The effects of estimating good vs. poor knowledge of results during acquisition of a spatial motor task.

Jana Azizieh, BKin

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Under the supervision of Jae Patterson, PhD

Faculty of Applied Health Sciences, Brock University

St. Catharines, Ontario

DEDICATION

To my mom, dad and my brother James

ABSTRACT

Recent studies have shown that providing learners Knowledge of Results (KR) after "good trials" rather than "poor trials" is superior for learning. The present study examined whether requiring participants to estimate their three best or three worst trials in a series of six trial blocks before receiving KR would prove superior to learning compared to not estimating their performance. Participants were required to push and release a slide along a confined pathway using their non-dominant hand to a target distance (133cm). The retention and transfer data suggest those participants who received KR after good trials demonstrated superior learning and performance estimations compared to those receiving KR after poor trials. The results of the present experiment offer an important theoretical extension in our understanding of the role of KR content and performance estimation on motor skill learning.

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CHAPTER 1: REVIEW OF LITERATURE

1.1 Motor learning and augmented feedback

Motor skills play a crucial role across the life span (Voelcker-Rehage, 2008). Poulton (1957) first distinguished skills as open or closed. Open skills require the performer to adjust or regulate their movement within the environment, as an open skill is affected by external factors. An example of an open skill would be a chip shot where the position of the hole, obstacles like trees, and the effect of the wind play an integral role in the outcome of the ball. In opposition, closed skills are skills in which performance can be planned in advance without expectation of the environment predicted in advance (Chen, Hendrick & Lidor, 2002; Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky, Wulf, Larque de Medeiros, Kaefer & Tani, 2008a; Chiviacowsky, Wulf, Larque de Medeiros, Kaefer & Wally, 2008b; Janelle, Kim & Singer, 1995; Janelle, Barba, Frehlich, Tennant & Cauraugh, 1997; Patterson & Carter, 2010). Following Poulton (1957), Schmidt and Lee (2005) defined motor skills as a sequence of voluntary body, head, and/or limb movements directed towards a desired outcome. Motor skills were further categorized into discrete, continuous and serial skills. Discrete skills have a distinct beginning and end. Continuous skills have no distinct beginning and end; they require repetition of movement patterns. Serial skills require various steps or a series of discrete movements to complete the task. According to Wulf and Shea (2002), a skill is defined as complex if it cannot be mastered in a single session, has more than one degree of freedom, and has the potential to be ecologically valid (the setting of the study must approximate the real-life situation that is under investigation). The idea holds that more complex tasks, by nature, engage the learner in cognitively effortful learning processes (Guadagnoli & Lee, 2004; Wulf & Shea, 2002). Motor skills are a fundamental aspect of human life and the measurement of these skills is crucial to understanding the factors facilitating human performance (Voelcker-Rehage, 2008).

There are important distinctions that differentiate motor development, motor learning, and motor control. Motor development refers to sequential age-related changes in behaviour; factors within a person that may lead to developmental changes include maturation/aging and experience (Clark & Whitall, 1989). An example of motor development is the progression for an infant to sit up straight independently (Malina, Bouchard & Bar-Or, 2004). Not all changes in movement, however, are developmental. Motor learning is defined as relatively permanent changes in the capabilities of a motor skill related to training rather than maturation or aging (Schmidt & Lee, 2005). An example of motor learning would be learning to play tee ball and then transferring that skill to softball or baseball. Schmidt and Lee (2005) defined motor control as the study of how the central nervous system is organized to control and coordinate movements based on sensory information from the environment and/or the body. The study of how movements are controlled (motor control) and how movements are learned (motor learning) are components constituting the study of human movement (Schmidt & Lee, 2005).

Feedback is regarded as a critical variable for skill acquisition and is defined as any kind of sensory information related to a response or movement (Schmidt &Wrisberg, 2004). Augmented feedback refers to enhancing task intrinsic feedback with an external source (Magill 2001; Schmidt & Lee, 2005), such as a therapist or device (biofeedback or timer) (van Dijk, Mulder, & Hermens, 2007). In contrast, inherent or intrinsic feedback refers to the abundance of information that is naturally available in the task that is not provided from an external source (Sidaway, August, York, & Mitchell, 2005). Therefore, intrinsic feedback can be derived from vision, audition, tactile and/or proprioception. Where augmented or extrinsic feedback is presented to the learner from an external source and can be provided during and/or after a movement (Sidaway et al., 2005).

Augmented feedback can be subdivided into knowledge of performance (KP) and knowledge of results (KR). KP is information regarding the movement characteristics of the performer (Salmoni, Schmidt & Walter, 1984; Sidaway et al., 2005) whereas KR is feedback regarding the accuracy of a response outcome relative to a task goal (Magill, 2004). Several studies have manipulated the presentation features of feedback information (e.g., frequency, delay, bandwidth and summary) in order to determine the optimal KR schedule to facilitate learning. KR is a source of meaningful outcome information provided to the learner. Furthermore, KR is generally defined as verbal, terminal, augmented feedback (Schmidt & Lee, 2005). In contrast, KP is information regarding the movement characteristics of the performer (Salmoni et al., 1984; Sidaway et al., 2005). Typically, augmented information can be presented to the performer before the motor action (e.g., limb position), during the action (e.g., the way the movement feels), or upon completion of the motor action (e.g., the movement outcome in reference to motor task goal) (Schmidt & Lee, 2005). For example, in learning a springboard dive, the feedback provided is relatively similar for KR ("your score was 4.5 out of 10) and KP ("you un-tucked your legs too late"). Each type of feedback is beneficial to learner, however, a performer may be more efficient at using one type of feedback over another depending on whether the task is related to an outcome goal (bean tossing target) or technique goal (kinesthetic performance) (Wulf & Shea, 2002).

