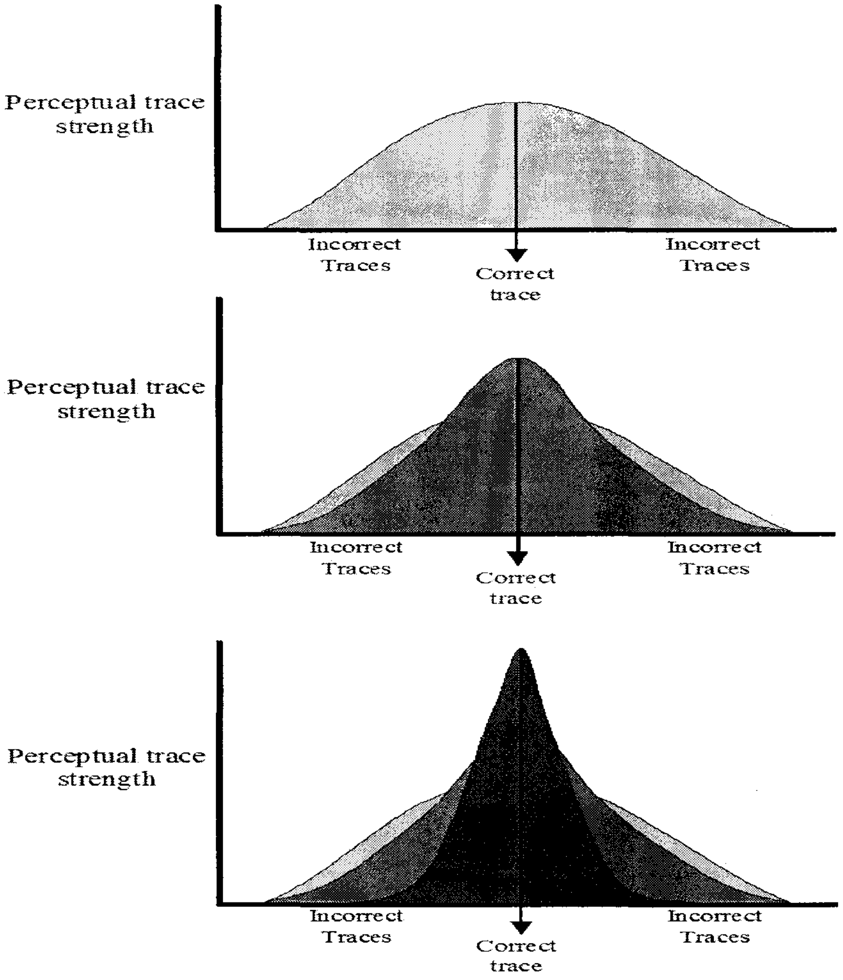

Figure 1. Adams' conceptualization of perceptual trace strength with continued learning.

Generality Effects in Motor Control

The specificity research suggests that motor skills are represented in memory in a highly specialized way--one that provides for optimization when the skills required for performance are either identical to the learned skills or, at least, when they are performed under the same conditions as experienced in learning. But, such a viewpoint contrasts sharply with evidence that motor control is highly flexible and non-specific. Indeed, other research focusing on motor skill generality suggests that the representation of motor control in the central nervous system provides opportunities for skills to be performed in many different ways. Lashley (1942) provided an early demonstration of generality by asking blindfolded participants to write words with their dominant hand, non-dominant hand, and foot. The similarity of the individual's handwriting characteristics under the different conditions and with different effectors was remarkable (see Bruce, 1994; Schmidt & Lee, 2005, p. 194, for more details). Further evidence by Bernstein (1947) and others (Merton, 1972; Raibert, 1977) supported the argument that the representation that underlies handwriting skill was *abstract* – one that was not stored in memory as a representation that was imbedded with neural commands to specific effectors. For example, although handwriting is a skill learned almost entirely with just one effector system--the fingers of the dominant hand, with the elbow and shoulder mainly fixed-- Merton (1972) has shown that a blackboard-sized signature (when reduced in size photographically) is nearly identical to that person's usual signature, even though the effector system has changed (shoulder and elbow movements with the fingers largely fixed). Generality findings such as these, and others, contributed to the development of one of the most widely cited motor control and learning theories to date—schema theory (Schmidt, 1975, 2003).

Schema Theory

Schema theory (Schmidt, 1975, 2003) formalized the generality of motor skill representations in detail, and provided a number of testable hypotheses. Schema theory suggests that motor skills were represented by *two* generalized memory structures.

According to schema theory, a class of motor skills is represented by a single representation, the generalized motor program (GMP), which stores the invariant features that control the movement's production (such as the relative timing of unspecified degrees of freedom; the order by which the individual parts of the movement unfold during action; and the relative force). A *class* of motor skills would be defined as a set of goal-directed actions that all share similar underlying characteristics, or "form," such as relative timing relationships. For example, over-arm throwing might be a single class of motor skills because all throws share similarities in the underlying timing patterns that are involved in producing the action. Any one performance of the GMP is facilitated by retrieved information from a second memory representation, the recall schema, which is responsible for assessing and supplying the parameters for the action (such as the overall time and force) to the GMP. The recall schema works like a type of regression equation by scaling the parameters as needed. According to the theory, when the performer attempts an action in the class, s/he retrieves the GMP for that class, and then specifies the values of the parameters to the program necessary to suit the environmental demands. In summary, one memory representation (the GMP) is needed for the underlying characteristics of an entire class of movements. The other representation (recall schema) can be used to supply the GMP with the details needed to produce a specific action as needed (i.e., the specifics do not need to be stored in advance). Thus, two generalized representations eliminate the need to have a separate program for each and every different way that the action can be produced.

According to schema theory, the development of the recall schema is contingent on the performer's ability to extract four pieces of information from every movement attempt. Once a GMP is selected and the recall schema has assigned the appropriate parameters for the movement, four sources of information are available briefly in short-term memory. Specifically, there is information about the *initial conditions* prior to movement (e.g., body position), the specific movement *parameters* that were assigned to the GMP (e.g., overall timing and force), *augmented feedback* about movement outcome, and the *sensory consequences* of the movement execution itself. It is the interplay between these sources of information that help establish the schema. Using the over-arm throwing example, each practice attempt at throwing different distances produces information that is abstracted and used to update the accuracy and reliability of the schema. The schema comes to represent the relationship between (a) the parameters of the GMP that were used on each attempt and (b) the outcome (e.g., distance thrown) that was produced in the environment on that attempt. Figure 2 is a diagram of how multiple practice attempts using different parameters and achieving different movement outcomes would develop the schema. In this way, the schema is not a collection of specific memories, but rather a rule that expresses the relationship among variables (e.g, if I use this much force, I will achieve this distance). In this sense, schema theory provides at least one way to conceptualize the generalizability of motor control.

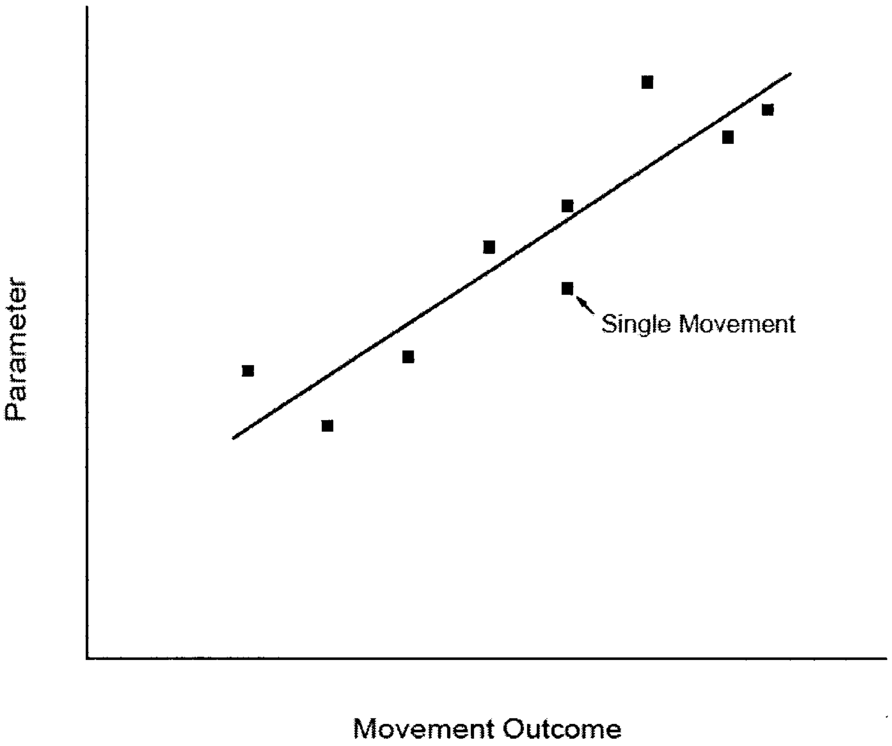

Figure 2. Conceptualization of the development of the schema rule.

Variability of Practice

Schmidt theorized that for successful motor learning it is not only important how much a skill was practiced, but also that how the skill was being practiced was *varied* (Moxley, 1979). Variety in practice allows the establishment of stronger interplay between the initial conditions, parameters and movement outcome, and consequently, strengthening of the schema rule. Indeed, schema theory predicts that practicing a variety of movement outcomes with the same general program (i.e., by using a variety of parameter values) will provide a plethora of informative experiences to build the schema upon.

The *variability of practice* hypothesis has been researched fairly extensively to test this tenent of schema theory (for a review see Van Rossum, 1990). It has been shown that learners acquire motor skills more effectively using variable practice over constant practice (i.e., where only one variation of the task is practice). For example, Shea and Kohl (1990, 1991) demonstrated the beneficial effects of variable practice on retention performance of a motor skill. In their design (1990), participants were required to learn how to produce a 175N force on a grip force transducer. The authors had the participants practice in either a criterion group (i.e., participants practiced producing the 175N force solely for a set number of trials), variable + criterion group (i.e., participants practiced producing the criterion force, 175N, plus forces ±25 or ±50 relative to the criterion), or criterion + criterion group (i.e., only 175N was practiced but for the same number of trials as the variable + criterion group). Results revealed that it was those individuals who had practiced in the variable + criterion group that showed superior retention performance compared to the other groups. Moreover, in a follow-up study (1991) it was found that increasing the amount of variability of practice increased retention to a greater extent on the same task. Importantly, the variability of practice effect has also been shown to transfer to novel variations of the motor skills practiced either different but within the range of skills practiced (e.g., McCraken & Stelmach, 1977) as well as for skills outside the range of skills practiced previously (e.g., Catalano & Kleiner, 1984).

Co-Existence of Generality and Specificity Effects?

Evidence to support the existence of both specific and general motor skill representations is abundant in the literature. However, rarely (if ever) have these apparent contradictions been acknowledged or discussed explicitly in theories of motor control (see Chamberlin & Magill, 1992, for a notable exception). How can extreme specificity and generality effects be explained within a single theory of motor control? One answer to the foregoing question is to deny that specificity and generality effects represent a problem for motor control theory. Essentially, the denial comes in the form of an "apples vs. oranges" argument – research paradigms that demonstrate specificity of learning effects are so different from the paradigms that reveal generality effects that their comparison, and divergent results, are moot issues. However, this explanation is unsatisfactory as will be demonstrated in the work to follow. What if both specificity and generality effects were found within the *same* paradigm? In that case, one would argue that motor control theory would be forced to consider seriously the problem of how such diverse effects could co-exist.

Are there particular learning conditions that produce highly specific products of practice, while other conditions produce more generalized products? One possible example might be a situation in which a particular member of a class of actions--because it has a "special" status in society--receives an inordinate amount of practice. One example might be baseball pitching (i.e., over-arm throwing); baseball pitchers have very high levels of practice at a 60.5-ft. distance (the regulation pitching distance in baseball), so this particular set of conditions might yield a very specific skill, perhaps separable in some way from over-arm throwing in general. Other potential candidates may be tasks that have more precise beginning and end points, with little variability in practice and game performance. Archery, darts, horseshoes, or rifle/pistol shooting come to mind as activities that have little variability in practice location, and also have outcome performance goals to targets also with little variability (e.g., the bullseye). In all of these examples, performers have very high levels of practice from particular locations.

In this dissertational work, we chose to examine the *set shot* in experienced basketball players. Set shots are typically performed as a coordinated lower and upper body shooting motion where the feet do not leave the floor. Importantly set shots are not typically practiced from spots other than the foul line (15 ft.) because, in a game, they can be easily blocked by an opponent. We assumed that the set shot represented a general class of skills for which one particular member, the *free throw*, had a unique status because of its role in the game of basketball. Examining a class of tasks (e.g. set shots) where one member of the class (e.g., the free throw) had received far more practice than the others allowed an evaluation of the performance of this particular variant relative to other variants that had received much less practice. Views that emphasize generality (such as schema theory) are essentially silent about any specific advantages afforded to the member of the class receiving extra practice, and focus more on the benefits from this one variant for the entire class. In contrast, specificity views would predict the emergence of a distinguished memory representation for that particular variant within the class.

A series of experiments that demonstrate the co-occurrence of generality and specificity effects within a single paradigm will be described. Such findings are in contrast, and call into question, the predictions made by schema theory. In this context, we introduce the term an *Especial* skill and offer compelling evidence for its existence. We define an especial skill as *one which, as a result of massive amounts of practice, has a special status within a generalizable class of motor skills, and which is distinguished by its enhanced performance capability relative to the other members of the same class.* We demonstrate the reliability of the effect (Experiments 2 and 4[1]), investigate potential mechanisms underlying the development of especial skills (Experiments 2, 4, 5, and 6), compare especial skills to other skills (e.g., jump shots; Experiments 3 and 5) and with participants of varying skill levels (Experiment 2b), and examine the timing structure of shot execution of this especial skill to elucidate if the free-throw is unique, relative to other members of the same class of skills (Experiment 6). Implications of the existence of especial skills are then discussed in terms of motor control theory, conditions of practice, and future directions.

---

[1] Data from Experiments 1-3 were published in Keetch et al., *Journal of Experimental Psychology: Human Perception and Performance (2005,31, 970-978).* Data from Experiment 4 appeared in Keetch et al., *Journal of Sport and Exercise Psychology (2008, 30, 723-736).* Full publication information is found in the List of References.

Chapter 2

Experiments 1, 2, and 3

Especial Skills: Their Emergence with Massive Amounts of Practice

Abstract

Differing viewpoints concerning the specificity and generality of motor skill representations in memory were compared by contrasting versions of a skill having either extensive or minimal specific practice. In Experiments 1 and 2, skilled basketball players performed set shots more accurately at the foul line than what would be predicted based on the performance at nearby locations, suggesting considerable specificity at this distance. The effect was replicated even when the lines on the court were obscured (in Experiment 2). However, the effect was absent when jump shots were executed in Experiment 3. The same specificity effect was not demonstrated by novice players (Experiment 2b), whose set shot performance was accurately predicted (hence, showing generality). We argue that massive levels of practice accumulated by skilled players at one particular member of a class of actions produce specific effects that allow this skill to stand out from the other members of the class, giving it the status of an *especial* skill. Various theoretical views are proposed to account for the development of these skills.

Introduction

Over the years, one of the most fruitful areas of research within the motor learning domain has been investigation of products of practice. Specifically, motor learning enthusiasts have theorized about how motor skills are developed with practice; how said skills become established in memory, and are successfully called upon and executed when required within given environmental demands. Of course there have been varying viewpoints and consequently lines of research in pursuit of a greater understanding of the nature of learned representations. The concepts of "specificity" and "generality" of motor skills has been the focus of research and debate in motor skills for almost a century. Some believe that motor skills are developed and represented in a very specific way, the notion of *specificity*; while others believe motor ability is much more flexible in nature, the notion of *generality.*

Conceptualizations of motor skills being represented in a general way have been evidenced on future performance attempts with different tasks or conditions of performance. It has been thought, and shown, that learned behaviours are applicable to a relatively wide range of task configurations and/or conditions under which the skill is being tested. Schmidt formalized the notion of generality of motor skill representation with Schema theory (1975). Schema theory suggested that motor skills were represented by two structures stored in memory. The first structure, call the *generalized motor program* (GMP), was viewed as responsible for storing the invariant features that supported a class of movements (e.g., over-arm throwing), such as the order of individual parts, and relative force and timing of those parts. A separate structure, called the *recall* *schema*, was responsible for supplying the parameters that were needed and appropriate to scale a specific implementation of the generalized motor program to the environmental demands. According to the theory, each practice attempt at, for example, throwing different distances produces information that is abstracted and used to update the accuracy and reliability of the schema.

The schema than comes to represent the general relationship between (a) the parameters of the GMP that were used on each attempt, and (b) the outcome (e.g., distance thrown) that was produced in the environment on that attempt. A useful analogy is the regression equation, where individual data points are used only to build and improve the equation's predictive capabilities (see Figure 2), and are not themselves stored as part of the representation. According to the schema view, shifting to a new instance of the same class (i.e., a task performed using the same GMP but with novel parameters) occurs effectively because the person can generate parameters for an environmental situation that has never been experienced previously. Considerable work has shown that varying (vs. holding constant) the parameters experienced in practice increased generalization to variants that had not been experienced earlier (whether within the range of tasks practiced or not, previously) (e.g., Catalano & Kleiner, 1984; McCraken & Stelmach, 1977; Shapiro & Schmidt, 1982; Shea & Kohl, 1990, 1991). In this sense, schema theory provides a way to conceptualize at least one way in which skill learning can be generalized.

An alternative focus, the specificity of learning notion, conceptualizes that one acquires capability that is highly specific to the particular skill performed in practice as well as the conditions (or context) under which the skill was experienced. When the skill is changed even slightly in subsequent performance attempts, decrements in performance are seen relative to performance of persons who have practiced the skill under the same configuration as required later. Moreover, skill tends to be sensitive to the context in which it is practiced, so that performance of the same skill in a different context produces decrements relative to performance in the same context, such as practicing in one room, and being tested in either the same or a different room (e.g., see chapters in Davies & Thomson, 1988). Such a point of view predicts that the transfer from one skill to another will be quite small—even if the tasks have some similarities—unless the tasks are practically identical.

Recent work that has seen the direct manipulation of the conditions of practice in tasks requiring precise aiming has provided support for specificity in skill learning. In this research (e.g., Elliott & Jaeger, 1988; Newell, Shapiro, & Carlton, 1979; Proteau, Marteniuk, & Levesque, 1992; Tremblay & Proteau, 1998), vision of the task and/or moving limb was either made available or not in practice. Participants then performed under similar or switched conditions in transfer. In support of a specificity viewpoint, performance was usually best when the transfer conditions matched those conditions that had been available during the practice trials. Moreover, the degree of specificity appears to be particularly large when the skills are very highly practiced (Khan, Franks, & Goodman, 1998, Proteau, Tremblay, & DeJaeger, 1998; Wilde & Shea, 2004; Yoshida, Cauraugh, & Chow, 2004; see Proteau 1992, 1995, and Khan & Franks, 2004, for reviews).

Considerable controversy presently exists about the extent to which the product of practice tends to be specific or more general. In order to provide additional insight into this question, we sought a way to examine a class of tasks where one member of the class had far more practice than the others. This would allow an evaluation of the performance of this particular variant relative to other variants that had received much less practice, allowing an evaluation of the transfer from the highly practiced variant to the relatively "new" one and vice versa. Schema theory would predict considerable transfer but is essentially silent about any specific advantages afforded to the member of the class receiving extra practice and focus more on the benefits from this one variant for the entire class. Other views that claim more specificity in learning would predict far less, or even no, transfer with the emergence of a distinguished memory representation for that particular variant within the class.

In studying this question we quickly realized that a problem we faced was that if we used naïve participants in a simple laboratory task, it would be difficult to create a situation where there is sufficient practice so that differences between the highly practiced variant and other members of the class of skills could be seen in the data. Consequently, the present research adopted a different approach wherein we used a naturalistic task for which such a condition – with very high experience at one version, and minimal experience at the others – was already met. We assumed that the *set shot* in basketball (typically performed as a one-handed shot where the feet do not leave the floor) represented a general class of skills for which one particular member, the *free throw*, had a unique status because of its role in the game of basketball. We capitalized on the use of skilled performers, as experienced basketball players have accumulated massive amounts of practice (certainly many thousands of practice attempts) specifically at 15 ft. (the foul line), yet only minimal practice attempts at any of the other distances. Also, by utilizing experienced players whom have accrued many years of practice at their craft (i.e., 10+ years), better ensured that the motor skill representations that had developed (whether specific or general in nature) were indeed well established in memory.

The theoretical predictions were simple. Viewpoints that emphasize the specificity of learned motor skill representations predict that years of practicing the set shot from the foul line would result in a memory that is highly specific to that context. Thus, performance from 15 ft. (at the foul line) should be reflected in a level of success that stands apart from the performance of the set shot at other, adjacent distances from the basket. In contrast, generality views (and schema theory in particular) predict no particular advantage when the set shot is performed from the foul line distance, with all the task-variations benefiting from the high level of practice at the foul line. Three experiments are reported that provide experimental tests of these predictions.

Experiment 1 – Specificity vs. Generality of Basketball Set Shot Performance in Experts

Studies of manual aiming, dating as long ago as Woodworth (1899), and frequently associated with the work of Fitts (1954), have found a close relationship between force production and error. Schmidt, Zelaznik, and Frank (1978) pointed out that, as the distance to the target increases, an individual must generate increased levels of force, which produces increased levels of variability in force output, resulting in a linear increase in the endpoint variability of the aimed movement (Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979; see also Abrams, Meyer, & Kornblum, 1989; Meyer, Abrams, Kornblum, Wright, & Smith, 1988; Patla, Frank, Allard, & Thomas, 1985). For an aiming task such as basketball shooting, both theory and common experience predict that a critical performance variable is the distance of the shooter to the basket.

In the present study, skilled players were asked to produce set shots at 9, 11, 13, 15, 17, 19, and 21 ft. from the basket. Based on force-variability principles, a decline in success rate was predicted as a function of the distance of the shot. Specifically, a negatively sloped regression line would appear as the error in shot success would increase linearly as a function of distance because increased levels of force would be required as the distance increased, thereby increasing the force variability in the movement output and increasing error. The predictions regarding the existence of a skill with particular, specific properties at 15 ft. (the foul line) must, therefore, be considered relative to performance *expected* from other, adjacent members of the class. Using a regression line established from the data generated at distances of 9, 11, 13, 17, 19, and 21 ft., the appropriate comparison for performance at the foul line (15 ft.) is the level predicted by the regressed interpolation. If specific effects result from high levels of practice at 15 ft., then the actual level of performance at the foul line should be significantly greater than the level predicted from the regression equation. This distinguished level of performance could occur even though the performance levels at the other distances would conform closely to the regression line. In contrast, Schema theory

(1975) would predict that performance at the foul line should be the same as the predicted level of performance based on the regression equation developed from the surrounding shooting distances, and thus performance at the foul line would fall close to the regression line created. Reason being, any practice of the set shot, regardless of distance to the basket, is merely used to update the schema applicable to all set shots.

Method

Participants

Eight male college student-athletes between 18 and 22 years of age volunteered to participate. They were all members of the California State University, Long Beach basketball program, which competes in Division I of the NCAA[2]. Participants represented all positions on the team (guard, forward, and center), and each had more than 12 years of experience in basketball shooting. None was informed about the purpose of the experiment.

Materials and environment

Basketball set shots were performed by all participants with their preferred limb. The action required a coordinated shooting motion involving the upper and lower limbs, with the feet maintaining contact with the floor at all times. The task was to propel an official leather basketball (Rawlings NCAA) toward a regulation basketball rim, mounted 10 ft. above the floor of a standard basketball court. Shots were taken from seven locations positioned in a straight line from the backboard, toward the center of the court. Each location was measured from the front edge of the rim, at intervals of 2 ft. beginning

---

[2] Data for Experiment 1 was collected by Doug Young at California State University, Long Beach.

from the shortest distance of 9 ft. Each location was marked and labelled using a 2 x 10 in. strip of masking tape. Participants were asked to position their feet as closely as possible to, but not on, the tape when taking the shot.

Procedure

The experiment began after the participants read and signed the ethics consent and listened to a standardized set of instructions. A total of 175 shots was performed on each of two consecutive days of testing (25 shots per distance per day), for a total of 350 shots (50 shots per distance). The shots were taken with 5-s rest intervals between trials, with a predetermined quasi-random order such that no more than two shots were taken at the same distance on consecutive trials. No emphasis was placed on the performance of any particular distance, and all participants were encouraged to perform each trial, regardless of distance, with the same level of effort and desire to score the shot.

Each trial began with the verbal announcement of the target distance (in feet), at which time the participant moved to the appropriate location before being handed the basketball. The participant then shot the basketball without any pre-shot routine (e.g., without dribbling the ball). The intertrial interval began when the ball returned to the floor after the shot. Performance on the trial (successful/unsuccessful) was recorded by an experimenter during the intertrial interval while another experimenter retrieved the ball. Participants were able to watch the ball flight and could determine goal success from the visual feedback.

Results and Discussion

The data were collapsed over the 50 shots at each of the shooting distances; the resulting means for each participant were used for further analyses. For each participant, the mean scores at the 9-, 11-, 13-, 17-, 19-, and 21-ft. distances were used to compute a linear regression equation, which accounted for 85.5% of the variance in the data, on average. These individual regression equations were then used to predict each participant's performance at the 15-ft. distance. The resulting set of predicted data were then compared with the participants' actual data from the 15-ft. distance in a one-tailed, directional, paired-samples t-test (we used a directional test because the hypotheses predicted either no difference or a specific, directional difference).

The results are illustrated in Figure 3. On the basis of the individual regression equations, the across-participants mean predicted percent success at the foul line was 72%. The participants' actual performance was 80.8%. This difference was statistically significant, $t(7)= 4.87$, $p<.05$, indicating that the data generated by the regression equations systematically underestimated the participants' actual performances at the foul line.

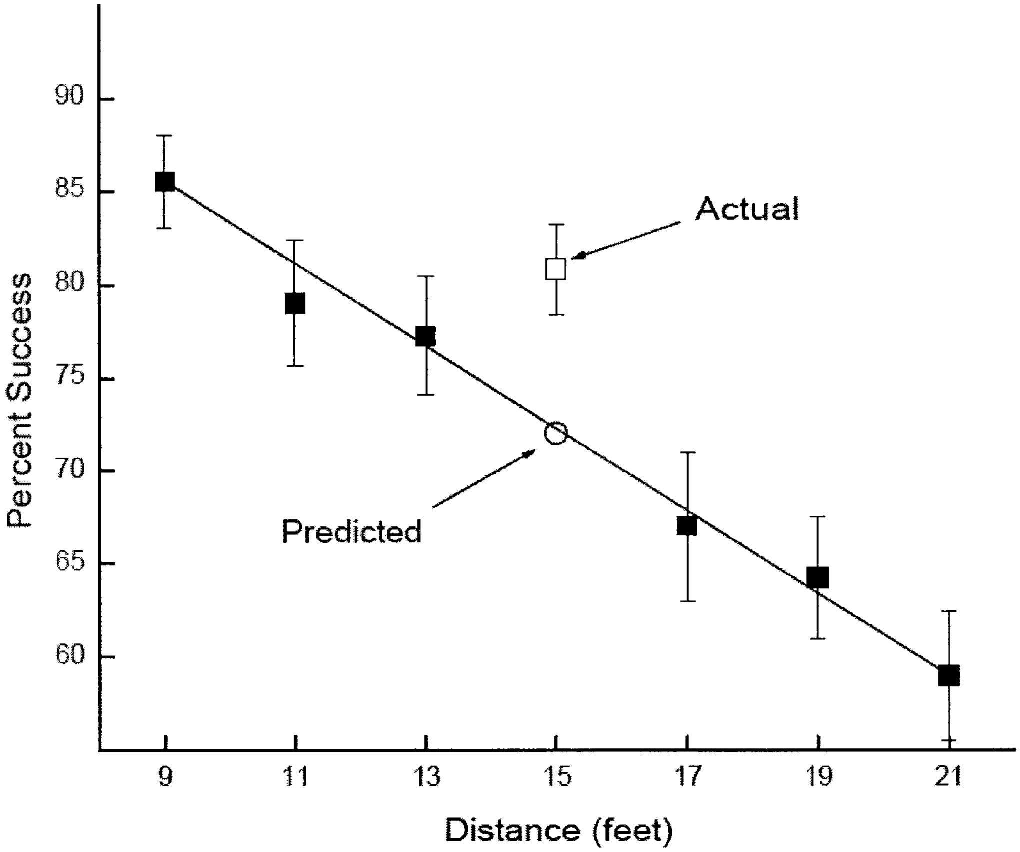

Figure 3. Expert set-shot performance (% success) as a function of the distance from the basket in Experiment 1. The filled squares represent the actual performance at the non-foul line distances; the unfilled square represents the actual performance at the foul line (15 ft.); and the unfilled circle represents the predicted success at the foul line (15 ft.) based on individual regression analyses using the non-foul line distances.

The results of this study support the emergence of a specific advantage for one highly practiced member of a class of basketball set shots. The free throw performances of expert basketball players were roughly equivalent to their set shot performance at the 9-11 ft. distance, and were significantly more accurate than free-throw performances that were predicted by regression analyses. These findings suggest that years of specific practice at the foul line produced a skill that has a specific motor-control advantage at that particular distance, and which provides little or no detectable advantage for any other distance, regardless of its proximity to the foul line (at least, no advantage for any of the other distances examined in this experiment). These findings are not predicted by generality views such as schema theory (Schmidt, 1975), which holds that nothing specific is learned about shooting at any one of the particular distances.

Experiment 2 – Replication and Extension: Does the Specificity Effect Remain with Removal of Incidental Visual Cues?

The purpose of the present experiment was twofold. First, quite simply, we were interested in attempting to replicate the specificity effect found at the foul line in skilled performers with a separate group of individuals. Second, we sought to investigate what might be some of the dimensions of this specificity effect. That is, which variables associated with the practice at the 15-ft. position are represented in the specific memory for that skill? An extreme view might hold that every aspect of the context becomes part of the skill. A more likely possibility, we suspect, is that several features of the 15-ft. context are represented, but not all of them. A basketball court has standard lines on the floor (the foul key in particular) that provide visual landmarks that could be used to stabilize free-throw performance. Are these lines, and the visual information provided by them, critical in influencing performance of this particular skill, and the specific advantages seen in the Experiment 1? It is certainly possible that they are, as the role of (seemingly) incidental cues in the establishment of memories, and the degrading effect if they are changed at test, is well documented in the literature (e.g., Smith & Vela, 2001).

A related set of findings has also been demonstrated for motor skills. For example, Wright and Shea (1991) found that actions learned in the context of specific, yet presumably incidental, visual cues were performed much more poorly when these incidental cues were no longer available at test compared to when they were available (see also Magnuson, Wright, & Verwey, 2004). In a different line of research, the often discussed "home-field advantage" in amateur and professional sport has been linked, in part, to an increased familiarity of the visual environment due to increased number of previous exposures available to the home team (Courneya & Carron, 1992).

The present study was conducted at a different university, using skilled females rather than males, with a smaller ball than used in Experiment 1 (but standard for females), and using five distances rather than seven. Nonetheless, the critical conditions of Experiment 1 were replicated here. As well, this experiment included an equal number of trials in which all of the set shots were taken in an altered visual context by the skilled players. In the altered context, the entire shooting area of the floor was covered with a tarp that effectively eliminated any of the incidental visual cues from the court surface that may have influenced performance in Experiment 1. In summary, Experiment 2 was conducted to assess the impact of the visual cues provided by the lines on the court, and to attempt to replicate the results of Experiment 1 in a separate group of skilled individuals.

Method

Participants

Eight female student-athletes between 18 and 23 years of age served as paid volunteers in the experiment. They were all members of the McMaster University basketball program, which competes in the league of Canadian Intercollegiate Sports. Similar to Experiment 1, the athletes represented all positions on the team and each had more than 10 years of experience in basketball shooting. None was informed about the purpose of the experiment. Participants gave informed consent prior to participation in the study in accordance with the guidelines established by the McMaster University Research Ethics Board.

Materials and environment

The materials and environment were similar to those in Experiment 1, with the following exceptions. For one-half of the trials, the part of the court used for the experiment was covered with a tarp material (Covermaster, Inc. floor covering). The participants shot a Spalding 28.5 TF-1000 zk Microfiber Composite basketball, standard for women's competition. Set shots were performed from five target locations positioned in a straight line directly away from the basket (9, 12, 15, 18, and 21 ft.). However, 12 markings were placed on the floor (and tarp) at intervals of 1.5 ft. starting at the 6-ft. location (see Figure 4). The reason for 12 markings instead of just for the five shooting distances was to make the target locations on the floor less obvious to the participants in the covered-floor condition (explained below). Each of the 12 locations was designated with a letter (A to L), with target distances being C, E, G, I, and K. An even number of marked locations was used; the absence of a "middle" location was expected to reduce the impression that any one of them coincided with the foul line. Each session was recorded using a Panasonic PV-DV400-K digital camera to augment data collection and analysis.

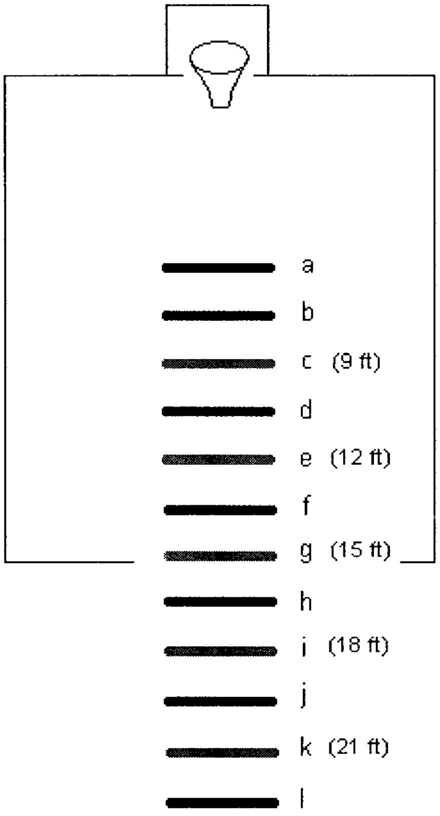

Figure 4. Experimental set up for Experiment 2 (and 3).

Procedure

The skilled players participated in two sessions, separated by about 24 hr. In one session ("uncovered floor"), the participants could see the normal basketball lines on the floor (e.g., key, 3-point zone). In the other session ("covered floor"), the entire half court used for the experiment was covered with the tarp. All participants performed 30 shots at each distance in each session (150 shots per day). In total, 300 set shots were performed, half with the floor uncovered and half with the floor covered. The floor-cover variable was counterbalanced, such that four participants performed in an uncovered/covered order, and the other four in the reverse order. Shots at each location were performed in blocks; six shots were performed at each distance before participants were moved to the next location on a verbal signal by an experimenter. The order of target distances was counterbalanced such that a complete repetition of the five distances was completed in each set of five blocks of trials (30 trials per set) before another repetition was started. A Williams square design (Williams, 1949) was used for counterbalancing such that, by the end of the second session, each location had been preceded and followed by every other target location twice. Participants were told to perform each shot at their own pace; however, a second experimenter controlled the overall flow between shots by handing over each basketball after about a 5-s interval. A third experimenter retrieved the basketballs and returned them to the second experimenter. Rest intervals were offered after every 60 shots.

Data analysis

Video analysis of the performance data facilitated later use of a four-point scoring system, rather than the two-point system used in Experiment 1. Three points were awarded for a successful, clean shot that resulted in minimal disruption in the downward trajectory of the ball's descent (a "swish," in basketball terms). Two points were awarded for a successful shot that resulted from the ball having hit and bounced off the top of the rim at least once before falling in. One point was awarded for an unsuccessful shot that resulted from the ball having bounced off the top of the rim at least once before falling away. Zero points were awarded for an unsuccessful shot that hit the bottom half of the rim and fell away, or that missed completely. Similar coding systems have been shown to be reliable in previous basketball shooting studies (Hardy & Parfitt, 1991; Wallace & Hagler, 1979); it was adopted here to increase the sensitivity of the scoring system. Two experimenters independently coded two athlete participants to test the inter-rater reliability of this coding system. Analysis revealed a correlation coefficient of r = 0.96, suggesting that the coding system was reliable. Thus, the primary investigator coded the remaining participants alone. Performance scores were converted to a percentage score: [(total points)/(3 x number of shots taken)] x 100.

Similar to Experiment 1, individual linear regressions were determined for each condition based on the four non-foul line distances (9, 12, 18, and 21 ft.). These regression equations were then used to generate predicted values at the foul line. The predicted data were compared to the actual data using a 2 (visual condition: uncovered, covered) x 2 (score: predicted, actual) repeated measures ANOVA. The effect of trial position within a block of trials was also examined using a 6 (trial position) x 2 (covered, uncovered) x 5 (shooting distance) repeated measures ANOVA.

Results and Discussion

The performance scores at the distances surrounding the foul line produced regression equations with R^2 values that accounted for an average of 85% of the variance in the uncovered floor condition, and an average of 88% of the variance in the floor-covered condition. Regression analyses of the uncovered-floor condition generated a mean predicted score percentage of 68.4% success at the foul line. The actual score was 74.9%. Regression analysis of the covered-floor condition revealed a mean predicted score of 66.9% for the foul line distance, compared to the actual percentage of 76.7%. The ANOVA revealed a main effect of the actual versus predicted scores, with $F(1,7)= 5.73, p<.05$. There was no significant main effect for visual condition [$F(1,7) = .01$] or for the interaction between score and visual condition [$F(1,7)=1.34$], both *p*s >.25. The means for all of the distances are shown in Figure 5.

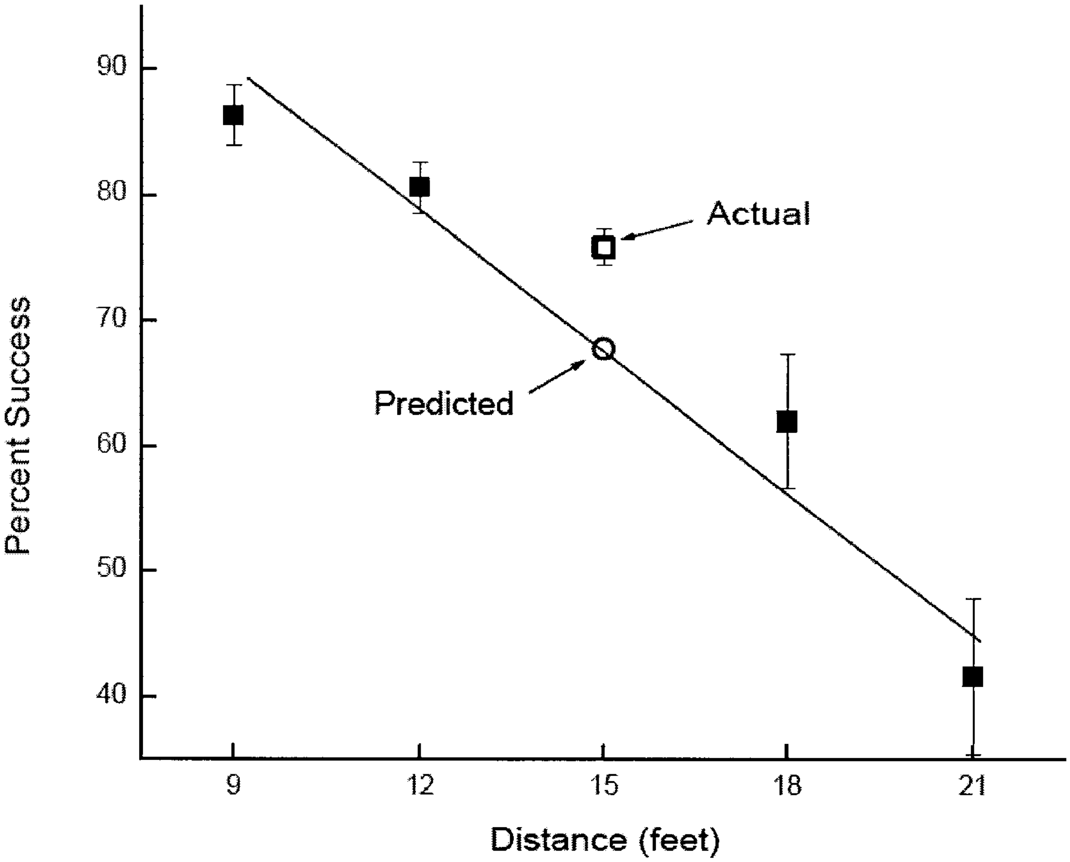

Figure 5. Expert set-shot performance (% success) as a function of the distance from the basket in Experiment 2.

The analysis of the position of a shot within a block of trials yielded just two significant main effects--for distance from the basket, $F(4, 28)=28.80, p<.001$, and for the trial position, *F*(5, 35)=4.18, $p<.001$. As depicted in Figure 6, performance became more accurate over repeated trials at the same distance within a block, but most dramatically from the first to the second shot taken at a new distance. The only significant differences found in the *post-hoc* tests were between trial position 1 and trial positions 2-6.

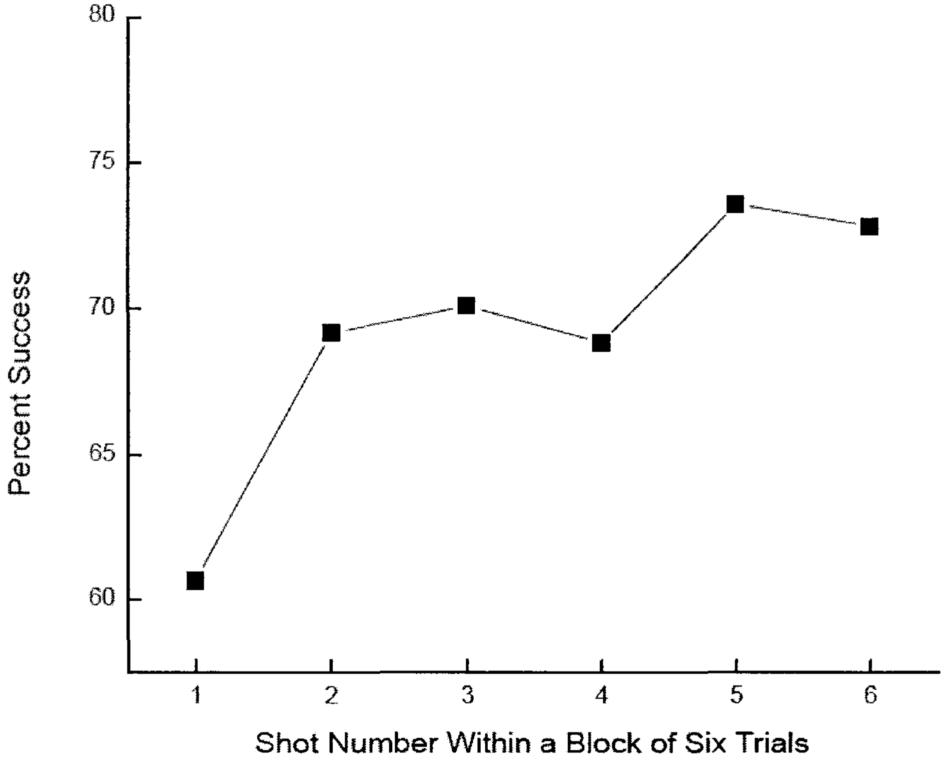

Figure 6. Set shot success (%) as a function of trial position in experts in Experiment 2.

These results both replicate and extend the findings from Experiment 1. The replicated findings again provide support for the existence of specific effects of practice at the foul line within the general class of set shots for skilled performers. Interestingly, the floor-covering variable produced no reliable effects; there was no detrimental effect on overall performance when all of the incidental cues on the court were covered. This suggests that the lines on the standard court were not a part of this specific representation. Also, covering the floor cues had no impact on the emergence of the free throw as a skill that stood out from performance at the other distances. The absence of any differential effect of the floor cover suggests that skilled players probably use direct visual information of the distance between their current location and the location of the basketball rim as the primary (and perhaps sole) source of perceptual input for movement preparation.

Performance on the first trial at a new distance was far less accurate than at any subsequent trial at that distance (i.e., within the immediate block of six trials). This finding is reminiscent of a *warm-up decrement* effect--a motor retention loss that received considerable attention over many years of study (Adams, 1952; Anshel & Wrisberg, 1993; Nacson & Schmidt, 1971; Schmidt & Nacson, 1971; Schmidt & Wrisberg, 1971; Wrisberg & Anshel; 1993; see Adams, 1961, for a review). For the purpose of the present investigation, it is interesting to note that the first-trial position was as detrimental to performance at the foul line distance as it was to performance at any of the other distances; i.e., neither the position by distance interaction, $F(20,140)<1$, nor the position by distance by floor cover interaction, $F(20,140)<1$, was significant. Thus, the trial-position effect was a *general* one--performance from the foul line was no more immune to this trial-position effect than was performance at any other distance.

Experiment 2b – Follow-up with Novice Players

Having found and replicated the specificity effect at the foul-line for experts in Experiments 1 and 2, we conducted a simple follow up study to examine whether or not *novice* basketball players would show the same performance effect. Our hypotheses were that overall shot success would be significantly lower in novices, compared to experts, at all shot distances. However, similar to experts, performance was predicted to conform to force-variability principles by showing a decrease in shot success as shot distance increased. In terms of foul line performance in particular, we predicted that novices would not show the same specificity effect. Instead, we posited that novices' actual performance at the foul line would be accurately predicted by their performance at the other shooting locations, thus showing a generality effect as would be predicted by schema theory. Reason being, novices, with minimal shooting experience from the foul line (or any other shot location for that matter), should not have established a specific representation for the free-throw. In an indirect way, finding no specificity effect in novice performers at the foul line would also attest to the fact that the performance advantage found in experts is a product of massive amounts of practice.

Method

Participants

Nine female university students between 19 and 24 years of age served as paid volunteers. All participants had only recreational experience with basketball shooting. That is, all had some experience with basketball shooting (understood what a set shot was and how it was performed) but none had any formal training, coaching, or team experience. None was informed about the purpose of the experiment and gave informed consent prior to participation in the study in accordance with the guidelines established by the McMaster University Research Ethics Board.

Procedure

The materials, environment and procedures used were identical to those in Experiment 2, with the exception that for the novice players, no shots were performed in a floor covered condition. The novices were not required to participate in the floor covered condition, as it was assumed they would not show a specificity effect at the foul line (nor be overly successful in the floor uncovered condition), and therefore this performance data would be of limited theoretical interest. Therefore, the novice players participated in one session in which the normal basketball lines on the floor were visible.

Data analysis

The same four-point scoring system was used to code the data as in Experiment 2 and the resulting performance scores were converted to a percentage score: [(total points)/(3 x number of shots taken)] x 100. For each participant, the mean percentage scores at the 9-, 12-, 18-, and 21-ft. distances were used to compute individual linear regression equations, which accounted for 95.5% of the variance in the data, on average. These individual regression equations were then used to calculate a predicted success score for each participant's performance at the 15-ft. distance. Similar to Experiment 1, the resulting set of predicted data were then compared with the participants' actual data from the 15-ft. distance in a one-tailed, directional, paired-samples *t*-test (we used a directional test because the hypothesis predicted no difference). The effect of trial position within a block of trials was also examined using a 6 (trial position) x 5 (shooting distance) repeated measures ANOVA.

Results and Discussion

The results of novice set shot performance are illustrated in Figure 7. The across-participants mean predicted percent success at the foul line was 28.0%. The participants' actual performance was 28.8%. This difference was not significant, with $t(8)= 0.26$, $p>0.05$, indicating that the data generated by the regression equations systematically and accurately estimated the participants' actual performances at the foul line. Of note, in order for there to be a significant difference at $p =.05$, novices participants would have needed to have an actual performance score of 32.3% at the foul line.

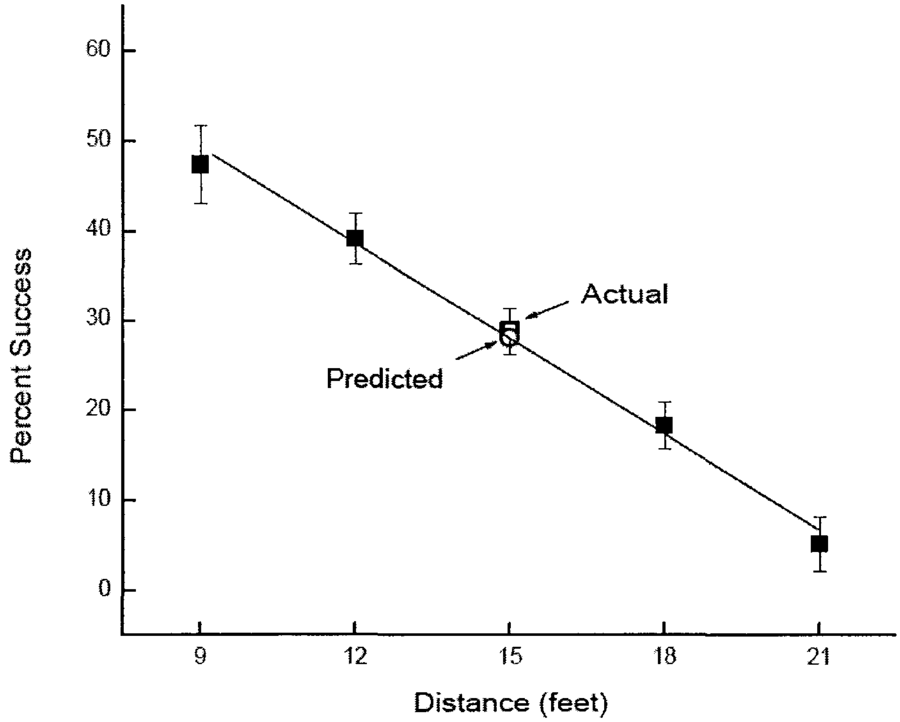

Figure 7. Novice set-shot performance (% success) as a function of the distance from the basket in Experiment 2b.

The analysis of the position of a shot within a block of trials yielded just one significant main effect for distance from the basket, $F(4, 32)=29.79, p<.001$. The main effect for trial position itself was not significant, $F(5, 40)=2.13, p=.08$, nor was the interaction, $F(20,160)=1.13, p=.32$. Performance was no more or less accurate over repeated trials at the same distance within a block, although there was a trend for trial 6 to be more accurate than the rest of the trials (see Figure 8).

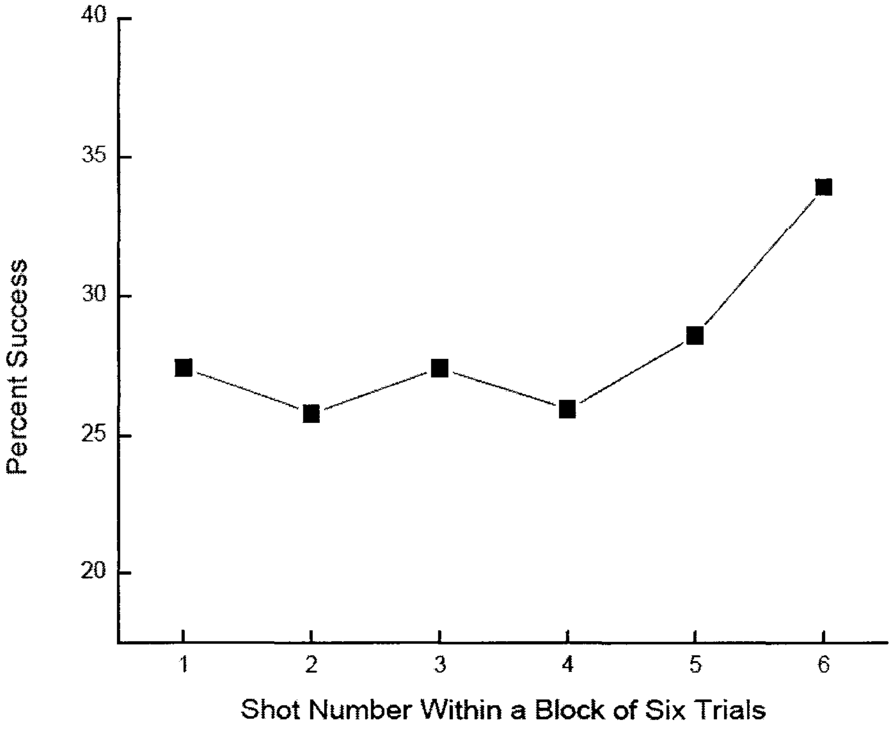

Figure 8. Shot success (%) as a function of trial position in novices in Experiment 2b.

As predicted, novice performance conformed to force-variability principles (i.e., increased error rate as shot distance increased). However, contrary to the results found in Experiments 1 and 2 with experts, free-throw performance in novices showed no specificity effect at the line. That is, performance was accurately predicted for the 15ft location based on performance at the other locations. This result is more in line with predictions of schema theory, that any practice that has been accumulated (regardless of location) has developed a more general performance effect. These results also provide evidence that in order for the specificity effect to develop, extensive practice must be accrued. Of course, we can not say exactly when the general effect turns into a specificity effect with our data (i.e., how much practice is needed to show this performance advantage at the line).

Experiment 3 – Jump Shot Performance

The set shot is a particular action that is normally executed at the foul line, as a free throw, with no defenders directly in front of the shooter to interfere with the shot. In contrast, the "jump shot" is typically taken during active play at many different locations on the court, from widely varying angles and distances to the basket. In this action, the player's feet leave the floor so that the shot can be taken at an increased elevation relative to a defender. Unlike the set shot, the jump shot is typically practiced with considerable variability in location (distance and angle to the basket), which is quite different than the constant distance and angle strategy that is typical of set-shot (free throw) practice. Therefore, it was predicted that no distinguished level of performance at the foul line would occur within the general skill of jump shots.

Method

Participants

The same varsity athletes that participated in Experiment 2 also participated in the present experiment.

Procedure

All trials for this experiment were conducted after the completion of the set shots for Experiment 2, on the same two days of testing. The equipment and testing area were identical to those in Experiment 2. In the present experiment, all participants performed the basketball jump shots with their dominant limb. The task involved a coordinated upper and lower limb shooting motion, during which the players' feet always left the ground. Participants were also instructed to take a single step into the jump shot, in a manner that was consistent with their typical practice performance. The goal of each participant was again to score as many shots as possible.

The experimental procedure was identical to that used in Experiment 2 (including the floor occlusion factor), with the exception that individuals now performed jump shots instead of set shots. The jump shots for the covered and uncovered courts were performed on separate days, as in Experiment 2.

Data analyses

All data collection and analysis procedures were the same as in Experiment 2, using the four-point scoring system. Two experimenters coded two participants independently, which resulted in a correlation coefficient of $r = 0.98$; therefore, the remaining participants were coded only by one experimenter. ANOVA models were the same as in Experiment 2.

Results and Discussion

The jump shot scores at the distances surrounding the foul line produced regression equations with R^2 values that accounted for an average of 82% of the variance in the uncovered floor condition, and an average of 79% of the variance in the floor covered condition. These findings are again consistent with force-variability predictions, with a linear increase in error (or, linear decrease in success) as the distance from the target increased, as seen in Figure 9.

Regression analyses of the uncovered floor condition generated a mean predicted score of 74.5% success at the foul line. The actual mean score was 75.4%. Regression analyses of the covered floor condition revealed a mean predicted score of 73.2% for the foul line distance, compared to the actual percentage of 74.2%. The ANOVA revealed that neither the main effect for shot (predicted vs. actual) nor the main effect for floor covering were significant, with both $Fs(1,7)<1$. The interaction also was not significant, $F(1,7)<1$. The means are also presented in Figure 9. The absence of a performance advantage at the foul line, contrary to the findings in Experiment 2, supports the contention that the foul line jump shot did not possess the specific products of practice as seen in the set-shot data by experts.

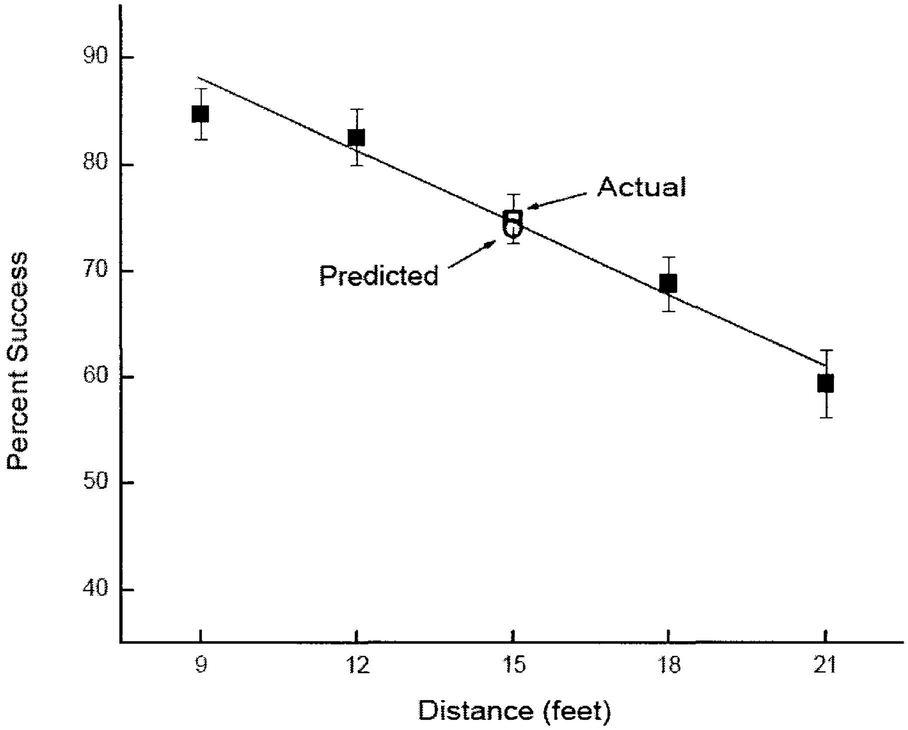

Figure 9. Expert jump-shot performance (% success) as a function of the distance from the basket in Experiment 3.

Similar to Experiment 2, the analysis of the trial-position data yielded just two significant main effects, for distance from the basket, *F*(4, 28)=35.01, *p*<.001, and for the trial position of the shot within a block of six trials, *F*(5, 35)=5.48, *p*<.001. Again, the most poorly performed trial was the first shot from the new distance. Unlike the finding in Experiment 2, however, not only was the first trial different from the rest, but shots at trial-position 2 were performed significantly more inaccurately than shots at positions 4, 5, and 6 (see Figure 10). This finding suggests that the jump shot required one more shot than the set shot to overcome the deficit from switching to this position from one of the other spots on the court.

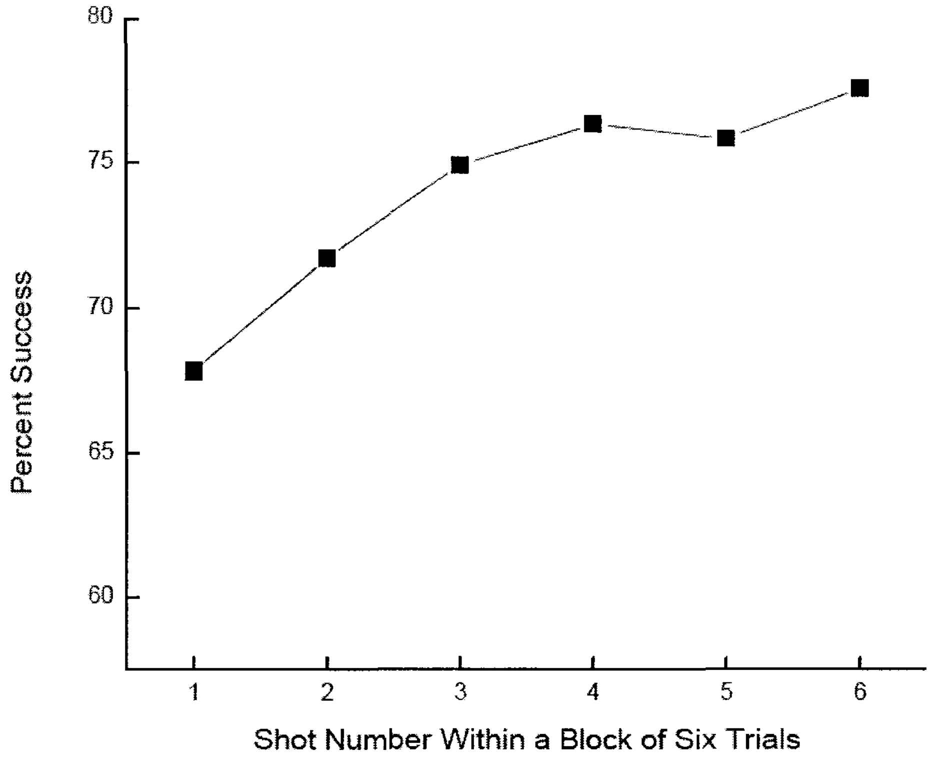

Figure 10. Jump shot success (%) as a function of trial position in experts in Experiment 3.

Note that the present results do not rule out the possibility that specific advantages might exist for some particular jump-shot distance and/or direction among the class of jump-shot skills--only that the 15-ft. position was not one of them. Experienced, high-level basketball players often seem to have “favorite” spots on the court from which they feel extraordinarily confident. Likely, this confidence has grown from many trials of practice at this spot, proportionally more so than at other positions on the court. The possibility that a performer’s self-selected “spot” might have specific advantages was addressed in Experiment 5.

General Discussion

To summarize, the key result from these experiments, particularly Experiments 1 and 2, is the remarkable degree of specificity as a product of practice. For experts, accuracy at the foul line was significantly greater than that predicted by the performances at the adjacent shot distances, suggesting that something over and above the generalized set-shot action was being learned in practice. Noteworthy, the same specificity effect was not found in novice players (Experiment 2b). Moreover, this specific advantage of practice at the foul line was apparently unrelated to the vision of the markings on the court, as the foul line advantage was not influenced by the presence of a floor covering (in Experiment 2) that obscured the standard court markings. In contrast, the jump shot results of Experiment 3 showed that shooting accuracy at the foul line was predicted well by performances at the adjacent distances; no distinct advantage for the jump shot occurred at the foul line, as had been seen for the set shot in the previous two experiments. With jump shots, none of the positions examined in this experiment should have considerably more prior practice than any other.

An incidental finding in the present studies was the effect of trial position. The finding is similar in some ways to previous findings of warm-up decrement, as performance after a rest interval shows a temporary loss for a short period after the activity is resumed. The present finding is different, however, in that it is the shift from one distance to another distance that caused the temporary decrement in performance. Since we cannot be certain of the cause for this effect (loss of set, forgetting, interference, etc.), we consider it to be of some theoretical interest for further research; although it will not be discussed further in this dissertation. However, the effect also has practical significance in that many free throws occur in pairs, and that the second of two free throws is likely to be more successful than the first. Interestingly, a similar finding appeared in data reported a number of years ago by Gilovich, Vallone, and Tversky (1985). In this frequently-cited study, Gilovich et al. analyzed some data sets for the presence or absence of so-called "hot-hand effects," testing the widespread belief that a basketball player has periods of "hot" and "cold" shooting spells. In one analysis, Gilovich et al. reported free-throw data for members of the Boston Celtics during the 1980-81 and 1981-82 seasons. From the data reported in their Table 3 (page 305; but not included in their reported analyses), the Celtics' players were successful on 70.6% of the first of two foul shots, and 75.2% on their second foul shot. A dependent *t*-test (n=9) revealed the 4.6% difference in shooting accuracy to be significant at $p<.005$, ($t(8)=3.72$) (see also Wardrop, 1995). Therefore, the incidental finding in our experiment is consistent with data from NBA game statistics.

High Levels of Practice and Specificity

It is likely that the differences we observed between the predicted and actual foul line performance was due to the extreme levels of practice these expert performers had experienced at the foul line in set-shot training. This claim is strengthened by the fact that we did not find the same effect in our novice players. We cannot be certain, of course, about the number of shots that had been taken over the years from the foul line by these experts, but it is safe to say it would number in the range of several thousands to several tens-of-thousands. In contrast, the amount of practice at any one of the other particular distances would be minimal if one assumes that set shots are normally practiced only at the foul line. Using expert basketball players, in which such a large discrepancy in practice levels exists for the free-throw versus the other distances, was probably a strong factor in allowing us to detect the specific advantages of the foul line. These findings are in contrast to the data by Chamberlin and Magill (1992a, 1992b). They used a class of tasks, with extended practice at one instance and minimal practice at others, with naïve participants in the laboratory. It is possible that the relatively small amount of practice in their study was one of the reasons for the failure to detect specificity effects. In addition, other research has shown that the size of the specificity effects (visual feedback specificity and effector specificity) appears to become *larger* when the skills are very highly practiced (Proteau, Tremblay, & DeJaeger, 1998; Park & Shea, 2003; Yoshida, Cauraugh, & Chow, 2004; for reviews see Proteau, 1992, 1995; Shea & Wulf, 2005), which is consistent with our findings here.

Individual-Differences Approaches

Even more generally, it is interesting to note that our evidence is consistent with earlier evidence from an individual-differences approach, which suggested that increasing levels of skill are associated with increased specificity-of-learning effects. Jones (1966), for example, reviewed work showing that, as a function of extended practice, a given task (a) correlates systematically lower with other reference tests of underlying abilities, and (b) correlates higher with a factor that is specific to *that* task. Jones hypothesized that practice was a process of simplification (see Schmidt & Lee, 2005, chapter 13, for a discussion), in that the tasks came to represent increasingly more task-specific (learned) factors and systematically fewer inherited abilities. It is interesting that the earlier individual-differences approach and current experimental approaches have seemingly converged on the same answer, but from very different starting points.

In a different way, the specificity of motor skills can be seen in a controversial viewpoint popularized by Franklin Henry in the 1960s. Henry and his many students (e.g., Bachman, 1961, and Lotter, 1961, to name two) discovered that the shared variance between the performance of any two motor tasks was essentially zero, even when those two tasks were seemingly rather similar (e.g., static vs. dynamic balance; speed of reaction vs. speed of movement). This suggested that motor abilities were specific to the task (Henry, 1968). And, many of the studies used tasks for which considerable practice was provided, showing that the learned representations (as opposed to fundamental abilities) were also quite specific (see also Fleishman, 1967; Fleishman & Rich, 1963).

Especial Skills

For these specific, highly proficient skills we propose to use the term *especial*, invoking Webster's meaning as "distinguished among others of the same class" (http://www.webster-dictionary.org/definition/especial). For the present purposes, we define an especial skill as *one which, as a result of massive amounts of practice, has a special status within a generalizable class of motor skills, and which is distinguished by its enhanced performance capability relative to the other members of the same class.* Our interpretation is that the high levels of practice of this particular variant of the set shot made this version especial in some way. Especial skills "stand out" from among the remainder of adjacent skills that do not enjoy this status as a result of massive levels of practice.

Especial skills seem possible in any number of real-world situations for which the (perhaps arbitrary) "importance" of one, particular member of a class of skills is far greater than all the rest. The free-throw among all possible set-shot distances is one example, of course, because of the nature of the game of basketball. There is almost certainly nothing that is "biologically special" about the 15-ft. distance and it is far more likely that the seemingly arbitrary choice of a free-throw distance in the rules of basketball was the ultimate basis for these effects. We can think of other examples as well, such as the 60.5-ft. throwing distance (relative to other throwing distances) for pitching in baseball (as mentioned earlier), the skills on a 3-m diving board (among all other possible diving-board heights), or perhaps the specialized welding techniques that an assembly worker might gain after years of doing the same task.

Also, we suspect that there will not be very many especial skills in one's *repertoire*. This concept seems limited to those skills that have an ideal pattern that is essentially invariant across different attempts--that is, to so-called "closed skills." Open skills, where the environment is unstable and or unpredictable, would seem not to be amenable to the development of especial skills. And, we suspect that massive amounts of practice at this one variant are going to be required. All of this suggests that the average person does not possess very many of these. As such, the concept of especial skills does not do very much damage to the "storage problem" for motor skills (Schmidt, 1975, 2003), adding only a few additional representations to memory.

Thus, at one level of theorizing, we argue that the general relationships among the distances, not at the free-throw line, are consistent with the schema prediction of generalization. However, at the 15-ft. distance, the extended practice has provided a specific advantage over and above the level provided by the generalization mechanism that is not predicted by schema theory. There are various ways that especial skills could develop.

Representation of Especial Skills

How can the existence of these especial skills be considered within the overall theoretical interpretations about skill learning? A number of possibilities exist.

Schema theory. First, the finding of especial skills is not really addressed by schema theory, as the focus there was more on the processes in generalization than on the specific products of practice. In this view, every production of an action (which receives feedback) is used to update the schema-rule. The individual parameters and movement outcomes are not stored directly, and they only serve to update the relationship. Thus, this theory does not provide a way for massive amounts of practice at one instance in a class to have any effect on *that* instance, as practice should contribute to all members in the class. When a free throw is made, according to this argument, the performer uses the schema for the set-shot program and parameterizes it "anew" for the 15-ft. distance. How can the specificity effects from especial skills, and the generality of the schema view, be reconciled?

Parameter specification. One possibility is that massive amount of practice almost solely from the foul line facilitates the assignment of parameters for this one member of the class (only). Thus, the extensive practice with feedback and constant perceptual cues could develop a specialized, perhaps automatic, mechanism for parameter selection. The performer's view of a highly recognizable set of sensory characteristics, unique to the 15-ft. distance and in a very stable environment, could recruit a highly consistent and accurate set of parameters. Here, one would expect to see the kinematics of the GMP being indistinguishable for the especial skill vs. all the rest in the class. Note that, strictly, such a view would be inconsistent with schema theory. The idea that massive amounts of practice at one specific instance (i.e., the free-throw) within a class of skills (i.e., set shots) improve that parameter-specification process for that unique instance is the topic of the Experiment 4.

Especial GMPs. Another view is that the performer, when faced with practice at a particular member of a class, develops a separate and new GMP for the action that optimizes the action. Having a GMP that must govern an entire class of actions has the benefit that it reduces the number of programs that one must have in order to perform (the so-called storage problem), but at the same time this GMP will probably be somewhat sub-optimal for any one, particular member of the class. If so, then extensive practice with feedback at this one member could develop a separate GMP that is used for only this one application. If this occurs, it should be detectable by examining the kinematics (chiefly the relative timing) of the especial skill vs. a nearby neighbor in the class; if differences occur, this would be evidence for a separate GMP having been learned. This idea is further investigated in Experiment 6.

In conclusion, Experiments 1 to 3 have demonstrated the free throw (i.e., the basketball set shot at 15-ft.) as an especial skill, one that stands apart from other members in its class by its enhanced performance capability. We suggest that the emergence of this especial skill in expert basketball players results from massive amounts of specific practice at the 15-ft location, compared to minimal practice at other set shot locations. We found that this specificity effect did not generalize to jump shot performance, or to novice performers with considerably less accumulated practice. Moreover, the specificity effect was not attenuated by removal of incidental visual cues. The existence of especial skills is troublesome for schema theory, as this theory makes no predictions about specific products of practice. The following experiments of this dissertation have been designed to further explore potential mechanisms underlying the specific performance advantage that is demonstrated when experts 'step up to the line'.

Chapter 3

Experiments 4 and 5

What makes Especial Skills Special? Examining the Learned-Parameters vs. Visual Context Hypotheses

Abstract

Results from Experiments 1 to 2 suggest that massive amounts of practice of the basketball free throw (a "set shot") results in the development of a specific memory representation that is unique to one shot-distance (15 ft.) in skilled players. We termed this distinct capability an *especial* skill. In an attempt to further understand what makes the free-throw an especial skill, and potential mechanisms underlying its development, two alternate hypotheses were examined. The *learned-parameters* hypothesis (overlearned specifications for the parameterizations of the set shot at 15 ft) and the *visual-context* hypothesis (unique visual context including the visual distance and visual angle to the basket) were contrasted. In Experiment 4, varsity players performed set shots from the foul line (15 ft) and locations that were equidistant (15ft) but at different angles to the basket (15°, 30°, 45° to the left and right of the foul line). Performance of the set shot at the foul line was superior to the other locations, which is consistent with our previous specificity findings. In Experiment 5, players performed set shots and jump shots at the foul line and at player-chosen "favorite" locations on the court. A double dissociation was found: performance of the set shot was superior to the jump shot at the foul line but was inferior to jump shot performance at the players' favorite locations. These results are contrary to the learned-parameters hypothesis, but more consistent with the visual-context hypothesis. These findings are discussed in terms of their implications for motor-control theory and in terms of the broader context of specificity versus generality in the learning of motor skills.

Introduction

A sport skill performed by highly trained athletes provides a clear demonstration of both the specific and general capabilities of exceptional human motor performance. Experiments 1 and 2 have demonstrated that the basketball set shot is one such sport skill. The set shot is a lower and upper limb shooting motion during which the feet do not leave the floor. This shot is almost always practiced from a line that is 15 ft. from a point directly beneath the basket (i.e., a free-throw from the foul line). The set shot is rarely practiced from other locations because of its limited usefulness in game play.

In Experiments 1 and 2, we asked skilled basketball players to perform set shots from several distances in front of, at, or behind the foul line at distances ranging from 9 to 21 ft. Performance success of the set shot was negatively related to the distance of the shooter from the basket. This relationship is consistent with laws of motor control (Abrams, Meyer, & Kornblum, 1989; Fitts, 1954; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979), and demonstrates the predictability (and hence, generality) of performance from known parameters. However, one finding was particularly noteworthy by its failure to conform to generality effects: For these highly practiced basketball players, performance of the set shot from a distance of 15 ft. was much more accurate than predicted by the relationship among the accuracies of set-shots attempted at different distances (see Figures 3 and 5; Experiments 1 and 2, respectively). Since this 15-ft. distance represents the location from which a set shot is used to perform a free throw in the game of basketball, we argued that the highly specific effect associated with this particular set-shot distance was due to the massive amount of practice that had been accumulated by years of practice at this one location. Our findings suggest that years of practice at the foul line produce a skill that has a specific motor-control advantage at that particular distance and which provides little or no detectable advantage for any other distance, regardless of its proximity to the foul line. Based on these results, we suggested that the massive amount of practice accrued over many years of basketball shooting establishes the free-throw as an especial skill – one that represents a highly specific capability among the general class of set-shot skills.

The emergence of the free throw as an especial skill in Experiments 1 and 2 inspired us to ask the question, what is the underlying mechanism of this highly specific effect at the foul line for experts? That is, what specific product of practice has resulted with massive amounts of practice at the foul-line? Experiments 4 and 5 were designed to examine two alternative hypotheses for the existence of especial skills: the *learned-parameters* versus the *visual context* hypotheses.

One possibility is that massive amounts of practice at one specific instance within a class of skills improve the *parameter-specification* process for that unique instance. That is, the extensive practice with feedback and constant perceptual cues could develop a specialized, perhaps automatic, mechanism for parameter selection. The performer's view of a highly recognizable set of sensory characteristics, unique to the 15-ft. distance and in a very stable environment, could recruit a highly consistent and accurate set of parameters. We call this the "learned-parameters" hypothesis. In the case of the basketball free throw, according to this view, years of practice have resulted in highly overlearned specifications for the parameterizations of a 15-ft. set shot (velocity, angle, spin, etc.), and this unique, learned capability has produced especial skills such as the free throw within the general class of set shots.

An alternative suggestion is that embedded within the learned representation for the free throw is a unique *visual context* for the performance of that particular set shot (which we term the "visual-context" hypothesis). Our previous findings (Experiment 2) revealed that the specificity of the free throw was impervious to the visual context of the floor markings, because their removal still resulted in a performance advantage at the 15-ft. location. Therefore, the role of the floor markings were considered incidental to overall effect seen in these studies. However, since the free throw is always taken from the same position on the court relative to the basket, both the visual distance and the angle of the shot to the basket could be embedded in the learned representation.

Experiment 4 -- The Learned-Parameters vs. Visual Context Hypotheses

We contrasted the learned-parameters hypothesis and the visual-context hypothesis in the present experiment by examining performance for 15-ft. shots taken from seven locations differing in their angular relation to the basket. The free throw represents a 15-ft. set shot taken from a 90° angle to the basket/backboard. We assessed performance at three locations to the left of the foul line position (at 45°, 60°, and 75° angles to the basket) and three locations to the right of the foul line (at 105°, 120°, and 135° angles). Based on the hypothesis that a learned-parameters specification for 15 ft. is acquired with massive amounts of practice, no difference was predicted in the performance of the set shot at the seven different spatial locations because each of these shots conformed to an instantiation of the same learned parameters for a 15-ft. shot. In contrast, the hypothesis of an overlearned, specific visual context for the free throw would predict that altering the visual angle changes the embedded visual context of the set shot. Hence, this hypothesis predicts that the performance at the six, non-90° angular locations would be less accurate than at the free-throw location.

Method

Participants

Ten female athletes were paid $20 (Cdn) for their voluntary participation in this experiment. They provided informed, signed consent prior to participation in accordance with McMaster University Research Ethics Board guidelines. All of the participants were varsity players in the Canadian Intercollegiate Sports league at the time of the study and represented all positions played in basketball (i.e., guard, forward, and center). The athletes ranged in age from 18 to 23 yr.

Materials and environment.

Set shots were taken with a Spalding 28.5 TF-1000 zk Microfiber Composite basketball, standard for women's competition, in a university gymnasium. Seven locations were marked on the gym floor, each designated by a letter (i.e., A to G). Each location was 15 ft. from the spot on the floor directly under the front edge of the backboard, at the following angular directions to the basket (looking at the backboard, from left to right): 45°, 60°, 75°, 90° (foul line), 105°, 120°, and 135°. The session was recorded using a Panasonic PV-DV400-K digital camera to augment data collection and analysis.

Procedure

The players participated in a shooting session lasting approximately 45 min. All participants performed 30 set shots at each of the seven locations (total = 210). Shots at each angular direction were performed in blocks of ten. Each block of shots began with the verbal announcement of the shot location by an experimenter (e.g., “B”), at which time the participant moved to the appropriate location, was handed a basketball, and prepared to shoot. Three replications of the experimental design were performed. One replication consisted of completing a block of 10 shots from each of the seven shot locations once (70 shots per replication). The order of shot locations was randomized within and between replications, but all participants performed the same randomization. Participants were told to perform each shot at their own pace; however, a second experimenter controlled the overall flow between shots by handing a basketball to the participant after about a 5-s interval. A third experimenter retrieved the basketballs. All participants were encouraged to perform each shot with the same level of effort and desire to score the shot, regardless of location. Participants were instructed also to perform every shot in the same manner, as they would typically shoot a free throw (e.g., shot preparation, feet remaining on floor, attempt to “swish” the shot rather than bank it off the backboard). This instruction was particularly important in the assessment of the learned-parameters hypothesis, as it was assumed that each shot, regardless of location, would be performed with the same force production. Participants were able to watch the ball flight and could determine goal success from the visual feedback. Rest intervals were offered after every set of 70 shots.

As in Experiments 1- 3, performance data from the video footage were coded using a four-point scoring system. Shots that were successful, with little to no rim contact (a "swish") were assigned a score of three points. Shots that were successful, but had bounced off the top of the rim at least once before falling in, were assigned a score of two points. Shots that were unsuccessful, but had touched the top of the rim at least once before falling away, were assigned a score of one point. Unsuccessful shots that had hit the bottom portion of the rim or missed completely were assigned a score of zero points. Performance scores were converted to a percentage score: [(total points)/(3 x number of shots taken)] x 100.

Results and Discussion

Average performances for the set shots at the seven different locations are illustrated in Figure 11. Separate linear + quadratic functions, which accounted for 52% of the variance in the data, on average, were computed for each of the participants using their performances at each of the locations to the left and right of the foul line. The computed functions were then used to interpolate a predicted success rate at the foul line, against which the athlete's actual performances at the foul line were compared, using a paired, one-tailed t-test. The actual performance at the foul line ($M = 81.2\%$) was significantly more accurate than the predicted performance ($M = 75.8\%$), $t(9) = 1.84$, $p<.05$.

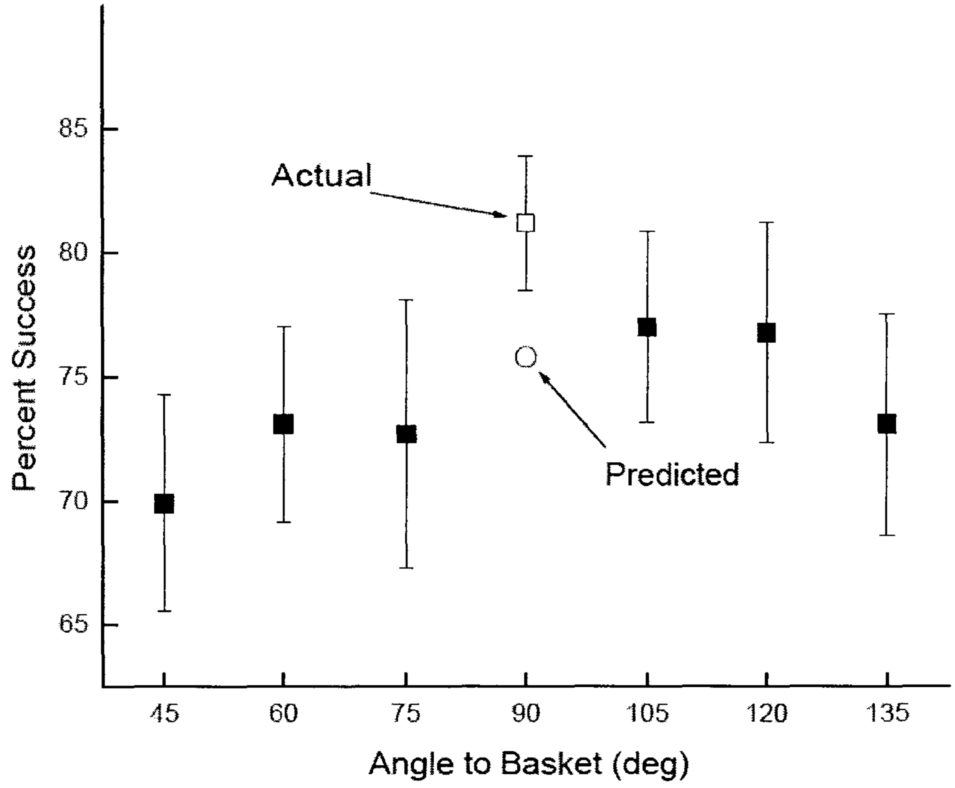

Figure 11. Expert set-shot performance (% success) as a function of the angle of the shot to the basket in Experiment 4.

An analysis of variance was also run on the performance scores for the six non-foul line locations. A repeated measures, 2 (side: left or right of the foul line) x 3 (15°, 30°, or 45° deviation from the foul line) resulted only in a main effect for side, $F(1,9) = 7.34, p < .05$. As illustrated in Figure 11, the athletes were generally more accurate when set shots were taken from a location to the right of the foul line ($M = 75.6\%$) than from left of the foul line ($M = 71.9\%$). This bias in favor of the angles to the right side, compared to the left side of the foul shot position was unexpected, given that post-experiment interviews revealed that 7 out of the 10 participants preferred to take shots in a game situation from the left side of the court.

Evidence against the learned-parameters hypothesis for especial skills was provided in the current experiment. If years of practice of the free throw had resulted in the acquisition of a specific parameterization memory for a 15-ft. generalized motor program, then we would have expected performance to be equally proficient, regardless of the angle to the basket. This hypothesis predicted that the especial free throw is part of the generalized representations for the class of 15-ft. set shots, but that massive amounts of practice at this one location has made the parameter selection more accurate and/or more stable. Even though the distances of these shots from the basket were identical – and hence should have had identical parameters – the 15-ft. set shots from angled locations were less accurate than they were from the free-throw line. Rather, massive amounts of practice of the free throw seem to have established a representation that is more specific than simply a learned 15-ft. parameterization of the general class of set shots.

One possible complication in our interpretation of the results is that a 90° angle to the basket might provide the opportunity for a shot to be more successful than other angles to the basket simply because a ball might successfully rebound off the backboard. Although we specifically instructed our participants to try to "swish" all of their shots, it remains possible that the backboard differentially aided the free throw. To assess this possibility we reanalyzed our data using only those successful shots that did not touch the rim of the basket (coded as a "3"). Using the same analysis as previously, we found that the actual shot success at the free throw line (*M*=68.0%) remained higher than predicted

(*M*=62.8%), although the probability of a type 1 error was now slightly higher than conventional levels of significance, $t(9) = 1.75$, p=.057. Although these findings again fail to support a learned parameters explanation of the especial effect, perhaps more evidence needs to be acquired before the hypothesis can be rejected outright.

An argument against the visual-context hypothesis might have been supported had we found a main effect for distance from the foul line. That is, if the angle to the basket were a generalizable, rather than a specific effect, then performance would have been expected to diminish as the angle to the basket became more severe (i.e., further from the free-throw position). Instead, we found a right side performance advantage compared to the left side, the reason for this effect unclear (as will be highlighted by players' chosen favorite shooting locations in the next experiment). Therefore, we argue that these data failed to reject the visual-context hypothesis that the especial-skill effect is due to the learned information used to regulate the performance of the free throw. The data tend to favor the argument that the specificity aspect of especial skills is due, at least in part, to the learned sensory-motor specificity. Previous research by Proteau and others (e.g., Proteau, 1992; Proteau, Marteniuk, & Lévesque, 1992) suggest that the visual context in which practice has been undertaken imbeds the sensory-motor information in the learned representation of the skill. The especial skills effect may be due, in part, to a similar product of learning.

Experiment 5 - Further Exploration of the Visual Context Hypothesis: Set shots vs. Jump Shots from Players Favorite Locations vs. the Line

Although the findings of Experiment 4 replicated and extended the expert performance results of Experiments 1 and 2, a very simple explanation for the results cannot be ruled out. Perhaps the findings were due to the fact that the visual context for a 90° angle shot is, in some sense, less complex than for the other shot angles. The visual representation of the basket is framed symmetrically relative to the backboard during a foul shot, whereas the visual representations for all of the non-90° positions have an asymmetric relation between the basket and the backboard (as well as other court sightlines). Thus, the possibility exists that the results of Experiment 4 were due simply to a simpler visual perspective for the foul shot compared to that for the other 15-ft shots. In Experiment 5 we used a slightly different experimental method to examine this possibility.

Experienced basketball players frequently report that there is a "favorite" location on the court from which they are more likely to practice based on the plays developed by the coach, their role on the team, or from which they simply feel more comfortable or confident. The amount of practice that has been devoted to taking a jump shot at this location may represent the development of another especial skill, albeit within the class of jump shots rather than set shots. If this favorite location represents an especial jump shot, then one would predict a *double dissociation* when jumps shots and set shots are taken at the foul line and the favorite location. Specifically, jump-shot performance at the favorite location would be superior to set shot performance, while set-shot performance would remain superior to jump-shot performance at the foul line. Further, as we were to discover, the favorite location was not taken at a 90° angle to the basket. Therefore, if the double dissociation were shown, this finding would provide evidence against the idea that the results of Experiment 4 were due to the visual complexity of a non-90° angled shot.

Method

Participants

The same varsity athletes that participated in Experiment 4 also participated in the present experiment. Testing for the present experiment was conducted immediately after the data for Experiment 4 were collected.

Materials and environment

Two locations were marked on the gym floor. The first was located in the same position as the 90° (foul line) from Experiment 4. The second was the player's reported "favorite" location (the "Xs" in Figure 12 illustrate the position of each player's favorite location). All other aspects concerning the materials and environment were the same as in Experiment 4.

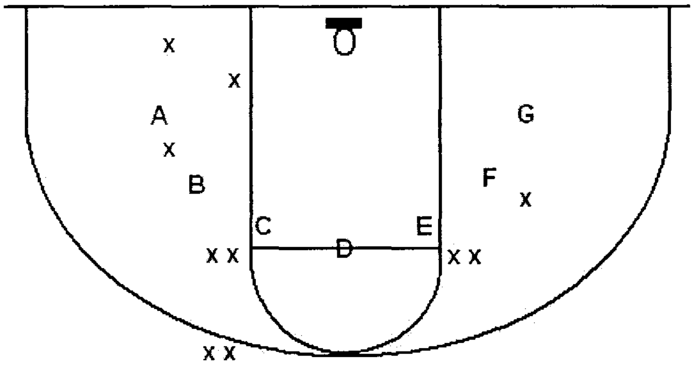

Figure 12. Schematic locations of the set shots taken in Experiment 4 (locations A to G in the figure) and the approximate locations of the players' preferred shots in Experiment 5 (individual Xs in the figure).

Procedure

The players participated in a session lasting approximately 15 min. All participants performed 30 jump shots at the foul line, 30 set shots at their favorite location, and 30 jump shots at their favorite location (total = 90). Scheduling of these shots was similar to Experiment 4 – three replications of 10 shots at each of the three positions. The intertrial experimental procedures were identical to those in Experiment 4. Inclusion of the free-throw data from the first shooting session (Experiment 4) with the "favorite" location data collected here permitted us to test for the predicted double dissociation.

Results and Discussion

Performance data were submitted to a 2 (shot location: foul line vs. favorite) x 2 (shot type: set vs. jump) repeated measures ANOVA. Neither main effect was significant, with *F*'s (1,9) = 2.69 and 0.11, respectively, for location and shot-type, *p*'s>.05. However, the interaction was significant, *F*(1,9) = 18.79, *p* < .01. As illustrated in Figure 13, performance at the foul line was more accurate when taken with a set shot (*M* = 81.2%) than when taken with a jump shot (*M* = 71.6%). Conversely, performance at the players' favorite location was more accurate when taken with a jump shot (*M* = 72.8%) than when taken with a set shot (*M* = 64.8%). All pairwise comparisons (Tukey's HSD) were significant except for the difference between the two jump shots.

The double dissociation illustrated in Figure 13 provides three additional lines of evidence regarding the specificity effects found in these experiments. The effect of shot type was in opposite directions depending on the location of the shot. The set shot's unique advantage occurred only at the foul line, whereas the set shot was performed less accurately than the jump shot at the player's favorite location. This double dissociation provides additional evidence that these skills are represented separately in memory. According to schema theory (Schmidt, 1975), these skills represent different classes of actions, under the control of separate memory structures –generalized motor programs in the language of schema theory.

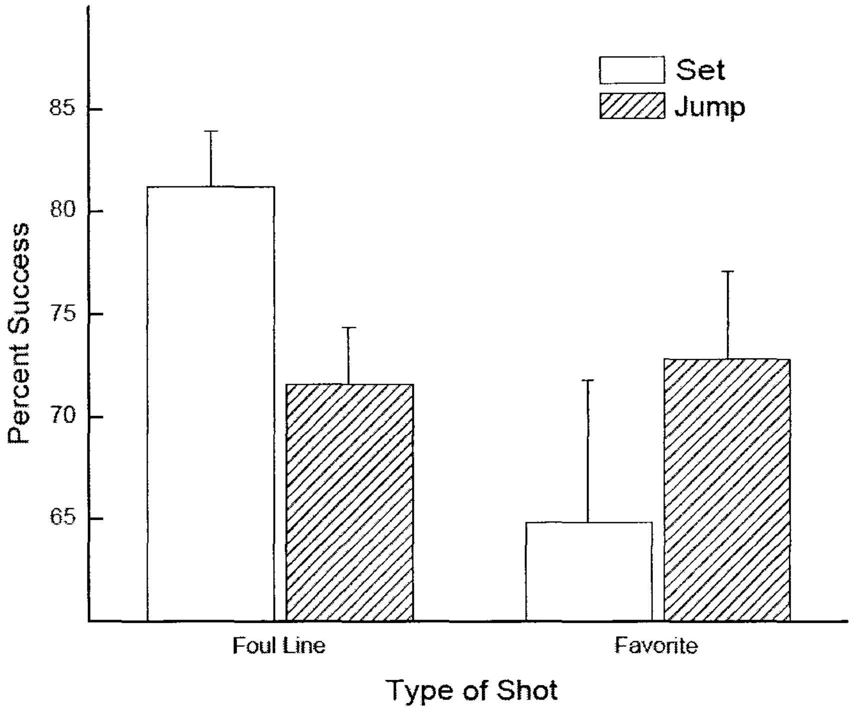

Figure 13. Shooting performance (% success) as a function of the type of shot taken (set shot vs. jump shot) and shot location on the court (at the foul line vs. at the players' favorite spot) in Experiment 5.

A second line of evidence concerns the simple, symmetrical visual context explanation for Experiment 4. Data in the present experiment (although with a jump shot) suggest that such perceptual symmetry may not have an important effect. Performances of the jump shot at the favorite location and at the foul line were statistically equivalent. This was so despite the fact that the average distance from the basket of the favorite location and non-90° locations were roughly the same (16 vs. 15 ft., respectively). In this comparison, the favorite location provided a more asymmetrical visual angle to the basket than the foul line. This finding provides no support for a visual-simplicity explanation for the results of Experiment 4; instead, it focuses the explanation for the effects on a learned, specific representation in memory.

However, although a simple, generalized visual-simplicity explanation was not supported, it remains entirely plausible that visual context is a specifically learned component of the especial skill effect. Shooting the basketball from the favorite location provided no particular advantage for the athlete when it was performed with a set shot, even though the visual angles of the shot to the basket for the jump- and set-shots were identical. In fact, performance of the set shot from the favorite location (*M* = 64.8%) was generally less accurate than was the set shot from the non-90° angles in Experiment 4 (*M* = 73.8%); the distances for these shot-types were about the same. Clearly, if the embedded visual context is responsible for the especial jump shot, it is specific to that memory representation, and does not transfer to the performance of the set shot.

General Discussion

Findings of Experiment 4 replicated and extended our initial experiments that revealed high levels of specificity as a product of extended practice. Set-shot performance at the foul line was more accurate than predicted based on performance at locations that were equidistant to the foul line, but angularly distinct. This finding provides evidence against the learned-parameters hypothesis. Even though the distances of these shots from the basket were identical – and hence should have had identical parameters – the 15-ft. set shots from angled locations were less accurate than they were from the free-throw line. The participants of this study were varsity level athletes averaging 11 years of experience with basketball shooting (experience of players ranged between 9 and 14 years). Based on years of experience, surely these players have accumulated extensive amounts of free throw practice (i.e., in the tens to hundreds of thousands of practice trials). This massive amount of practice of the free throw seems to have established a representation that is more specific than simply a learned 15-ft. parameterization of the general class of set shots.

Dissociations are powerful ways to discover whether two hypothetical processes are really the same process, or represent fundamentally different processes (see Bridgman, Kirch, & Sperling, 1981, for an example concerning visual processes). These dissociations can be relatively simple and one-directional, where a variable might affect measures of one process but not the other process. This type of dissociation is relatively weak because of the null effects for one of the processes. A far stronger interpretation is afforded by situations where a variable produces *decrements* in measures of one process, but produces *increments* in measures of the other process – often termed a "double dissociation." This is the type of dissociation found in the present study, as the shot-location variable produced opposite effects for the set shots and jump shots. Our interpretation, based on the double dissociation found, is that these two shot-types are represented separately in memory.

One interpretation, and its implication for motor control theory, is that there could be actually *four* different skills represented by the shots taken in this study. The first two are the especial skills found for the set shot at the foul line and by the jump shot at the players' favorite locations. These appear to be highly specialized and specific to these particular locations and conditions. The third "skill" could be the class of set shots taken at positions *other than* the foul line. The evidence supports this interpretation here and in Experiments 1 and 2 showing the regularities among these variations of set-shot performances across various distances and locations. The fourth "skill" is the class of jump shots taken at positions *other than* the player's favorite position. Strictly, we do not have evidence here of this effect, as this would require systematic relationships across various jump-shot distances surrounding that for the player's favorite position; but such a result was shown for jump shots by Experiment 3. Also, on other grounds, there is ample evidence of the generality of these kinds of skills in studies of both performance and learning (Schmidt & Lee, 2005, Chapter 13). This claim for especial skills for the foul shot – and also for the jump shot at the player's favorite location – could be tested using measures of kinematics, chiefly relative timing. If these are really separate programs, one should be able to show that certain measures of the patterning (such as relative timing) are invariant across changes in shot-distance. And, the relative timing in the set shot at the foul line should be different than that in the non-foul line set shots. It is the examination of relative timing of set shots across location that is the topic of Experiment 6.

Chapter 4

Experiment 6

Is the Especial Free Throw Represented by the Same or a Distinct Set Shot Generalized Motor Program?

Abstract

One hypothesis put forth to explain the performance advantage found with the especial free-throw in Experiments 1 and 2 is that with extensive specific practice this skill may come to be represented by a separate generalized motor program (GMP) compared to set shots performed at other locations. This hypothesis was tested in the present experiment by examining invariance in component durations (e.g., proportions of the overall duration) of set shot execution phases (e.g., dip, propel up, and release) of successful shots at the foul line compared to non foul line locations in experts. If the timing structure of an action sequence is determined by the GMP, then the durations of all the components of the sequence should maintain a constant proportion of the overall duration, even if the overall duration of the sequence changes (Schmidt, 1982, p.308). Therefore, invariance in component durations across shot locations would indicate the utilization of the same GMP, whereas variance in timing would suggest distinct GMPs are used. Gentner's (1987) *interaction test* was used as a means of analysing invariance in the timing data of each expert. Planned comparisons analyses of significant effects and interactions revealed that although some variance was found within experts, a general pattern of invariance across shot phases was evident between the 15ft and other shot locations, suggesting that the especial free-throw is not represented by a separate generalized motor program that is distinct from other set shots.

Introduction

The finding that a highly specific exemplar (the free throw) could exist amidst the background of a very general performance capability (set shots), which we termed an *especial* skill, poses a real and significant problem for theories of motor control, particularly schema theory (Schmidt, 1975, 2003). The existence of an especial skill is problematic because, according to schema theory, the foul shot should belong to a class of motor skills (set shots) that becomes increasingly generalized with advanced skill. In this context, schema theory does not provide a prediction for why massive amounts of practice at one instance in a class should have any special effect on *that* instance, as practice should contribute to all members in the class. So how might our findings of a specific performance advantage at the foul-line be reconciled with schema theory? Recall from schema theory (1975), that a *class* of motor skills (i.e., a set of goal-directed actions that all share similar underlying characteristics) is stored in memory as a *single* representation, the generalized motor program (GMP). The GMP is responsible for representing the *invariant features* that control the movement's production (e.g., relative timing, relative force, and sequencing of submovements). Therefore, schema theory would predict that set shots make up a class of motor skills, responsible for controlling the invariant characteristics of all set shots, regardless of where on the court the shot has been taken.

Experiments 1 and 2 revealed that when the set shot was taken at the free throw, its performance was far superior to performances at nearby locations. What does this finding suggest about how the free throw is represented, and what are the implications of this finding for schema theory? We argued that the free-throw was an especial member of set shots within the general class of set shots. However, is it possible that these skilled basketball players have developed a generalized motor program (GMP) for the free throw, based on many thousands of shots taken at just one distance (i.e., the foul line) that is separate from the GMP used for other set shots at different locations? If so, how could we measure this? If a class of skills is represented by a single GMP, *invariant features* should be consistent between members of the class and remain consistent regardless of how any member of the class is being executed (e.g., what parameters are implemented). Next, we review research examining the invariant feature of *relative timing* and offer it is a means to undercover potential differences in the motor program representations of our skilled players.

In the 1970s research began to target possible invariant features of GMPs. Armstrong (1970) asked participants to learn a movement pattern with a control stick that required a sequence of elbow flexions and extensions. The entire pattern was to be completed with a target movement time of 4 seconds and each reversal of direction had a specified amplitude and duration required in order to perform the pattern optimally. Participants received visual feedback of their performance (i.e., a trace of their performance superimposed over the target pattern) after each trial. Intriguingly, Armstrong noticed that as practice progressed, although participants were not always producing the 4-second criterion movement, a distinct pattern was resulting within the phases in the movement. The timing of the reversals of the movement was similar to the goal movement time even if it was produced too quickly (i.e., in 3 seconds). That is, the ratio of the time of each part to the total time of the movement remained essentially the same such that the timing of all parts of the movement changed proportionately, when the participants changed the duration of the whole movement.

Armstrong's findings suggested that as participants learned the task, they could change the overall movement time of the action while preserving the fundamental timing structure, or relative timing. Therefore, overall movement time was flexible but the relative timing within the movement was non-flexible (invariant), such that the goal pattern consisted of an underlying timing and sequence of events that remained constant but could be executed at different speeds. Although Armstrong's finding of invariance in relative timing occurred through the *accidental* speeding up of movements by participants, similar invariances in relative timing have been shown in other complex sequential tasks where participants have been explicitly *instructed* to speed up their movements and/or to specifically *ignore* the timing structure learned in practice (e.g., Shapiro, 1977; Summers, 1977). These studies have demonstrated that although participants could alter their overall movement times, they were unable to disregard the learned relative timing pattern as the fundamental timing pattern was retained in well learned tasks.

Research effort testing the GMP theory has also focused on more gross motor skills such as over-arm throwing (Roth, 1988), locomotion (Shapiro, Zernicke, Gregor, & Diestel, 1981), and triple-jumping (Maraj, Elliott, Lee, & Pollock, 1993). For example, Shapiro et al. (1981) had participants walking and running on a treadmill at different speeds (e.g., 3 to 12 km/hr). The authors had segmented the step cycle into distinct phases and measured the duration of each of these phases: toe-off in swing to maximum knee flexion (flexion phase); maximum knee flexion in swing to heel-strike (first extension); heel strike in stance to maximum knee flexion (second extension); and, maximum knee flexion in stance until toe-off again (third extension). Between the speeds of 3 to 6km/hr, while the participants were walking, the proportional timing between the phases to the overall movement time of the step cycle remained consistent. At speeds of 8 to 12 km/hr, while the participants were running, the timing between phases changed compared to the slower speeds (i.e., different proportions of the movement), but remained consistent within these faster designated speeds (see Figure 14).

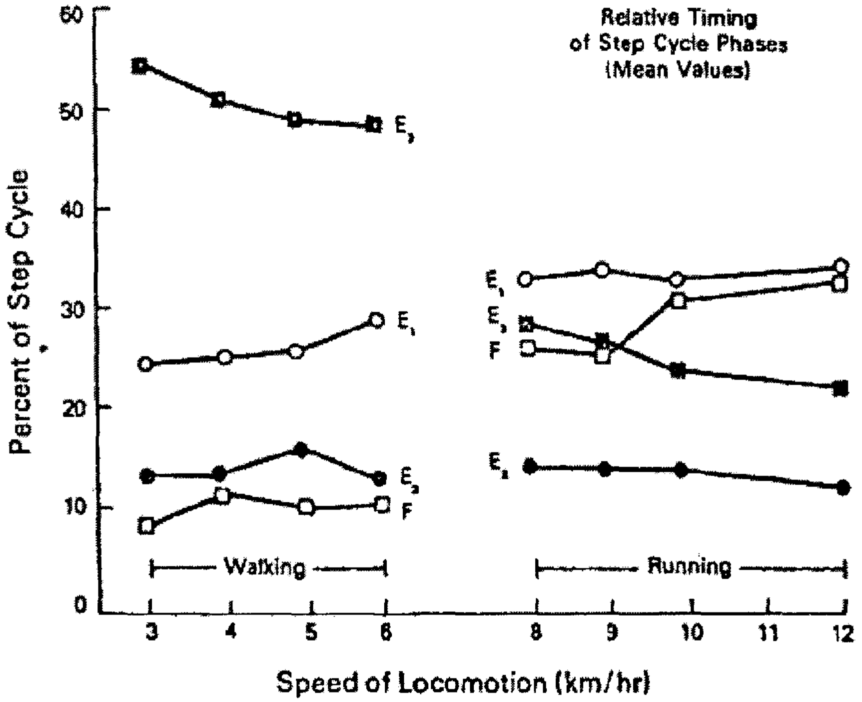

Figure 14. Proportions of cycle duration required by each of the phases of the step cycle as a function of the speed of walking (left) and of running (right). The proportions stay reasonably invariant during each gait, but shift markedly between gaits. F = flexion phase; E1 = first extension phase; E2 = second extension phase; E3 = third extension phase. (From Shapiro et al., 1981).

Because the relative timing between the step cycle phases were different between walking and running, the authors concluded that walking and running were governed by different GMPs, which could be parameterized at different speeds.

Although quite compelling and in support of GMP theory, certain criticism was levelled at the Shapiro et al. results, most notably by Gentner (1987). One suggested weakness of this investigation, and others, examining GMP theory is that the conclusions were based on data that had been averaged over trials and participants. Gentner proposed that GMP theory describes individual timing sequences of a movement that are unique to each participant. Therefore, using averaged group data is inappropriate to test the theory because the model makes predictions about consistency/invariance within a participant and not between participants (i.e., therefore when averaged group data are used, this confounds within and between subject measures of variance). Because it is important that any analysis maintains information about individual instances, Gentner introduced a more appropriate statistical analysis to test GMP theory which he termed the *interaction test* of invariance. In this method, separate ANOVAs are calculated for each participant, with components of the movement sequence (e.g., phases in the step cycle) and parameter(s) (e.g., speed of locomotion) as factors. If there is no significant interaction between the component phases and parameters, this is evidence that the components of the movement have an invariant structure across all conditions. When Gentner re-analysed data from the Shapiro et al. study using his interaction test, he found that while several phases of the walking cycle did show invariance (i.e., changed proportionally with changes in overall duration), maximum knee flexion in stance until toe-off (E3 in the diagram above) did not maintain a constant proportion.

Using Gentner's interaction test for statistical analysis of invariance, Maraj, Elliott, Lee, and Pollock (1993) examined relative timing characteristics of the standing and running start in expert triple jumpers. Although the authors found no differences in durations for the components of the action between the dominant and non-dominant leg in the standing start, there were differences in relative timing between the two take-off start types (i.e., standing vs. running). Therefore, while the experts exhibited effector independence of the GMP (i.e., different effectors were governed by the same GMP), it appeared that different GMPs controlled jumps from standing and running starts. Taking together, it seems that examining invariance in the proportional timing within a movement pattern can be used as a reasonable measure to help identify how a skill is represented in memory, and moreover, differentiate it from other motor skills.

The emergence of the free throw as an especial skill in Experiments 1 and 2 inspired us to ask the question-- is the especial free-throw represented by the same or a distinct set shot generalized motor program (GMP)? One interpretation we posited to explain our especial effect, is that with massive amounts of practice, there is the establishment of a separate generalized motor program for the free-throw that is distinct from the motor program used to execute set shots from other locations. By examining the timing structure of the set shot from the foul-line (i.e., the free-throw) compared to set shots performed at non-foul line locations, we were able to test this hypothesis. If the foul shot at 15ft demonstrated a different relative timing structure than other set shots, this would suggest that these skills are represented by a different GMP. Such a finding would argue against our conclusion of an “especial skill” as we have defined it, however, because the free-throw could not then be considered a special instance of a more general class of shots. However, if the foul shot and set shots performed from other locations had a similar relative timing structure; this finding would suggest that the players possess a single GMP for all set shots (including the foul-shot). If this is the case, we would know that the especial effect or performance advantage that occurs at the free-throw line is not attributed to the GMP representation used to execute the timing and sequencing of this shot.

Method

Materials

Video footage captured from Experiment 2 of set shot performance of the eight expert basketball players was used for present purposes.

Procedure

The video footage was initially imported onto a Dell Inspiron 5100 laptop computer using Windows Movie Maker v2.1. From the fully recorded shooting session, the footage was edited such that individual video files were created for each participant at each of the 5 shooting locations (e.g., 9-, 12-, 15-, 18-, and 21 ft.), for each successful shot completed. Once the video clips were created, they were then imported into the software program, Dartfish ProSuite v4.0, for relative timing data collection through frame-by-frame time-stamp tracking.

Several predefined critical points in set shot movement execution were marked and time-stamped (i.e., the time in the clip at which the critical point occurred) in each clip (see Figure 15). The critical points were as follows: a) ready/stable; b) maximum knee flexion; c) pre-release position; and, d) ball release point. "Ready and stable" was defined as the point when the player was positioned at the appropriate shooting line, directly facing the basket, looking up at the basket, but had not initiated the shooting motion (i.e., the frame prior to initial knee flexion). "Maximum knee flexion" was defined as the point in the shot when the player had maximally flexed their knees/dipping down into the shot but had not started propelling upward/extending the knees. "Pre-release position" was defined as the point prior to ball release, where the player had extended their legs, straightened their back, and had propelled their arms and ball upwards (i.e., elbows still at roughly 90 degrees, player dependent). "Ball release point" was defined as the point when the ball had been released by the player, their body was fully extended, and the wrist flexed forward to finish the shot[3]. These critical points were adapted from studies by Southard and colleagues (Southard & Amos, 1996; Southard & Miracle, 1993) examining rhythmicity of free-throw performance.

---

[3] Two experimenters independently examined video clips of two players to test the inter-rater reliability of this time-stamping system. Analysis revealed a correlation coefficient of $r = 0.92$, suggesting that the time-stamping system was reliable. Thus, I time-stamped the remaining players' video clips alone.

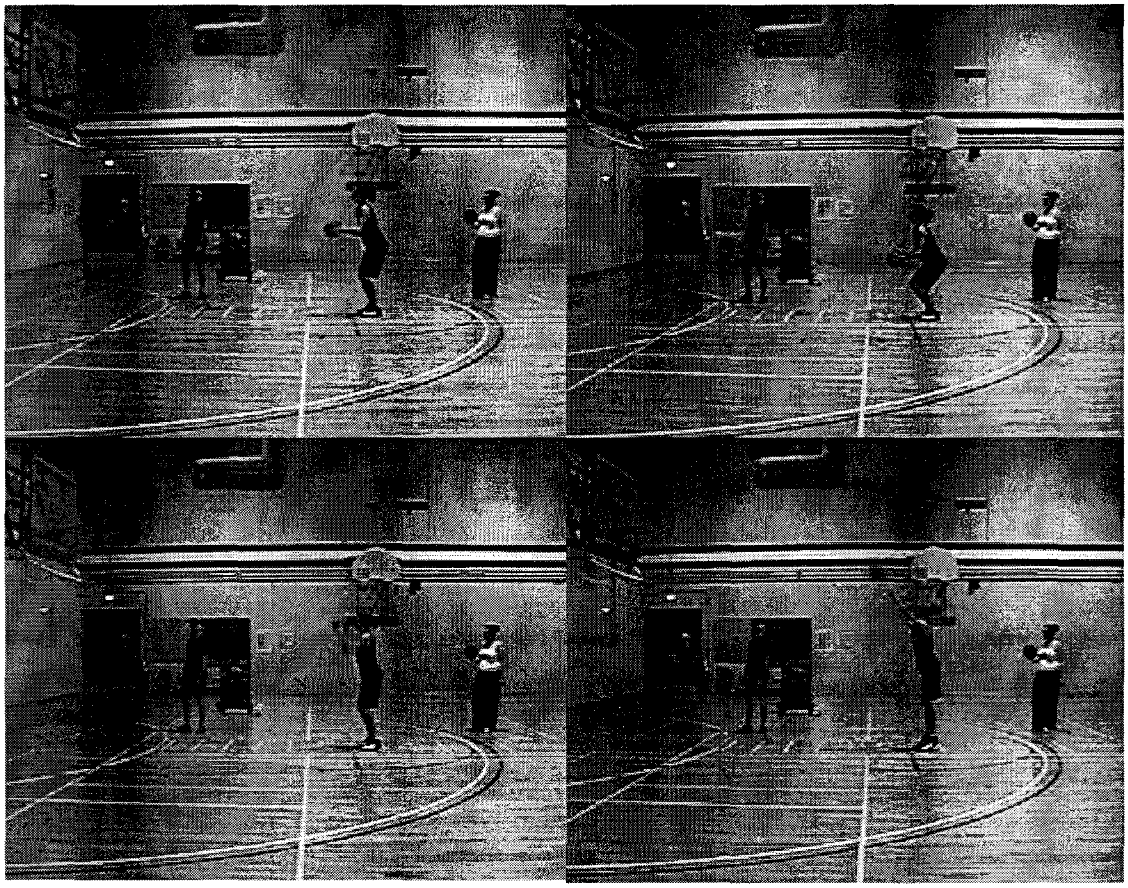

Figure 15. Diagram of critical point time-stamps of set shot performance in Experiment 6. Top left = Ready and Stable, Top Right = Maximum Knee Flexion, Bottom Left = Pre-Release Position, Bottom Right = Ball Release Point

Having time-stamped these critical points, three shot phases (between ready/stable to maximum knee flexion, herein called *dip*; maximum knee flexion to pre-release position, herein called *propel up*, and; pre-release position to ball release point, herein called *release*), were calculated by subtraction. In addition, subtracting the time-stamp captured for ready/stable from ball release point allowed us to find an overall duration time for shot execution. Therefore, each shot was segmented into shot phases which were comprised of specific component durations that were proportions of the overall duration.

In determining what shots were most important to analyse, we decided the key shots of interest would be those where the motor program had been executed as optimally as possible. Therefore, only shots that were coded as a "swish" and rewarded a score of 3 in Experiment 2 were considered for the present analysis. Moreover, to make sure there was an equal representation of shot number across distances and participants, we initially examined the video clips of the farthest distance of 21 ft for number of swishes. The shots taken at this distance had the lowest success rate compared to the other shot locations, but we found that 5 of the 8 players had achieved at least 10 swish shots from 21 ft. Therefore, we included video clips of 10 swish shots from every shooting location (9-, 12-, 15-, 18-, and 21-ft) for these 5 participants in the relative timing analysis. A random selection was taken when more than 10 swish shots occurred for a particular player/condition. For the other three participants, we included video clips of 10 swish shots from all locations except the 21 ft location due to lack of swish shot success (experts 1, 4, and 5, had 7, 2, and 4 swish shots from 21 ft., respectively).

Data Analysis

Initially, differences in average overall durations and standard deviation across shot distance (9-, 12-, 15-, 18-, and 21-ft) were compared in repeated measures ANOVAs, with distance as the repeated measure.

More pertinent was our examination of the variance (or invariance) of the component duration data of shot phases across distances within participants, using the logic of Gentner's interaction test. Therefore, the component duration data of five of the expert players (experts 2,3,6,7, and 8) were analysed using a 5 [distance (9-, 12-, 15-, 18-, and 21-ft)] x 3 [shot phase (dip, propel up, release)] mixed ANOVA, with distance as a between-trial factor and shot phase as a within-trial factor. As three of the expert players did not have a representative amount of successful swish shots from 21 ft, these remaining three skilled players' data (experts 1, 4, and 5) were analysed using a 4 distance (9-, 12-, 15-, and 18-ft) x 3 shot phase mixed ANOVA.

Based on Gentner's logic, the absence of an interaction between shot phase and distance would be evidence to support invariance in component duration. A main effect for shot phase, in the absence of an interaction, would suggest that the phases within the set shot differ in component duration but that these durations remain relatively the same across all conditions. However, an interaction between shot phase and distance factors would indicate that the shot phases were not invariant across the distances. The most critical test was any post hoc analysis of the interaction that revealed shot phases between 15 ft (i.e., foul-line) compared to the other distances.

Results

Group Data

Overall duration data (and standard deviations) as a function of distance are depicted in Table 1. The ANOVA for overall duration revealed no significant effect for shot distance, $F(4,28) = 1.50, p = 0.23$, therefore; regardless of location, shots were executed in a similar amount of time (9ft $M = 655$ msec; 12ft $M = 682$ msec; 15ft $M = 749$ msec: 18ft $M = 731$ msec; 21ft $M = 640$msec). Analysis of standard deviations also revealed no significant effect, $F(4,28) = 1.40$, $p = 0.26$ (9ft $SD = 70.9$ msec; 12ft $SD = 72.2$ msec; 15ft $SD = 73.1$msec; 18ft SD=104.5 msec; 21ft SD=98.7msec).

Table 1

Overall Duration of Shots (msec) and Standard Deviations across Distances in Experts in Experiment 6.

	Distance (ft) 9	12	15	18	21
Group	654.7(70.9)	681.9(72.2)	748.6(73.1)	730.5(104.5)	639.5(98.7)
Expert 1	685.3(48.6)	671.8(76.9)	576.8(55.1)	606.8(82.9)	590.4 (119.6)
Expert 2	564.8(51.2)	568.2(46.9)	551.9(41.7)	603.3(45.7)	591.6(74.4)
Expert 3	683.5(67.0)	660.1(51.5)	666.6(56.6)	663.3(79.3)	646.6(50.0)
Expert 4	943.5(59.5)	1014.9(67.8)	1080.1(41.1)	1153.3(32.1)	917.0(141.4)
Expert 5	560.1(120.1)	733.3(79.5)	765.0(148.8)	671.6(130.8)	620.2(151.7)
Expert 6	635.2(83.9)	648.4(107.4)	1221.5(90.4)	985.3(108.8)	605.0(131.0)
Expert 7	528.5(74.9)	606.7(97.6)	620.0(106.9)	665.0(102.4)	678.3(75.2)
Expert 8	636.6(61.7)	551.6(50.0)	506.6(43.9)	495.0(44.5)	466.5(46.5)

Note. For experts 1, 4, and 5, movement time scores for 21ft are based on the average of 7, 2, and 4 shots, respectively.

Individual Data

The following are separate result summaries of the mixed ANOVAs that were conducted on all experts' data. Post hoc analyses were performed using Tukey's highly significant difference [HSD] test, with α set at .05, on shot phase main effects. However, *a priori* planned comparisons were used to examine significant main effects and interactions involving distance. Specifically, we were most interested in examining whether the variance in component duration for the foul shot (at 15ft) was different compared to the average of the other set shot distances. Also note that all within-trial effects remained significant ($p < 0.05$) following the Greenhouse-Geisser correction (Epsilon values ranged from .54 to .89).

Expert 1. The ANOVA examining component durations for expert 1 revealed significant main effects for shot phase, $F(2,72)=158.35$; $p<.001$ (dip = 290 msec, propel up = 238msec, release = 106msec) and distance, $F(3,36)=15.92$; $p<.002$ (9ft =228msec, 12ft = 224msec, 15ft = 192msec, 18ft= 202 msec). Post hoc analysis of the shot phase main effect revealed that component duration between each of the shot phases was significantly different from the others. Planned comparison analysis of the distance main effect revealed that component duration for 15ft was significantly different than the mean of all the other distances (p =.003). As well, a significant interaction between shot phase and distance, $F(6,72)=4.01$; $p<.002$, was found and is illustrated below in Figure 16. Planned comparisons revealed no significant difference between 15ft and the mean of the other distances in the propel up and release phases. However, as can be seen in Figure 16, a shorter component duration was observed at 15ft compared to the other distances, in the dip phase (p =.009).

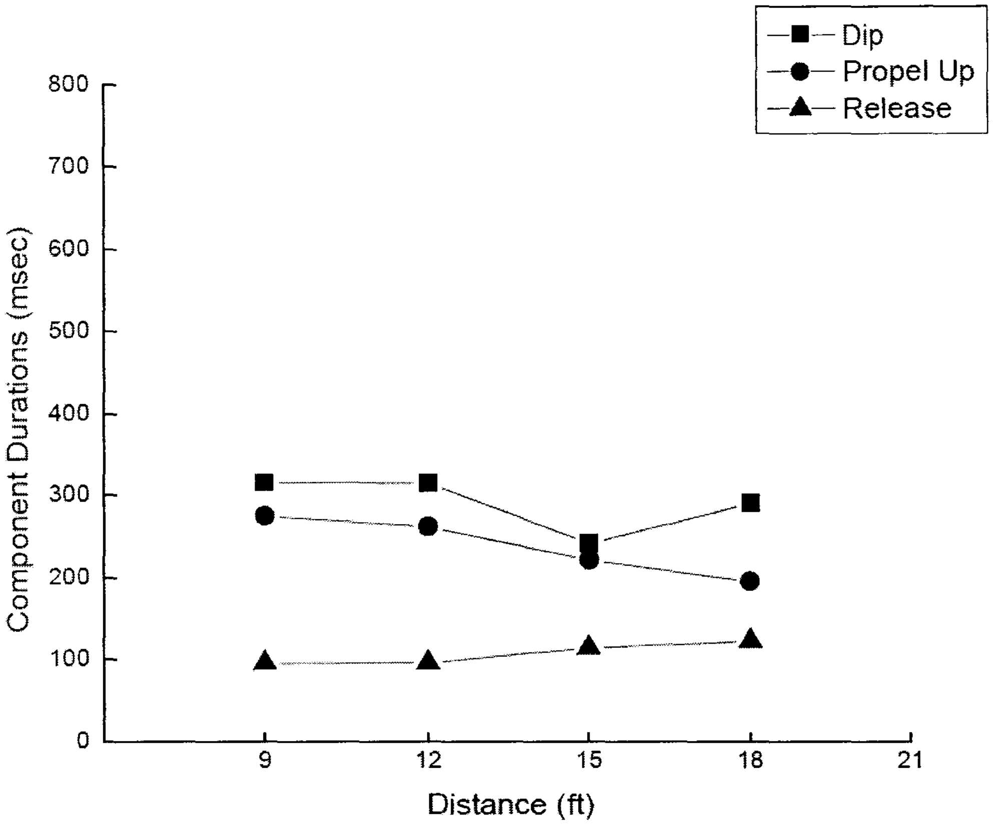

Figure 16. Shot phase (dip, propel up, release) component durations in milliseconds as a function of distance for expert 1.

Expert 2. The ANOVA examining component duration for expert 2 revealed a significant main effect of shot phase, $F(2,90)=213.19$; $p<0.001$ (dip = 269msec, propel up = 205msec, release = 102msec), where post hoc analyses revealed that each component duration between shot phases was significantly different from the others. As well, a significant interaction between shot phase and distance, $F(8,90)=5.24$; $p<.001$ was found. The shot phase by distance interaction is illustrated in Figure 17. Planned comparisons revealed significant differences between 15ft and the mean of the other distances in all shot phases (dip $p = .02$; propel up $p = .004$; release $p <.001$).

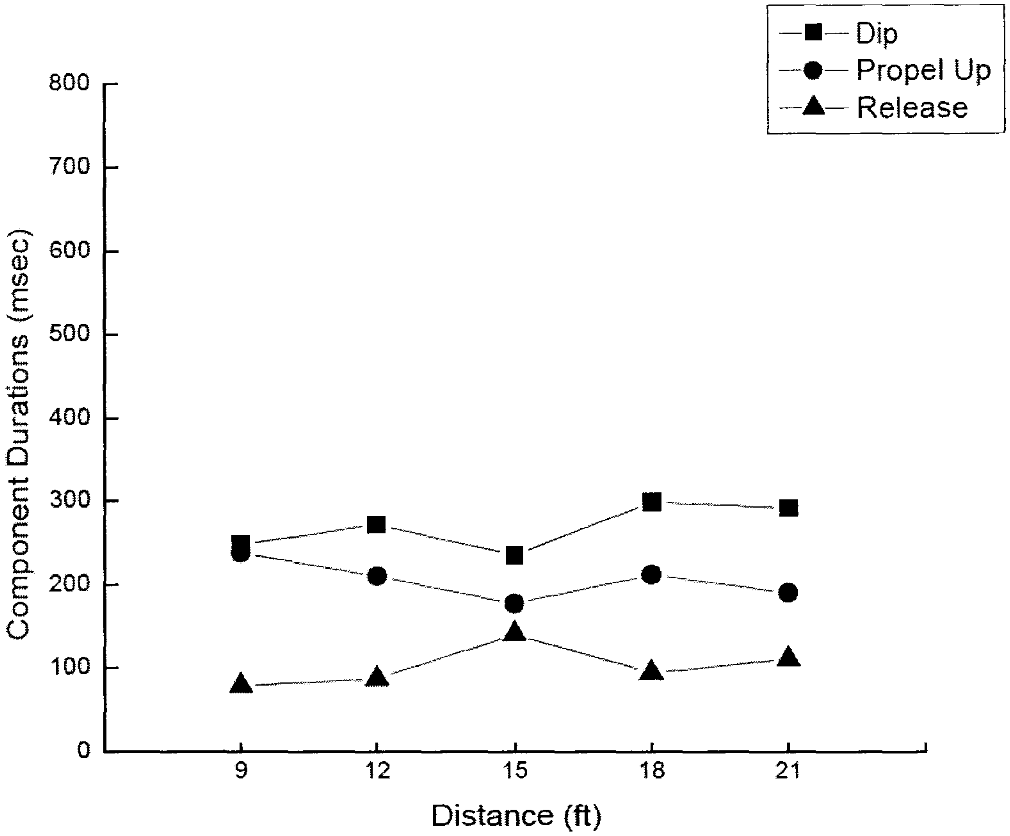

Figure 17. Shot phase (dip, propel up, release) component durations in milliseconds as a function of distance for expert 2.

Expert 3. The ANOVA examining component duration for expert 3 found a significant main effect of shot phase, $F(2,90)=224.16$; $p<0.001$ (dip = 305msec, propel up = 257msec, release = 105msec), where post hoc analyses revealed that each component duration between shot phases was significantly different from the others. As well, a significant interaction between shot phase and distance, $F(8,90)=2.97$; $p<.005$ was found. The shot phase by distance interaction is illustrated in Figure 18. However, planned comparisons revealed no significant differences between 15ft and the mean of the other distances in any shot phases.

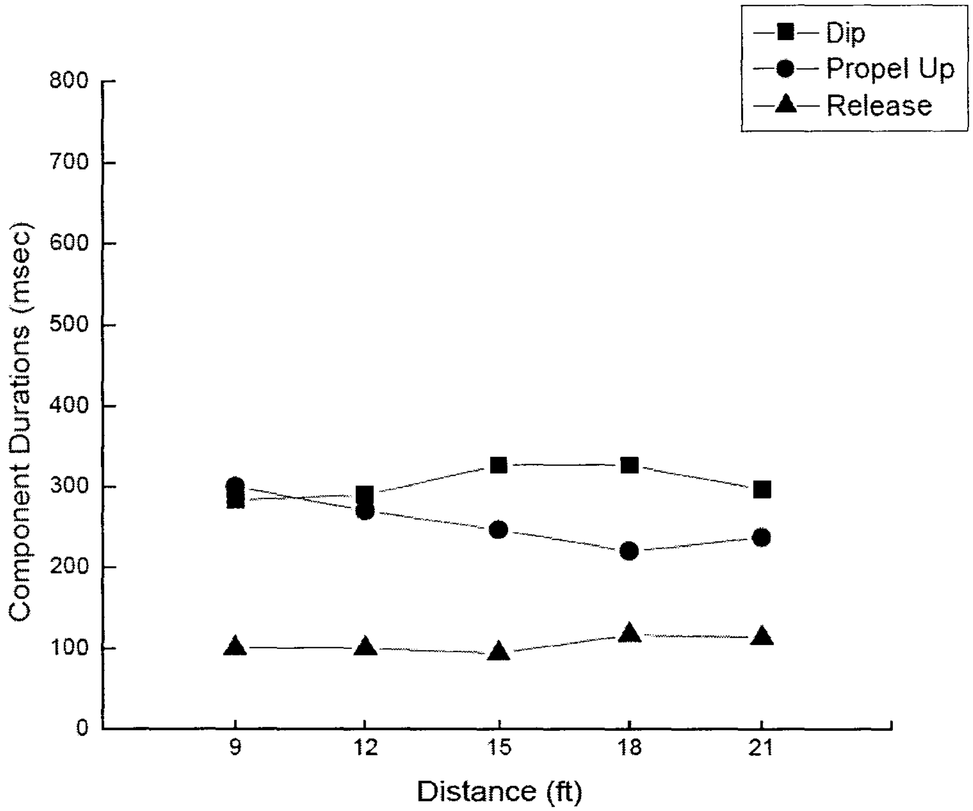

Figure 18. Shot phase (dip, propel up, release) component durations in milliseconds as a function of distance for expert 3.

Expert 4. The ANOVA examining component durations for expert 4 revealed significant main effects for shot phase, *F*(2,72)=355.82.35; *p*<.001 (dip = 422 msec, propel up = 536msec, release = 89msec) and distance, *F*(3,36)=29.63; *p*<.001 (9ft =315msec, 12ft = 338msec, 15ft = 360msec, 18ft= 384msec). Post hoc analyses of the main effect of shot phase revealed that component durations between each of the shot phases were significantly different from the others. Planned comparison analysis of the distance main effect revealed that component duration for 15ft was significantly different than the mean of all the other distances (p =.03). As well, a significant interaction between shot phase and distance, $F(6,72)=9.75$; $p<.001$, was found and is illustrated below in Figure 19. However, planned comparisons revealed no significant differences between 15ft and the mean of the other distances in any shot phases.

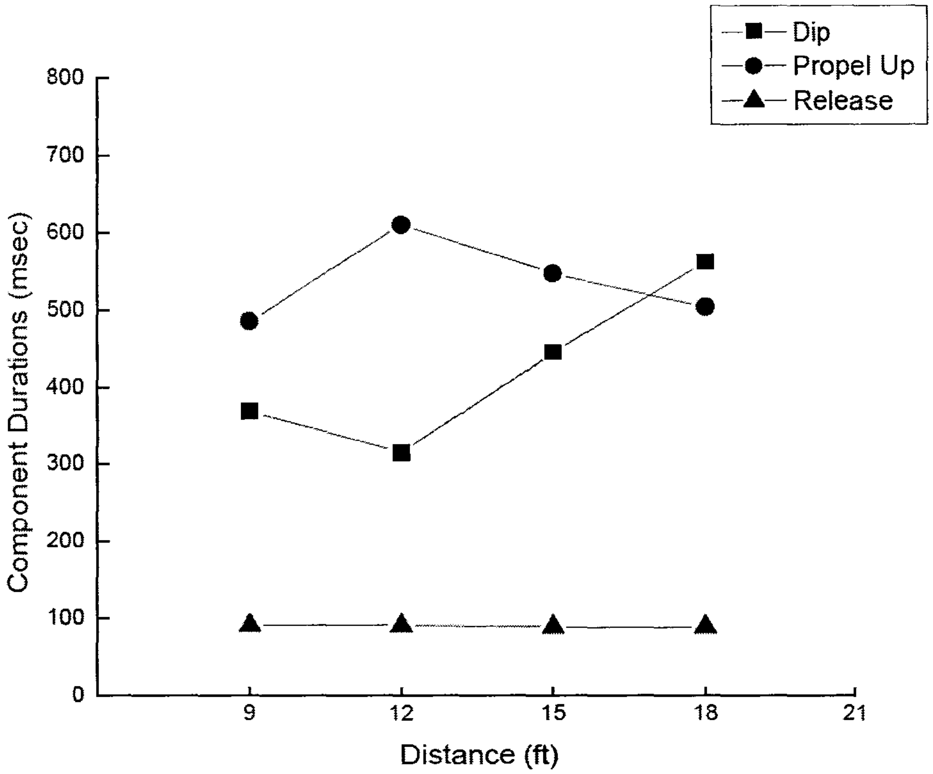

Figure 19. Shot phase (dip, propel up, release) component durations in milliseconds as a function of distance for expert 4.

Expert 5. The ANOVA examining component durations for expert 5 revealed significant main effects for shot phase, $F(2,72)=101.84$; $p<.001$ (dip = 309msec, propel up = 283msec, release = 90msec) and distance, $F(3,36)=5.44$; $p<.001$ (9ft =187msec, 12ft = 244msec, 15ft = 255msec, 18ft= 224msec). Post hoc analyses of the shot phase main effect revealed that component duration for the dip and propel up phases were not significantly different from each other but both different from the release phase. Planned comparison analysis of the distance main effect revealed that component duration for 15ft was significantly different than the mean of all the other distances (p =.02). As well, a significant interaction between shot phase and distance, $F(6,72)=4.47$; $p<.001$, was found and is illustrated below in Figure 20. However, planned comparisons revealed no significant differences between 15ft and the mean of the other distances in any shot phases.

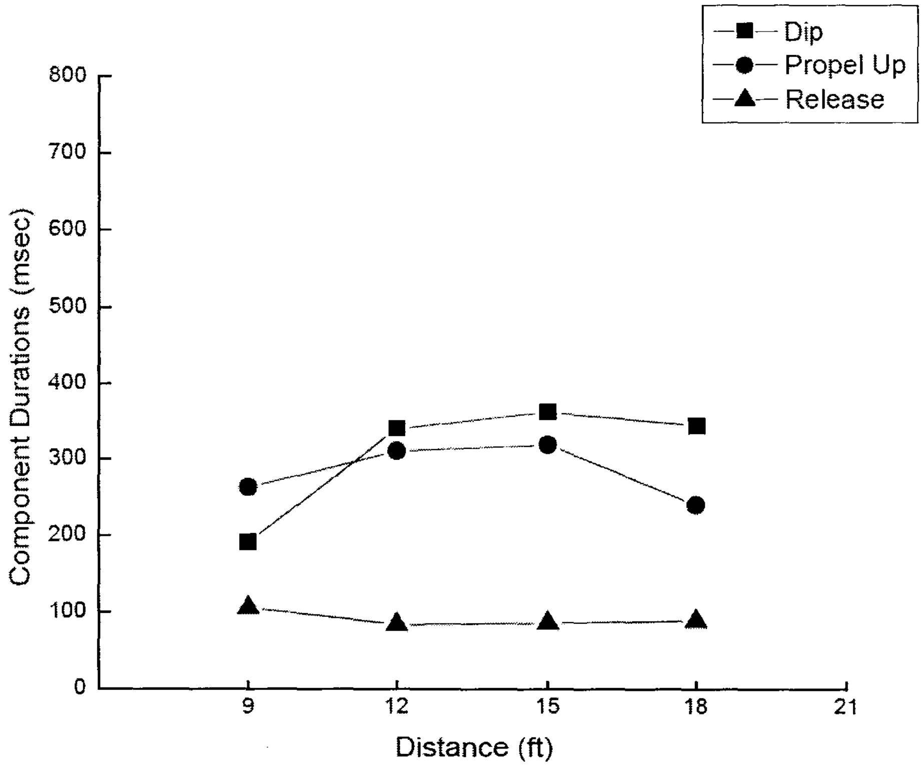

Figure 20. Shot phase (dip, propel up, release) component durations in milliseconds as a function of distance for expert 5.

Expert 6. The ANOVA examining component durations for expert 6 revealed significant main effects for shot phase, $F(2,90)=120.67$; $p<.001$ (dip = 336msec, propel up =

380msec, release = 102msec) and distance, $F(4,45)=26.77$; $p<.001$ (9ft =212msec, 12ft = 216msec, 15ft = 407msec, 18ft= 328msec, 21ft=202msec). Post hoc analysis of the shot phase main effect revealed that component duration for the dip and propel up phases were not significantly different from each other but both different from the release phase. Planned comparison analysis of the distance main effect revealed that component duration for 15ft was significantly different than the mean of all the other distances ($p < .001$). As well, a significant interaction between shot phase and distance, $F(8,90)=18.64$; $p<.001$, was found and is illustrated below in Figure 21. Planned comparisons revealed no significant difference between 15ft and the mean of the other distances in the dip and release phases.

There was a significant difference in the propel up phase ($p <.001$) for this player. Evident in Figure 21, expert 6 had a longer component duration at 15ft compared to the other distances in the propel up phase. As can be seen in Table 1, expert 6 had an overall shot duration that was considerably longer at 15ft (M= 1221.5 msec) compared to shots from the other locations (M =718.4 msec). Viewing the video footage, it was clear when expert 6 was at the foul-line; they would take an additional pause after maximum knee flexion prior to propelling upward. However, to keep the time-stamping of critical points consistent between participants and within this participant, we made no adjustments in the time-stamping process to account for this extra pause.

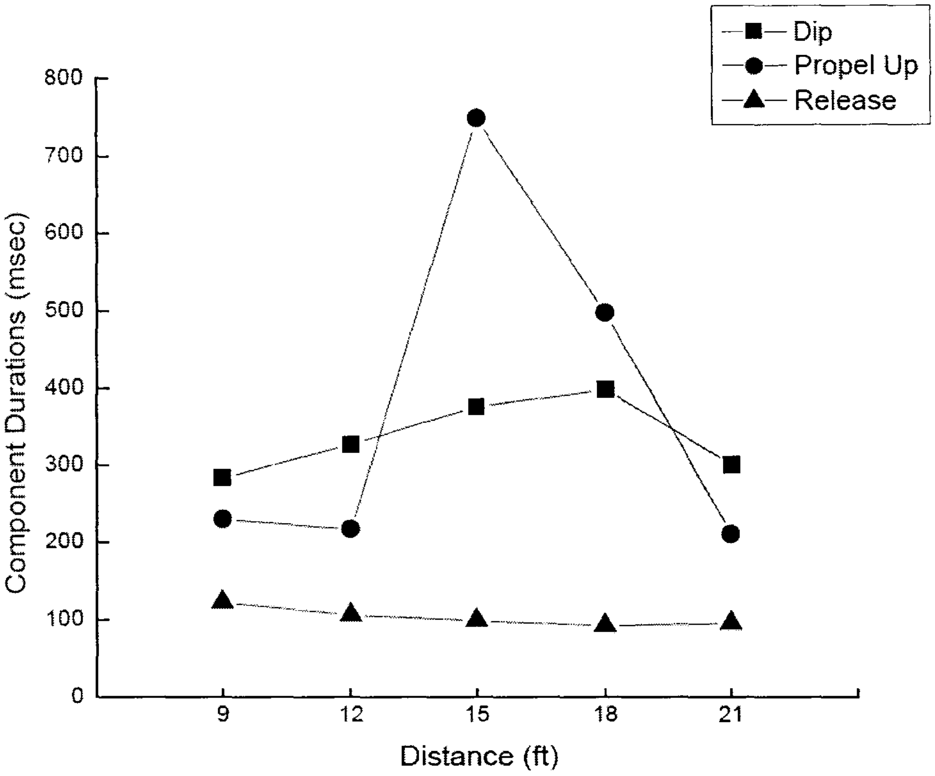

Figure 21. Shot phase (dip, propel up, release) component durations in milliseconds as a function of distance for expert 6.

Expert 7. The ANOVA examining component durations for expert 7 revealed significant main effects for shot phase, *F*(2,90)=197.39; *p*<.001 (dip = 259msec, propel up = 262msec, release = 98msec) and distance, *F*(4,45)=4.09; *p*<.001 (9ft =176msec, 12ft = 202msec, 15ft = 207msec, 18ft= 221msec, 21ft=226msec). Post hoc analyses of the shot phase main effect revealed that component duration for the dip and propel up phases were not significantly different from each other but both were different from the release phase. Planned comparison analysis of the distance main effect, however, revealed that component duration for 15ft was not significantly different than the mean of all the other distances (*p* =.99). As well, a significant interaction between shot phase and distance, *F*(8,90)=5.32; *p*<.001, was found and is illustrated below in Figure 22. Planned comparisons revealed no significant difference between 15ft and the mean of the other distances in the propel up and dip phases. However, there was a significant difference in the release phase (*p* =.02).

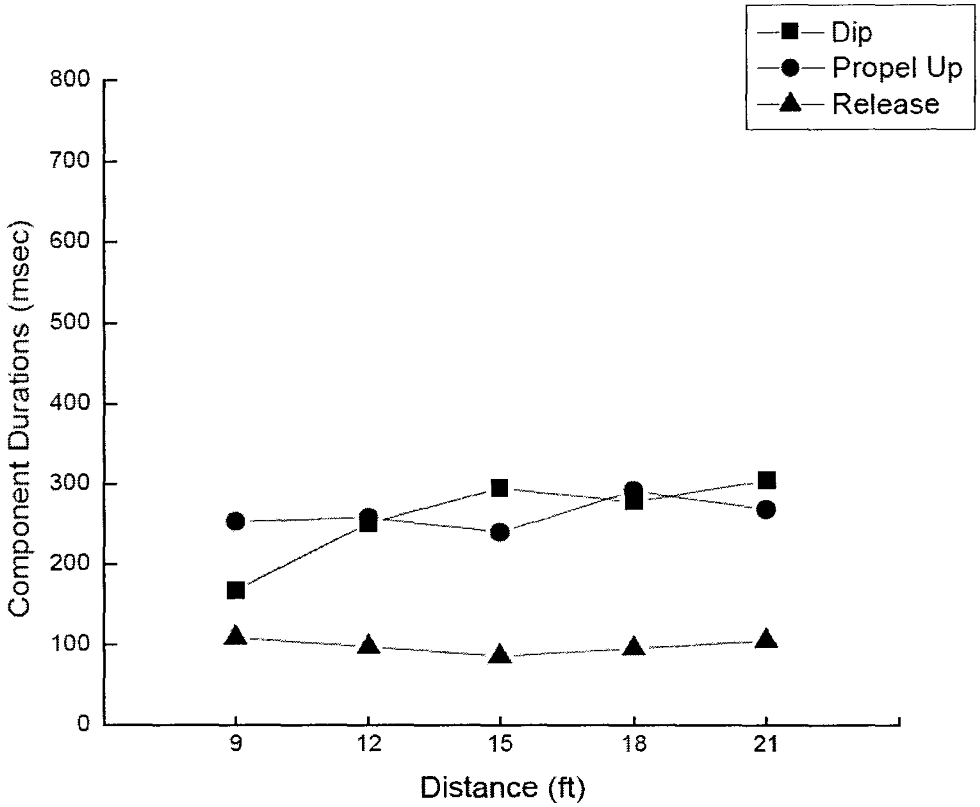

Figure 22. Shot phase (dip, propel up, release) component durations in milliseconds as a function of distance for expert 7.

Expert 8. The ANOVA examining component durations for expert 8 revealed significant main effects for shot phase, *F*(2,90)=106.60; *p*<.001 (dip = 207msec, propel up = 226msec, release = 98msec) and distance, *F*(4,45)=17.79; *p*<.001 (9ft =212msec, 12ft = 184msec, 15ft = 169msec, 18ft= 165msec, 21ft=156msec). Post hoc analyses of the shot phase main effect revealed that component duration for the dip and propel up phases were not significantly different from each other but both different from the release phase. Planned comparison analysis of the distance main effect, however, revealed that component duration for 15ft was not significantly different than the mean of all the other distances (*p* =.09). As well, a significant interaction between shot phase and distance, *F*(8,90)=8.64; *p*<.001, was found and is illustrated below in Figure 23. Planned comparisons revealed no significant difference between 15ft and the mean of the other distances in the propel up and dip phases. However, there was a significant difference in the release phase (*p* =.02).

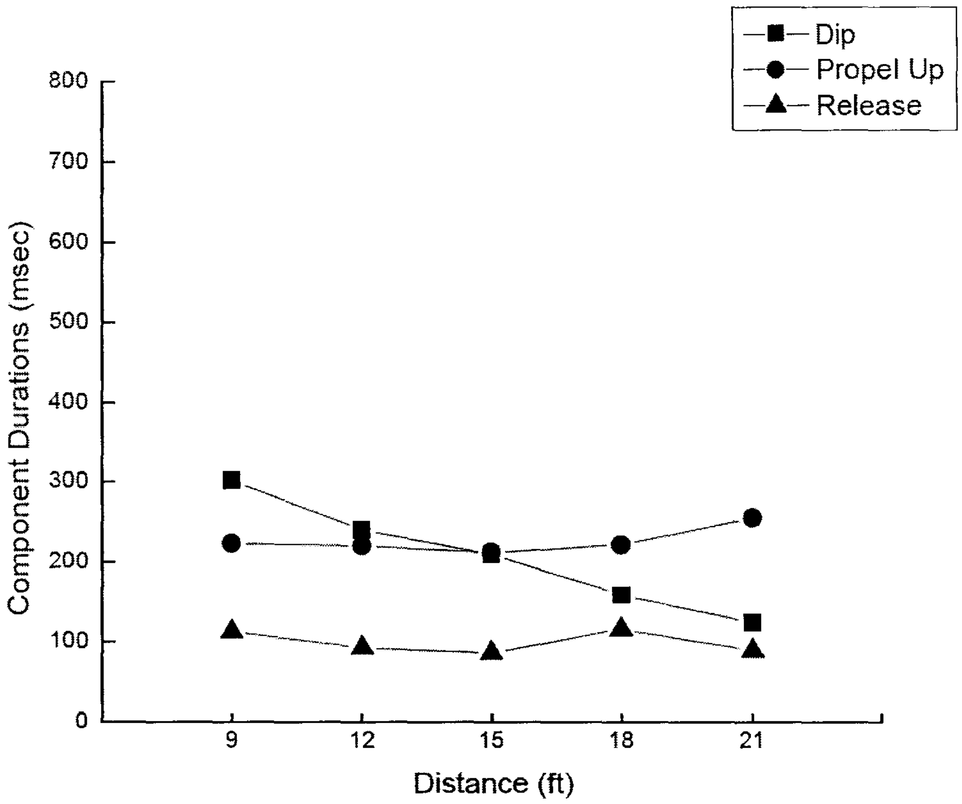

Figure 23. Shot phase (dip, propel up, release) component durations in milliseconds as a function of distance for expert 8.

Summary of Individual Data

All experts showed a main effect for shot phase, whereby component durations differed between shot phases. In half the experts (1-4) all shot phases differed in component duration, and in the other half (experts 5-8) dip and propel up component durations did not differ from each other but were different from the release phase. Moreover, 6 of the 8 experts showed a main effect for distance (not experts 2 and 3), 4 of which related to variance in component duration at 15ft compared to other distances. However, these main effects were superseded by the significant interaction of shot phase and distance, which was found in all experts.

The findings of the planned comparisons of the individual interactions are summarized in Table 2. As depicted in Table 2, 7 of the 8 experts showed invariance in timing in at least two of the three shot phases at the foul line compared to the other distances (with the exception of Expert 2 showing differences in all three shot phases). Specifically, Experts 3, 4 and 5 showed no significant differences in timing in any shot phase at 15ft compared to the other locations. The remaining experts each showed variance in only one shot phase and there did not seem to be a distinct pattern of where the variance in shot phase laid between these experts (e.g., Expert 1 in the dip phase, Expert 6 in the propel up phase, and Experts 7 and 8 in the release phase). Although some variance in timing was found, most notable is the relatively large degree of invariance demonstrated within and between individuals for shots completed at 15 ft compared to the other distances.

Table 2

Summary of Results of Planned Comparsion Analyses of 15ft shots compared to other distances from the Shot Phase by Distance Interaction in Experiment 6

	Shot Phases		
	Dip	Propel Up	Release
Expert 1	$p = .009$	ns	ns
Expert 2	$p = .02$	$p = .004$	$p < .001$
Expert 3	ns	ns	ns
Expert 4	ns	ns	ns
Expert 5	ns	ns	ns
Expert 6	ns	$p < .001$	ns
Expert 7	ns	ns	$p = .02$
Expert 8	ns	ns	$p = .02$

Note. ns = not significant ($p > .05$)

Discussion

Overall movement time of shot execution between shot locations did not differ within the group, nor did the measurement of variability. This latter finding is particularly interesting, as one might have suspected that years of practice specifically at the foul-line would have produced a shot execution with very little variability in experts at this location in comparison to less practiced locations. Instead, however, it seems through a lifetime of foul-shooting, regardless of practice location, these experts have developed a strong GMP for set shots in general, which contributes to minimal variability in shot execution, regardless of location.

In regards to the individual analyses examining relative timing structure, if we take the strictest view possible of the invariance hypothesis the most appropriate conclusion is that no evidence of invariance was found at all distances for 5 of the 8 experts. Such a conclusion would suggest that there is no GMP for the class of set shots in general. However, it may be unrealistic to think that we would not find any form of variance in the data even within individual performance. Indeed some have suggested that Gentner's interaction test may be too stringent and that a pervasive tendency toward *approximate* proportional scaling instead of *exact* proportional scaling (which is seldom seen) still supports the notion of the GMP (Heuer, 1988, 1991). Research on invariance in relative timing, and statistical tests of this invariance, like Gentners, are concerned with the proportions of *observed time intervals.* Heuer contends that "invariant relative timing on a *central level* of motor control is not necessarily accompanied by invariant relative timing on a *peripheral level*, where the observations are made; this occurs only if the expected delays between central commands and peripheral effects (motor delays) are constant throughout the movement" (1988, pg 552). He demonstrated that, given a central timing signal with perfect relative timing, a variable motor delay can result in an absence of invariance in observed performance. Therefore, one might not detect invariance at the level of the GMP by searching for invariances in motor output alone.

Although, of course, we have not examined central invariant timing directly in our work, there are a couple things to note from the present analyses that lead us to believe that a GMP for set shots does exist. First, as evident in Table 2, in 7 of the 8 experts no differences in the timing variances for at least two of the three phases of the foul shot in comparison to the other shot locations were found (with no differences in any phases for 3 experts). For expert 2, there was variance between all shot phases. Interestingly, this expert reported having the most experience with basketball shooting at the time of testing (16 years) compared to the other experts (closest level of experience was 13 years), which may suggest that something does change about the underlying representation of the foul shot compared to other locations with increased levels of experience. Second, when variance in timing was found, there was no distinct pattern of variance between the experts, suggesting that the differences are more likely a result of individual differences and less likely a result of the overall underlying representation that was used to execute these shots.

Few differences in the relative timing structure of set shots at the foul line were found compared to the other non foul line locations in the present analyses. Therefore, the interpretation that the free throw is represented in memory by a distinct motor program was not supported. It seems, based on our preliminary analyses, that set shots as an entire class are in fact represented by a single GMP (with perhaps the exception of expert 2). The data failed to reject notion of the free throw as "especial" – a special member of a *class* of actions.

Our finding that the underlying timing structure of shot execution remained similar for the free throw compared to the other set shot skills (i.e., is governed by the same GMP), of course does not mean that there are not other elements of free throw shot execution that become honed with advanced practice and lead to superior performance. Indeed, there is a relatively large literature examining other kinematic properties of shot execution. For example, several studies have examined shot success rate at the foul line by focussing on kinematics properties more specifically related to the arm and ball in shooting. For instance, Walter, Hudson, and Bird (1990) examined ball velocity and the contribution that each body segment made to ball velocity. Within an elite group of participants there was little variability of the ball velocity at release. They also found that early in the propulsion phase, the lower body was the main contributor; at the end of the propulsion phase, the forearm's contribution increased, and finally, just before release, the hand provided the major contribution. Tsarouchas, Kalamaras, Giavroglou, and Prassas (1990) analyzed expert free-throw performance and concluded that the trajectory of the ball prior to and after release approximated the same linear path, regardless of whether the performers used a high or low elbow technique when shooting. Hudson (1982) found that the best predictors of an elite shooter's accuracy were the height of release, angle of trajectory, wrist flexion velocity before and after release, and the weight and height of the subject. Taken together, it seems that aspects of motor execution related to properties at the end of the shooting motion when experts perform a free throw contribute to superior performance. Although such analyses were beyond the scope and purpose of the present study, future research is warranted to examine other kinematic differences in set shot performance at the foul line and other locations.

Chapter 5

GENERAL DISCUSSION

Theories of motor control, perhaps with the exception of the Adams (1971) theory, are based on the premise that we do not learn specific movements or actions. Rather, we learn to produce the capability of performing skills under a variety of conditions, both previously experienced and never before experienced. The general nature of this representation of motor skill provides two advantages: It reduces the memory storage requirements and provides additional flexibility when encountering unfamiliar movement requirements (Schmidt, 1975). So, what motor control mechanism or representation is responsible for the enhanced performance that occurs when experts performed especial skills from a very highly practiced location in a sport setting (i.e., the foul line in basketball)? Three possible explanations for the especial effect were tested in this work: 1) the learned parameters hypothesis (Experiment 4); 2) the especial GMP hypothesis (Experiment 6); and, 3) the visual context hypothesis (Experiments 2, 4, & 5).

Learned-Parameters Hypothesis

The *learned-parameters* hypothesis suggests that massive amounts of practice at one specific instance within a class of skills improve the parameter-specification process for that unique instance; years of practice have resulted in highly over-learned parameterizations of a 15-ft. set shot (velocity, angle, spin, etc). Skilled performers were required to perform set shots from several target locations around the basket that were all 15 ft. but at distinct angles from the basket (e.g., at the foul-line and 15°, 30°, 45° to the right and left of the foul-line). This hypothesis predicts that regardless of the angle of the shot, if it is taken from a distance that is 15 ft. to the basket then there will be no performance advantage at any particular location on the court. Our data did not support this hypothesis as set shot superiority was found at the foul-line compared to the level predicted based on performance at the other angled locations.

Especial GMP Hypothesis

The *especial GMP* hypothesis suggests that massive amounts of practice at one specific instance within a class of skills results in the development of a separate and new GMP for the action that optimizes the action. We tested the hypothesis that the free throw is governed by the same or a distinct GMP from other set shot skills by examining invariance in the relative timing structure of shot execution. If differences occurred between the free throw and the other set shots, this would provide evidence that a separate GMP had been learned. Our data did not support this hypothesis as relatively few differences were found in the experts' timing structure at 15ft compared to the other locations. The relative absence of unique timings amongst the set shots suggests that this class of skills is represented in memory by a single GMP, and that the free throw is not unique among them.

Visual-Context Hypothesis

The *visual-context* hypothesis suggests that embedded within the learned representation for the free throw is a unique visual context for that specific set shot. Since the free throw is always taken from the same position on the court relative to the basket, both the visual distance and the angle of the shot to the basket could be embedded in the learned representation. The removal of the incidental floor markings (i.e., the key) had no impact on the specificity effect in Experiment 2, and therefore seemed not to be an important part of learned representation. However, in Experiment 4, performance was found to be superior at the foul line compared to other angled shot locations, even though they were all performed from the same distance (15ft). Presumably, a shot from 15ft, regardless of the angle to the basket, required the same mechanics for shot execution. We concluded that performance was degraded at the other 15 ft locations because of the change in the highly practiced visual context of the shot.

Based on this latter finding, we believe further investigation of the visual context hypothesis is warranted and may shed light on the mechanism underlying the specificity effect found with the free-throw especial skill. We suspect that what develops with extensive practice is a strong visual-motor representation that is dependent on the visual context in which the skill is performed. A brief review of research addressing the role of visual information in effective motor control over extended practice is discussed next.

Role of Vision in Motor Control over Extended Practice

Considerable research has examined the role of visual information in the regulation of goal-directed movements with extended practice (e.g., Proteau et al. 1987, 1992, Proteau & Cournoyer, 1990; Proteau & Marteniuk, 1993; Elliott, Chua, Pollock, & Lyons, 1995; see Proteau, 1992 and Elliott & Lyons, 1998 for reviews). The prevailing thought in this research is that use of sensory feedback (particularly vision) during movement execution is and remains important for effective motor control during practice and learning. Proteau and colleagues have shown that a) what is learned is specific to practice, and b) sensory information (particularly vision) becomes increasingly important as practice continues. These studies have been framed by Proteau (1992) as the *specificity of learning hypothesis* which states that practice with afferent information leads to the development of specific sensorimotor representations that are used to compare sensory information on any given trial with expected sensory consequences. Once this specific representation has been created, any changes in the sensory information results in a decrement to performance, and this decrement becomes larger as practice increases. For example, Proteau et al. (1987) had individuals learn a manual aiming movement either under full vision (of limb and target; LT) or no vision (target only; T). Having practiced for either 200 or 2000 trials, participants were then transferred to a no vision test. Although all groups improved over acquisition the key finding was that in transfer the LT2000 groups performed markedly worse than the T2000 group. This supported the specificity of learning hypothesis such that what is learned is specific to the conditions of practice and sensory feedback increases in importance as practice increases.

Proteau and Marteniuk (1993) further examined what aspects of the visual context individuals use to ensure optimal aiming accuracy and its effects on transfer after extended practice. As well as full vision and no vision conditions, these authors had some individuals practice in a condition in which visual information was only received at the end of their movement (i.e., once the stylus hit the target area) but was absent during movement initiation and execution. In no vision transfer, participants in this visual knowledge of results condition showed decrement in their performance (e.g., increased error) which was exacerbated as practice levels increased. This was in contrast to performance of another visual practice condition where participants were presented visual information for a fixed period prior to movement initiation that was subsequently removed during movement execution. This latter group did not show the same decrement in performance in transfer. The authors suggested that the increasing reliance on vision as a function of practice was primarily due to the ability of participants to effectively use online visual information from the moving limb (also see Proteau & Cournoyer, 1990). All these results, Proteau thought, were in support of specific sensorimotor representations developing with extended practice where decrements could be predicted if the sensory information did match the expected sensory consequences.

Elliott and colleagues have also examined the use of vision during motor skill acquisition (Elliott et al., 1995; Elliott, Lyons, & Dyson, 1997; Robertson, Collins, Elliott, & Starkes, 1994, Robertson & Elliott, 1996; for a review see Elliott & Lyons, 1998). Although these authors agree that sensory information remains important as practice progresses as suggested by Proteau, they do not agree that specific sensorimotor representations developed. Instead, these authors believe that with extended practice, individuals learn to optimize the use of feedback that is available and adopt more general control strategies that can be modified to fit situations that have similar circumstances. For example, to examine how general or specific visual information-processing procedure are Elliott et al. (1995) manipulated the amount of visual feedback to which participants were exposed during movement acquisition in a manual aiming task. This task involved moving a mouse on a graphics tablet to displace a small cursor from a home position to a target located 13cm away. Individuals were trained such that they either received 400ms of visual information after movement onset or 600ms of visual information after movement onset. After acquisition, these groups were then switched to the opposing condition in transfer. Results revealed that individuals that had been trained in the 600ms group and were switched to having 400ms of information, increased their peak velocities in transfer in order to get to the vicinity of the target quicker and be able to use the visual feedback for online error corrections, which resulted in them maintaining their accuracy scores in transfer. The 400ms group that now received 600ms also changed their strategy and slowed their movement times in order to use the extra visual feedback available which resulted in them increasing their accuracy. The authors suggested that the information processing strategies acquired in one situation are often flexible enough to be adjusted and applied to different sensory circumstances, with the amount of positive or negative transfer being dependent on how useful the developed control strategy is in similar or dissimilar situations, respectfully (Elliott et al. 1997).

Using another approach to examine the role of practice on visual feedback utilization, Robertson et al. (1994) had expert and novice gymnasts walk across a balance beam under different visual conditions: full vision, no vision, and intermittent vision (vision available for 20ms and off for periods ranging between 80 and 500ms). If the specificity effect was to hold, then it would be expected that the experts would show severe decrements in performance when vision was removed. However this was not the case, experts actually maintained their movement time performance regardless of visual condition. In a follow up study, these authors uncovered the finding that although movement time scores remained equivalent in no vision transfer, the experts took more steps to complete the movement and made considerably more postural adjustments. So although the experts were able to maintain their speed, they were performing the task quite differently in the absence of vision. Vision was not necessary, but it certainly contributed to performance when it was available. The authors suggested that the experts were more adept at using other sources of afferent information to help their performance (i.e., proprioceptive, vestibular, etc) when vision was unavailable, but this takes extensive practice to develop (Robertson & Elliott, 1996). In terms of novice performance, elimination of vision had a profound negative effect on movement time and form. Presumably, for these individuals, vision dominated because they had not developed other strategies to maintain performance, and so performance suffered when this source of visual information was removed. Taken together, it seems when vision is available, it plays a dominant role in the error-reduction process but part of becoming skilled is the ability to rapidly and efficiently adjust a movement in progress by making use of response-produced feedback (Elliott & Lyons, 1998).

Overall, whether it be more specific representations or optimized control strategies that are established, this research underscores the importance of using online sensory information (especially vision) for successful execution of motor action, particularly as practice progresses.

Visual Control in Basketball Shooting

To this point investigations of the especial skill effect have manipulated visual conditions by removing incidental visual cues and by repositioning the players themselves relative to the position of the basket and backboard. However, it is likely that there are other elements of the visual context that are important, perhaps critical, in the visual-motor representation that develops with extended practice. For example, players typically focus their eyes on the target of their shot during free-throw preparation and execution. This can include such aspects as the basket/rim, the backboard, or a combination of both. Ripoll, Bard, and Paillard (1986) have shown that skilled basketballs players orient their gaze toward the basket sooner and maintain vision in the region of the target longer than do lower skilled players. Moreover, Vickers (1996; Harle & Vickers, 2001) has demonstrated that long target fixations prior to movement execution is a necessary component of pre-programming (e.g., parameter selection), successful free throw performance, and defines a distinguishing mark of expertise.

More recent investigations have examined visual attention and motor control in basketball shooting (de Oliveria, Huys, Oudejans, van de Langenberg, & Beek, 2007; de Oliveria, Oudejans, & Beek, 2006, 2008; Oudenjans, van de Langenberg, & Hutter, 2002). Specifically, these investigations have examined the use of online visual information throughout the shooting process and its subsequent impact on performance. Oudenjans et al. (2002) used a temporal occlusion method to examine expert basketball shooters jump shot performance. Constraints were imposed on vision that made environmental information available or unavailable during specific phases of the shooting action. Four vision conditions were used: no vision, full vision, early vision (vision occluded during the final ±350ms before ball release), and late vision (vision occluded until the final ±350ms). It was found that shooting accuracy was comparable to the level achieved in the full vision condition when shooters received late visual information, while severe decrements in performance were observed when visual information was available only early in the movement (i.e., removed in the final 350ms before the shot).

The authors suggested that the final shooting movements were controlled by continuous detection and use of visual information until ball release.

de Oliveria et al. (2006) followed up the work of Oudenjans et al. by examining preferred timing of optical information pick-up in expert players with different shooting styles (e.g., low vs. high, see Figure 24). With a low shooting style, the ball and hands remain below eye level before the final extension of the elbow, after which they move in front of the face (Kreighbaum & Barthels, 1981). With a high shooting style, the ball is first carried to a position above the head followed by an extension of the elbow until ball release (Hay, 1973).

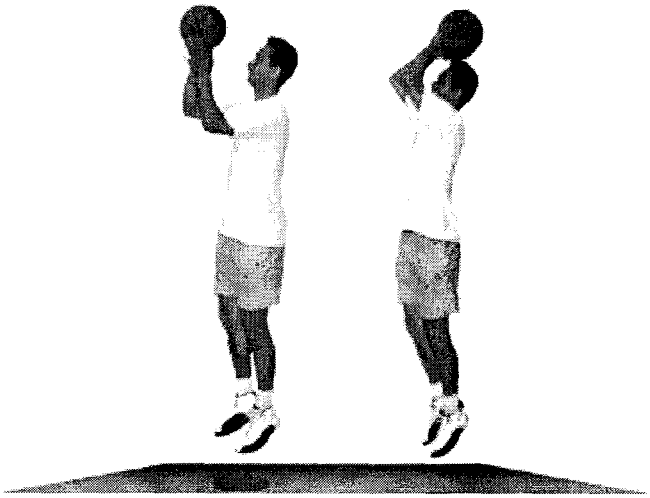

Figure 24. Image of low-style (left) and high-style (right) shooting.

Vision was manipulated by opening and closing liquid-crystal occlusion goggles at pre-set intervals. Specifically, the goggles were open for 350ms and closed for 250ms in a 600ms shot cycle. Having these established pre-set timing intervals of visual occlusion, participants could control when they saw the basket by modulating the timing of their movements. It was found that participants tailored their movements in order to receive optical information as late in the shot as possible given their shooting style. In another manipulation, de Oliveria (2007) had participants shoot under normal vision conditions or with a delay in movement initiation after the removal of vision (e.g., zero, one or two seconds). Endpoint accuracy (in terms of percentage of hits and variability in ball landing position) was significantly better under normal viewing conditions and became progressively worse with increased delays, again suggesting that participants were using online visual information to guide their actions. Regardless of shooting style, these shooters preferred to look at the target (e.g., the basket) as late as possible before their final shooting motion and use this visual information (specifically, endpoint target information) to facilitate successful shot execution (de Oliveria et al., 2008). Based on the findings of the basketball studies of Oudenjans et al. (2002) and de Oliveria and colleagues (2006, 2007, 2008) and considering the established importance of online visual control for effective regulation of goal-directed movements with advanced levels of practice (e.g., see Elliott & Lyons, 1998; Proteau, 1992 for reviews), we posit that the especial effect found for the free throw in our experts may very well be a product of how well they have learned to use and integrate online visual context information into the execution of this motor skill.

It is very possible that what has been engrained with massive amounts of practice at the foul-line (resulting in superior performance) is an optimization of use of visual information related to the visual context of the basket at 15ft. Consequently, a logical future direction would be to manipulate the visual information provided to the experts during preparation and execution of the free throw. Could removal of vision at certain points in the movement translate into a reduction or elimination of the specificity effect found at the foul-line? One way this question could be addressed is by implementing a temporal occlusion methodology similar to Oudenjans et al. (2002). In this design, players would be required to participate in two experimental sessions. In the first session, players would replicate the protocol in Experiment 2 whereby they perform set shots at several locations spanning 9 to 21-ft, including the foul line at 15-ft. During this session, participants would be wearing occlusion goggles; however vision would not be occluded (but this session would allow the players to get used to performing with the goggles and provide us with data to make comparisons of predicted and actual levels of performance at the foul line). In the second session, players would return and shoot a series of free-throws under the occlusion conditions (n=3) where vision would be removed at various points in movement preparation and execution: no vision (vision occluded for the entire execution of the task), early vision (vision occluded during the final ±350ms before ball release), and late vision (vision occluded until the final ±350ms). By occluding vision at different stages (e.g., early and late) it would be possible to find out whether early or late visual information is necessary for accurate shooting of the free throw and most importantly, to ascertain what role online vision plays in the expression of the especial effect. Of course it is assumed that complete removal of vision would cause a decrement in performance in these players. In terms of the occlusion conditions, if early vision is necessary (as suggested by Vickers, 1996) for successful performance, then one might expect early vision performance to be similar to full vision and the especial effect would remain, while late viewing performance would be impaired and the especial effect would be reduced. On the other hand, if late vision is important (as suggested by Oujendans et al., 2002 and de Oliveria and colleagues, 2006, 2007) than the reverse results would be expected. Namely performance with early vision available would be impaired as would the especial effect, but late vision performance would remain similar to full vision and the especial effect would remain.

Since the learned-parameters and especial GMP hypotheses were not supported, it seems appropriate to conjecture that the distance of the shot taken or the timing structure of shot execution itself are not critical factors for the expression of the especial effect. Instead other factors from the specific conditions of practice that accrue with massive amounts of practice are important (e.g., visual-motor representations). Indeed, future research endeavours should further explore the visual context hypothesis as a viable mechanism to explain the especial effect.

Effect of Advanced Skill on Memory Representation: General to Specific?

In trying to reconcile our findings with motor control theories that advocate specificity (e.g., Proteau, 1992) vs. generality (e.g., Schmidt, 1975), one possibility is that memory representations may initially be general but become more specific at higher levels of performance. In this view, the rules governing the generalizability of actions change across practice – with a relatively large degree of adaptability found early in practice (e.g., to facilitate the learning of new skills and adaptability to new situations) and greater specificity later in practice (e.g., to meet specific task demands) (Shea &

Wulf, 2005). For example, Shea and colleagues (Park & Shea, 2003, 2005 Wilde & Shea, 2006) have examined how memory representation structure changes with extended practice. Wilde and Shea (2006) found that a 16-element movement sequence (requiring specific force-time patterns) was stored in a relatively abstract manner after 1 day of practice. They came to this conclusion because participants were capable of performing proportional (i.e., the production of the sequence where the entire response had been rescaled in one or more movement dimensions (e.g., force, time, spatial position) and non-proportional (i.e., the production of the sequence where only one or more parts of the sequence, but not all, were rescaled) transfer tests as well as the retention test where they were required to perform the task that they had practised during acquisition. However, when 3 additional days of practice were provided, participants were able to effectively transfer to the proportional but not the non-proportional transfer condition. The authors suggested that the processing of the sequence became increasingly more specific over extended periods of practice. Extended practice resulted in faster and more seamless response production (i.e., superior performance) but at the cost of a decreased ability to transfer.

Similarly, Park and Shea (2003, 2005) examined effector independence in a similar movement sequence task over practice. Effector independence refers to the ability to perform a task similarly with any effector (e.g., limb) (and is an important prediction of the original conception of schema theory). The authors found that after 1 day of practice with the dominant limb participants were effective in transferring to their nondominant limb (thus showing effector independence), but after 3 additional days of dominant limb practice performance with nondominant limb transfer performance was no better than that after 1 day of practice. If considered in this context, the specificity-of-practice effects we observed in Experiments 1, 2, and 4, would therefore not invalidate the schema notion; rather, they might simply be more relevant for an advanced stage of learning of our experts (i.e., performers with 10+ years of accumulated practice at their craft under specific conditions of practice). As well, our finding of generality in performance of the non-foul line shooting skills in these same experiments, could also conform to this line of reasoning, as compared to the extensively practiced 15-ft location, these other set shot skills have minimal practice and so may still be represented in a more abstract/flexible manner. It is an interesting finding on its own that specificity and generality effects have been demonstrated to co-exist in a single paradigm, and this warrants further theoretical consideration.

Implications for Conditions of Practice

Although the work presented here has been situated and discussed in terms of motor control theory and how the results we have revealed can be reconciled in previous theory and promote future theory, another important avenue to consider is the practical implications of this work. We have conjectured that the especial skills effect (i.e., performance advantage of the free throw at the foul line compared to other set shot skills) is due to the massive amounts of constant/specific practice accumulated predominantly at the foul-line (15ft). Does this mean we should advocate to coaches and players that constant practice is the best way to achieve high levels of performance at the foul-line? Or could the especial effect be a by-product of how practice has been structured based on the rules of game, and therefore other methods of practice increase performance even more? We know that there is a large literature that describes the superiority of promoting variability of movement experiences during practice rather than constant practice for long-term learning gains (e.g., Schmidt, 1975, 2003; Shea & Kohl, 1990, 1991; see van Rossum, 1990 for a review). Could even greater gains be achieved if experts are initially trained, or continue to train, with more variability? Or does the nature of the skill, a so-called "closed skill" (where the ideal pattern is essentially invariant across different attempts) and field context necessitate more specific conditions of practice?

One way to address these questions is through a training study with novices. In one motor learning study, Schoenfelt, Snyder, Maue, McDowell, and Woolard (2002) had novice performers practice set shots over several weeks in various practice conditions and conducted a retention test 2 weeks later. Members of the constant practice group practiced solely from the foul line; those in one variable group practiced 2 ft. in front and behind the foul line; participants in the another group practiced both at the foul line as well as in front of and behind the foul line; and those in a final variable group practiced at the foul line and at the right and left elbows of the key. It was shown in retention that those who had practiced in the variable group practicing in front of, at, and behind the line showed the highest percent improvement in free-throw performance (10.9%) compared to their pre-test scores, with the constant group showing the smallest improvement (1%). This result is consistent with the tenants of schema theory. However, based on the findings of our work with skilled performers showing specificity at the foul line, presumably having experienced large quantities of specific practice at the foul line with minimal practice of set shots are other locations, calls into question optimal conditions of practice. A necessary future approach to the further study of the especial skills effect would include a long term learning study to examine the effect of massive amounts of constant (similar to our experts in the present study) vs. variable practice on free-throw performance. Would the especial effect dissipate if the nature of practice were different from the initial learning stage of set shot performance? Perhaps variable practice would be optimal initially, but then more constant/specific practice would be beneficial later by virtue of the nature of the set shot in the game of basketball. If performers were given extensive practice under variable or constant conditions, would the especial effect still hold? That is would constant practice yield superior performance for the free throw compared to variable practice, or would variable practice negate the effect while improving performance of the set shot class of actions as a whole? These questions warrant future research. Not only would it give a better understanding of critical elements required to develop especial skills (or remove them), but it would serve to answer important questions with regards to condition of practice, training, and instruction.

Other Especial Skills

The evidence for the existence of especial skills would be weakened if they were found only to exist for basketball set shots. Inspired by our work, a recent study by Simons, Wilson, Wilson, and Theall (in press) examined the capability of college baseball pitchers to throw strikes from varying distances. The rules of baseball require pitchers to throw from a location that is 60.5 ft. from home plate, and pitchers spend most, if not all, of their practice time throwing from this distance. Simons et al. (in press) examined performance accuracy when throwing from nine unequal distances (36.5 – 84.5 ft), including locations that were just *one foot* on either side of the regulation distance (i.e., 59.5 and 61.5 ft). The pitchers attempted to throw strikes, as determined by a commercially available "strike zone" device that provides a target and means of assessing whether or not a pitch would be called a strike for a batter of average size. As depicted in Figure 25, the data of Simons et al. revealed that pitches thrown from the regulation 60.5-ft mark were 42% more accurate than predicted based on the regressed data. But, perhaps more astonishingly, the pitchers were significantly more accurate at the regulation length than at either the 59.5 ft or 61.5 ft distances. A change in movement distance of just *one foot* (a distance variation of just 1.6%) completely nullified the specificity effect – the pitchers' performances at one foot closer to, or further from the plate reduced accuracy to the levels predicted by the regression equations. In our data we found that distances of 2 ft. from the foul-line showed no specificity in performance. In Simons et al., an alternation of just one foot away from the regulation pitch distance changed performance drastically, suggesting minimal transfer of the skill developed at 60.5 ft. This extreme level of specificity of the baseball pitch extends the especial effect finding beyond simply a basketball foul line, set-shot effect.

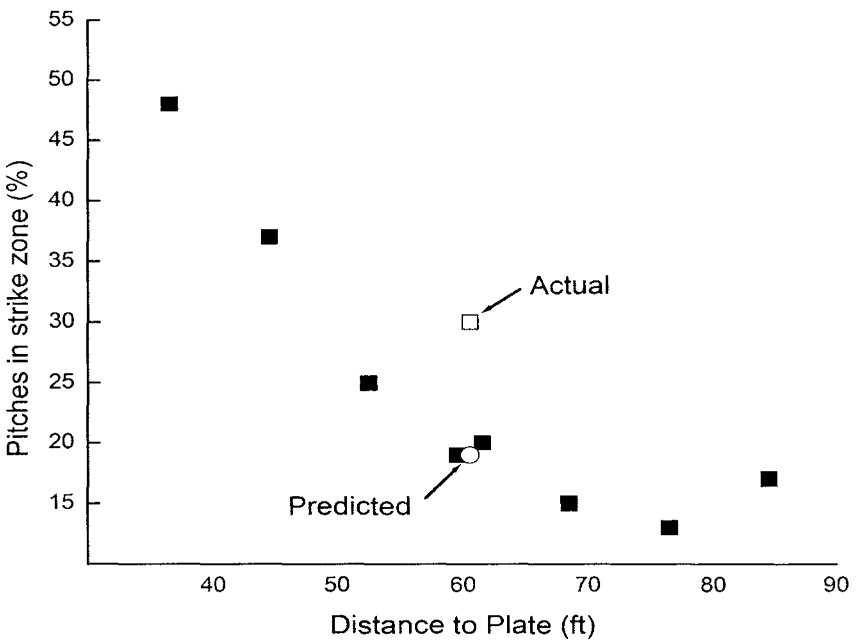

Figure 25. Baseball pitching performance (% pitches entering the strike zone) as a function of the distance from the pitching location to the plate. The filled squares represent the actual success at the irregular pitching locations; the unfilled square represents the actual success at the regulation distance (60.5 ft.); and the unfilled circle represents the predicted success at the regulation distance (60.5 ft.) based on individual regression analyses using the irregular pitching distances (with permission of the authors).

Future research should also be directed at uncovering other tasks that conform to the criteria of especial skills. Perhaps only certain types of tasks would be likely to produce an especial effect. Potential candidates may be tasks that have more precise beginning and end points, with little variability in practice and end game performance. Archery, darts, or rifle/pistol shooting come to mind as activities that have little variability in practice location, and also have outcome performance goals to targets also with little variability (e.g., the bullseye).

Conclusion

It appears that our new finding of especial skills, together with the specificity effects that have emerged in the recent literature, encourages a somewhat different theoretical approach to motor learning and control. Such an approach would seem to require provisions for the co-existence of motor skill generality and specificity. Further, it would seem to require a shift of emphasis toward specificity as a product of the very high levels of practice necessary for the phenomenal level of skill that comes with expertise. Future theoretical efforts could be directed at incorporating and understanding both the generalities in the class of actions and the specificity of the especial skills that happen to have received massive amounts of practice.

Moreover, it would be beneficial to further consider the mechanisms behind what truly make these skills especial, beyond massive amounts of practice in specific practice conditions. Such designs could look at what factors make the strong performance superiority effects disappear. As it stand now, massive amounts of practice produce specific capabilities— in terms of the set shot taken at the foul line or the pitch taken from the pitcher's mound—that are demonstrably separate from the seemingly similar skills that surround them.

List of References

Abrams, R.A., Meyer, D.E., & Kornblum, S. (1989). Speed and accuracy of saccadic eye movements: Characteristics of impulse variability in the oculomotor system. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 529-543.

Adams, J.A. (1952). Warm-up decrement in performance on the pursuit-rotor. American *Journal of Psychology, 65*, 404-414.

Adams, J.A. (1961). The second facet of forgetting: A review of warm-up decrement. *Psychological Bulletin, 58*, 257-273.

Adams, J. A. (1971). A closed-loop theory of motor learning. *Journal of Motor Behavior, 3,* 111-149.

Adams, J. A. (1987). Historical review and appraisal of research on the learning, retention, and ransfer of human motor skills. *Psychological Bulletin, 101,* 41-74.

Anshel, M.H., & Wrisberg, C.A. (1993). Reducing warm-up decrement in the performance of the tennis serve. *Journal of Sport & Exercise Psychology, 15,* 290-303.

Armstrong, T.R. (1970). *Training for the production of memorized movement patterns* (Tech. Rep. No. 26). Ann Arbor: University of Michigan, Human Performance Center.

Bachman, J.C. (1961). Specificity vs. generality in learning and performing two large muscle motor tasks. *Research Quarterly, 32,* 3-11.

Bernstein, N.A. (1947). *On the structure of movements.* Moscow: State Medical Publishing House.

Bernstein, N.A. (1967). *The co-ordination and regulation of movements.* Oxford: Pergamon Press.

Bernstein, N.A. (1996). On dexterity and its development. In M.L. Latash & M.T. Turvey (Eds.), *Dexterity and its development* (pp. 3-244). Mahwah, NJ: Erlbaum.

Bridgman, B., Kirch, M., & Sperling, A. (1981). Segregation of cognitive and motor aspects of visual function using induced motion. *Perception & Psychophysics*, 29, 336-342.

Bruce, D. (1994). Lashley and the problem of serial order. *American Psychologist, 49,* 93-103.

Catalano, J.F., & Kleiner, B.M. (1984). Distant transfer in coincident timing as a function of practice variability. *Perceptual and Motor Skills, 58,* 851-856.

Chamberlin, C.J., & Magill, R.A. (1992a). A note on schema and exemplar approaches to motor skill representation in memory. *Journal of Motor Behavior, 24,* 221-224.

Chamberlin, C.J., & Magill, R.A. (1992b). The memory representation of motor skills: A test of schema theory. *Journal of Motor Behavior, 24,* 309-319.

Cormier, S.M., & Hagman, J.D. (Eds.) (1987). *Transfer of learning: Contemporary research applications.* New York: Academic Press.

Courneya, K.S., & Carron, A.V. (1992). The home advantage in sport competitions: A literature review. *Journal of Sport & Exercise Psychology, 14,* 13-27.

Davies, G.M., & Thomson, D.M. (1988). *Memory in context: Context in memory.* New York: Wiley.

de Oliveria, R.F., Huys, R., Oudejans, R.R.D., van de Langenberg, R., & Beek, P.J. (2007). Basketball jump shooting is controlled online by vision. *Experimental Psychology, 54,* 180-186.

de Oliveria, R.F., Oudejans, R.R.D., & Beek, P.J. (2006). Late information pick-up is preferred in basketball jump shooting. *Journal of Sports Sciences, 24,* 933-940.

de Oliveria, R.F., Oudejans, R.R.D., & Beek, P.J. (2008). Gaze behaviour in basketball shooting: Further evidence for online visual control. *Research Quarterly for Exercise and Sport, 79,* 399-404.

Eich, J., Weingartner, H., Stillman, R.C., & Gillen, J.C. (1975). State-dependent accessibility of retrieval cues in the retention of a categorized list. *Journal of Verbal Learning and Verbal Behavior, 14,* 408-417.

Elliott, D., Chua, R., Pollock, B.J. & Lyons, J. (1995). Optimizing the use of vision in manual aiming: The role of practice. *Quarterly Journal of Experimental Psychology, 48A,* 72-83.

Elliott, D., & Jaeger, M. (1988). Practice and the visual control of manual aiming movements. *Journal of Human Movement Studies, 14,* 279–291.

Elliott, D. & Lyons, J. L. (1998). Optimizing the use of vision during motor skill acquisition. In J. P. Piek (Ed), *Motor behavior and human skill: A multidisciplinary approach* (pp. 57-72). Champaign, Il: Human Kinetics.

Elliott, D., Lyons, J., & Dyson, K. (1997). Rescaling an acquired discrete aiming movement: Specific or general motor learning. *Human Movement Science, 16,* 81-96.

Fitts, P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47*, 381-391.

Fleishman, E.A. (1967). Individual differences and motor learning. In R.M. Gagne (Ed.), *Learning and individual differences* (pp. 165-191). Columbus, OH: Merrill.

Fleishman, E.A., & Rich, S. (1963). Role of kinesthetic and spatial-visual abilities in perceptual-motor learning. *Journal of Experimental Psychology, 66*, 6-11.

Gentner, D.R. (1987). Timing of skill motor performance: Tests of the proportional duration model. *Psychological Review, 94,* 255-276.

Gilovich, T., Vallone, R., & Tversky, A. (1985). The hot hand in basketball: On the misperception of random sequences. *Cognitive Psychology, 17*, 295-314.

Hardy, L., & Parfitt, G. (1991). A catastrophe model of anxiety and performance. *British Journal of Psychology, 82,* 163-178.

Harle, S.K., & Vickers, J.N. (2001). Training quiet eye improves accuracy in the basketball free trow. *The Sport Psychologist, 15,* 289-305.

Hay, J.G. (1973). *The biomechanics of sports techniques.* Englewood Cliffs, NJ: Prentice-Hall.

Henry, F.M. (1968). Specificity vs. generality in learning motor skill. In R.C. Brown & G.S. Kenyon (Eds.), *Classical studies on physical activity* (pp. 328-331). Englewood Cliffs, NJ: Prentice-Hall.

Heuer, H. (1988). Testing the invariance of relative timing: Comments on Gentner, 1987. *Psychological Review, 97*, 402-497.

Heuer, H. (1991). Invariant relative timing in motor program theory. In F. Fagard & P.H. Wolff (Eds.). *The development of timing control and temporal organization in coordinated action* (pp. 37-68). Amsterdam: Elsevier.

Hudson, J. L. (1982). A biomechanical analysis by skill level of free throw shooting. In: J. Terauds (Ed.), *Biomechanics in Sports* (pp. 95-102). Del Mar, CA: Academic Publishers.

Jones, M.B. (1966). Individual differences. In E.A. Bilodeau (Ed.), *Acquisition of skill* (pp. 109-146). New York: Academic Press.

Jordan, M.I. (1995). The organization of action sequences: Evidence from a relearning task. *Journal of Motor Behavior, 27,* 179-192.

Keetch, K.M., Lee, T.D., & Schmidt, R.A. (2008) Especial skills: Specificity embedded within generality. *Journal of Exercise and Sport Psychology,* 30, 723-736.

Keetch, K.M, Schmidt, R.A., Lee, T.D., & Young, D.E. (2005). Especial skills: Their emergence with massive amounts of practice. *Journal of Experimental Psychology: Human Perception and Performance, 31,* 970-978.

Khan, M. A. & Franks, I. M. (2004). The utilization of visual feedback in the acquisition of motor skills. In A. M. Williams, & N. J. Hodges (Eds.), *Skill Acquisition In Sport Research: Theory and Practice* (pp.45-62). London: Routledge.

Khan, M. A., Franks, I. M., & Goodman, D. (1998). The effect of practice on the control of rapid aiming movements: Evidence for an interdependency between programming and feedback processing. *The Quarterly Journal of Experimental Psychology, 51*, 425-444.

Kreighbaum, E., & Barthels, K.M. (1981). *Biomechanics: A qualitative approach for studying human movement.* Minneapolis, MN: Burgess.

Lashley, K.S. (1942). The problem of cerebral organization in vision. In J. Cattell (Ed.), *Biological symposia. Vol. VII. Visual mechanisms* (pp. 301-322). Lancaster, PA: Jaques Cattell Press.

Lersten, K.C. (1968). Transfer of movement components in a motor learning task. *Research Quarterly, 39*, 575-581.

Lotter, W.S. (1960). Interrelationships among reaction times and speeds of movement in different limbs. *Research Quarterly, 31*, 147-155.

Magnuson, C.E., Wright, D.L., & Verwey, W.B. (2004). Changes in the incidental context impacts search but not loading of the motor buffer. *Quarterly Journal of Experimental Psychology, 57A*, 935-951.

Maraj, B.K.V., Elliott, D., Lee, T.D., & Pollock, B.J. (1993). Variance and invariance in expert and novice triple jumpers. *Research Quarterly for Exercise and Sport, 64,* 404-412.

Marteniuk, R.G. (1974). Individual differences in motor performance and learning. *Exercise and Sport Sciences Reviews, 2,* 103-130.

McCraken, H.D., & Stelmach, G.E. (1977). A test of the schema theory of discrete motor learning. *Journal of Motor Behavior, 9,* 193-201.

McCullagh, P., & Caird, J.K. (1990). Correct and learning models and the use of model knowledge of results in the acquisition and retention of a motor skill. *Journal of Human Movement Studies, 18,* 107-116.

Merton, P.A. (1972). How we control the contraction of our muscles. *Scientific American, 226,* 30-37.

Meyer, D.E., Abrams, R.A., Korblum, S., Wright, C.E., & Smith, J.E.K. (1988). Optimality in human motor performance: Ideal control of rapid aimed movements. *Psychological Review, 95,* 340-370.

Moxley, S.E. (1979). Schema: The variability of practice hypothesis. *Journal of Motor Behavior, 11,* 65-70.

Nacson, J., & Schmidt, R.A. (1971). The activity-set hypothesis for warm-up decrement. *Journal of Motor Behavior, 3,* 1-15.

Newell, K.M., Shapiro, D.C., & Carlton, M.J. (1979). Coordinating visual and kinaesthetic memory codes. *British Journal of Psychology, 70,* 87-96.

Oudejans, R.R.D., van de Langenberg, R.W., & Hutter, R.I. (2002). Aiming at a far target under different viewing conditions: Visual control in basketball jump shooitng. *Human Movement Science, 21,* 457-480.

Park, J.-H., & Shea, C.H. (2003). Effect of practice on effector independence. *Journal of Motor Behavior, 35,* 33-40.

Park, J.H., & Shea, C.H. (2005). Sequence learning: Response structure and effector transfer. *The Quarterly Journal of Experimental Psychology, 58A,* 387-419.

Patla, A.E., Frank, J.S., Allard, F., & Thomas, E. (1985). Speed-accuracy characteristics of saccadic eye movements. *Journal of Motor Behavior, 17,* 411-419.

Proteau, L. (1992). On the specificity of learning and the role of visual information for movement control. In L. Proteau & D. Elliott (Eds.), *Vision and motor control* (pp. 67-103). Amsterdam: Elsevier.

Proteau, L. (1995). Sensory integration in the learning of an aiming task. *Canadian Journal of Experimental Psychology, 49*, 113-120.

Proteau, L., & Marteniuk, R. G. (1993). Static visual information and the learning and control of a manual aiming movement *Human Movement Science, 12,* 515-536.

Proteau, L., Marteniuk, R. G., Girouard, Y., & Dugas, C. (1987). On the type of information used to control and learn an aiming movement after moderate and extensive training. *Human Movement Science, 6,* 181-199.

Proteau, L., Marteniuk, R. G., & Lévesque, L. (1992). A sensorimotor basis for motor learning: Evidence indicating specificity of practice. *The Quarterly Journal of Experimental Psychology, 44A*, 557-575.

Proteau, L., Tremblay, L., & DeJaeger, D. (1998). Practice does not diminish the role of visual information in on-line control of a precision walking task: Support for the specificity of practice hypothesis. *Journal of Motor Behavior, 30*, 143-150.

Raibert, M.H. (1977). *Motor control and learning by the state-space model* (Tech. Rep. No. AI-TR-439). Cambridge: Massachusetts Institute of Technology, Artificial Intelligence Laboratory.

Reeve, T.G., & Cone, S.L. (1980). Coding of kinesthetic location information. *Research Quarterly for Exercise and Sport, 51*, 349-358.

Robertson, S., Collins, J., Elliott, D., & Starkes, J.L. (1994). The influence of skill and intermittent vision on dynamic balance. *Journal of Motor Behavior, 26,* 333-339.

Robertson, S., & Elliott, D. (1996). Specificity of learning and dynamic balance. *Research Quarterly for Exercise and Sport, 67,* 69-75.

Roth, K. (1988). Investigations on the basis of the generalized motor program hypothesis. In O. G. Meijer & K. Roth (Eds.), *Complex movement behaviour: The "motor action" controversy* (pp. 261-288). Amsterdam: North Holland.

Schmidt, R.A. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82*, 225-260.

Schmidt, R.A. (1985). The search for invariance in skilled movement behavior. *Research Quarterly for Exercise and Sport, 56,* 188-200.

Schmidt, R.A. (2003). Motor schema theory after 27 years: Reflections and implications for a new theory. *Research Quarterly for Exercise and Sport, 74*, 366-375.

Schmidt, R.A., & Lee, T.D. (2005). *Motor control and learning: A behavioral emphasis* (4th ed). Champaign, IL: Human Kinetics.

Schmidt, R.A., & Nacson, J. (1971). Further tests of the activity-set hypothesis for warm-up decrement. *Journal of Experimental Psychology, 90*, 56-64.

Schmidt, R.A., & Wrisberg, C.A. (1971). The activity-set hypothesis for warm-up decrement in a movement-speed task. *Journal of Motor Behavior, 3*, 318-325.

Schmidt, R.A., & Young, D.E. (1987). Transfer of movement control in motor learning. In S.M. Cormier & J.D. Hagman (Eds.), *Transfer of learning* (pp. 47-79). Orlando, FL: Academic Press.

Schmidt, R.A., Zelaznik, H.N., & Frank, J.S. (1978). Sources of inaccuracy in rapid movement. In G.E. Stelmach (Ed.), *Information processing in motor control and learning*_(pp. 183-203). New York: Academic Press.

Schmidt, R.A., Zelaznik, H.N., Hawkins, B., Frank, J.S., & Quinn, J.T. (1979). Motor-output variability: A theory for the accuracy of rapid motor acts. *Psychological Review, 86,*_415-451.

Schoenfelt, E.L., Snyder, L.A., Maue, A.E., McDowell, C.P., & Woolard, C.D. (2002). Comparison of constant and variable practice conditions on free-throwing shooting. *Perceptual and Motor Skills, 94,* 1113-1123.

Shapiro, D.C. (1977). A preliminary attempt to determine the duration of a motor program. In D. M. Landers & R. W. Christina (Eds.), *Psychology of motor behavior and sport* (Vol. 1, pp. 17-24). Champaign, IL: Human Kinetics.

Shapiro, D.C., & Schmidt, R.A. (1982). The schema theory: Recent evidence and development implications. In J.A.S. Kelso & J.E. Clark (Eds.). *The development of movement control and coordination* (pp. 113-150). New York: Wiley.

Shapiro, D.C., Zernicke, R.F., Gregor, R.J., & Diestel, J.D. (1981). Evidence for generalized motor programs using gait-pattern analysis. *Journal of Motor Behavior, 13,* 33-47.

Shea, C.H., & Kohl, R.M. (1990). Specificity and variability of practice. *Research Quarterly for Exercise and Sport, 61,* 169-177.

Shea, C.H., & Kohl, R.M. (1991). Composition of practice: Influence on the retention of motor skills. *Research Quarterly for Exercise and Sport, 62,* 187-195.

Shea, C.H., & Wulf, G. (2005). Schema theory: A critical appraisal and re-evaluation. *Journal of Motor Behavior, 37,* 85-101.

Shea, J. B., & Morgan, R. L. (1979). Contextual interference effects on the acquisition, retention, and transfer of a motor skill. *Journal of Experimental Psychology: Human Learning and Memory*, 5, 179–187.

Simons, J.P., Wilson, J., Wilson, G., & Theall, S. (in press). Challenges to cognitive bases for an especial motor skill emerging at the regulation baseball pitching distance. *Research Quarterly for Exercise and Sport.*

Smith, S.M., & Vela, E. (2001). Environmental context-dependent memory: A review and meta-analysis. *Psychonomic Bulletin & Review, 8*, 203-220.

Southard, D. & Amos, B. (1996). Rhythmicity and preperformance ritual: Stabilizing a flexible system. *Research Quarterly for Exercise and Sport, 67*, 288-296.

Southard, D. & Miracle, A. (1993) Rhythmicity, ritual, and motor performance: A study of free. *Research Quarterly for Exercise and* Sport, 64, 284-290.

Summers, J.J. (1977). The relationship between the sequencing and timing components of a skill. *Journal of Motor Behavior, 9*, 49-59.

Thorndike, E.L. (1913). *Educational psychology*. New York: Columbia University Press.

Thorndike, E.L., & Woodworth, R.S. (1901). The influence of improvement in one mental function upon the efficiency of other functions. *Psychological Review, 8*, 247-261.

Tremblay, L., & Proteau, L. (1998). Specificity of practice: The case of powerlifting. *Research Quarterly for Exercise and Sport, 69*, 284-289.

Tsarouchas, E., Kalamaras, K., Giavroglou, A., & Prassas, S. (1988). Biomechanical analysis of free throw shooting in basketball. In Proceedings of the 6th ISBS Symposium, 1988 (edited by E. Kreighbaum and A. McNeill), pp. 551-560. Bozeman: Montana State University and the International Society of Biomechanics in Sports.

Van Rossum, J.H.A. (1990). Schmidt's schema theory: The empirical base of the variability of practice hypothesis. A critical analysis. *Human Movement Science, 9,* 387-435.

Vickers, J.N. (1996). Visual control when aiming at a far target. *Journal of Experimental Psychology: Human Perception and Performance, 2,* 342-354.

Wallace, S. A., & Hagler, R. W. (1979). Knowledge of performance and the learning of a closed motor skill. *Research Quarterly, 50,* 265-271.

Walters, M., Hudson, J. L., & Bird, M. (1990). Kinematic adjustments in basketball shooting at three distances. In: M. Nosek, D. Sojka, W.E. Morrison, & P. Susanka (Eds.), *Biomechanics in Sports VIII* (pp. 219-223). Prague: Conex.

Wardrop, R.L. (1995). Simpson's paradox and the hot hand in basketball. *The American Statistician, 49,* 24-28.

Wilde, H., & Shea, C.H. (2006) Proportional and non-proportional transfer of movement sequences. *Quarterly Journal of Experimental Psychology, 59,* 1626-1647.

Williams, E.J. (1949). Experimental designs balanced for the estimation of residual effects of treatments. *Australian Journal of Scientific Research A, 2,* 149-168.

Woodworth, R.S. (1899). The accuracy of voluntary movement. *Psychological Review Monographs, 3* (Whole No. 13).

Wright, D.L., & Shea, C.H. (1991). Contextual dependencies in motor skills. *Memory & Cognition, 19,* 361-370.

Wright, D.L., & Shea, C.H. (1994). Cognition and motor skill acquisition: Contextual dependencies. In C.R. Reynolds (Eds.), *Cognitive assessment: A multidisciplinary perspective* (pp. 89-106). New York: Plenum.

Wrisberg, C.A., & Anshel, M.H. (1993). A field test of the activity-set hypothesis for warm-up decrement in an open skill. *Research Quarterly for Exercise and Sport, 64,* 39-45.

Yoshida, M., Cauraugh, J.H., & Chow, J.W. (2004). Specificity of practice, visual information, and intersegmental dynamics in rapid-aiming limb movements. *Journal of Motor Behavior, 36,* 281-290.