During the acquisition phase of a motor skill, the scheduling of feedback is manipulated with the subsequent effects assessed on no-KR retention and/or transfer tests (Magill, 2004). Therefore, to infer learning, a retention and/or transfer test must be performed after a specified period of time. A retention test consists of withholding KR across all experimental conditions. To infer learning, there are two time periods for a retention test; an immediate and a delayed retention test. An immediate retention test is used to examine the initial differences in performance as a result of the different experimental conditions during the acquisition phase. The delayed retention test is used to measure the relatively permanent changes in capabilities that are associated with practice of the motor task as a function of the practice condition experienced. The immediate retention test occurs approximately 10-15 minutes after the last practice trial of the acquisition phase, which is consistent with most motor learning literature (e.g., Patterson &

Carter, 2010; Sidaway et al., 2005). The delayed retention test, however, is performed at least 24 hours after the last practice trial of the acquisition phase. The delay has been regarded as an appropriate amount of time to measure the relatively permanent effects of the practice condition experienced during the acquisition period. In addition to practice, sleep has been demonstrated to be a critical factor in motor skill learning (Walker, Brakefield, Morgan, Hobson & Strickhold, 2002).

Previous views of motor learning literature stress the important role of cognition when learning motor skills (Sherwood & Lee, 2003; Schmidt, 1988). Motor learning involves more than storing sensory and motor information that arises as a consequence of movement. Motor skill learning is highly cognitive in nature (Lee, Swinnen & Serrien, 1994), and the cognitive processes that sub-serve movement must be practiced.

1.2 Cognitive Effort

Cognitive effort refers to the mental work involved in the decision making process (Lee et al., 1994). In some cases, it has been suggested that practice conditions result in more intense use of processing resources. The effort by which these cognitive processes are undertaken is influenced by specific practice variables that promote the decision-making processes (Lee et al., 1994). For example, the advantages seen by observing a learning model suggest the observer becomes actively involved, albeit vicariously, in the process of learning (Lee et al., 1994). For augmented feedback to serve its most useful role, it must be given in such a way that it helps without discouraging the performer from learning to interpret intrinsic feedback. Learning to interpret one's own intrinsic feedback requires cognitive effort. However, there is no need for a learner to interpret intrinsic feedback when augmented feedback is given instantaneously upon movement completion (Lee et al., 1994). Swinnen, Schmidt, Nicholson and Shapiro (1990) provided augmented feedback immediately upon completion of the movement or after an 8-second delay. Subjects that received this 8-second delay either sat silently during the interval or attempted to estimate the magnitude of augmented feedback. Learning was assessed with an immediate 10-minute retention test and again with a 2-day delayed retention test. All groups performed without augmented feedback during these retention tests. Results of Swinnen et al. (1990) illustrated little differences between groups during acquisition. However, the retention results indicated the condition that estimated augmented information during acquisition outperformed the instantaneous augmented feedback condition. Cognitive effort has a critical impact on the learning process of motor skills (Lee et al., 1994). Cognitive effort is enhanced when a learner is forced to interpret their own intrinsic feedback. However, if augmented feedback is offered too frequently (as the guidance hypothesis states) this may be detrimental to the learning process, which undermines the learner's effort to learn the motor skill.

Over the past few decades, motor learning theories have predicted and explained the results from numerous variations in the nature and scheduling of KR on motor skill acquisition. Such theories include the guidance hypothesis (Salmoni et al., 1984), Adam's (1971) closed loop theory, Schmidt (1975) schema theory, and the challenge point framework (Guadagnoli & Lee, 2004)

1.3 The Guidance Hypothesis

The guidance hypothesis was proposed to explain the dual nature of KR in the learning of motor skills. Importantly, Salmoni et al. (1984) revealed that augmented information could have negative effects on the acquisition of a motor task if KR was presented too frequently or in a manner that was too easy to use. Salmoni et al. (1984) revealed the manipulation of KR schedules during acquisition and the learning effects of these manipulations were being assessed upon completion of a defined practice period with KR, and not during an immediate or delayed retention and transfer tests with KR no longer available (no-KR trials).

Salmoni et al. (1984) proposed three explanations for the negative effects of KR based on the predictions of the guidance hypothesis. The first view is that the learner becomes dependent on KR when it is presented too frequently or in a form that is too easy to interpret. Since KR becomes an essential part of the task (frequently presented) the learner performs effectively when KR is available but not when it is removed (Salmoni et al., 1984). The learner tends to have superior performance during the acquisition phase when feedback is present, however, during the no-KR trials, the performer shows inferior performance. A second explanation for the negative effects of guidance is that frequent KR schedules encourage the learner to make too many corrections during practice (referred to by Schmidt, 1991, as maladaptive short-term corrections), which leads to an inability to recognize and produce stable behavior in retention. Contrary to that explanation, however, Anderson, Magill, and Sekiya (1994) have shown that delaying KR over trials can lead both to more variable acquisition performance and to more accurate no-KR retention performance than does providing KR directly after each trial. The third explanation put forth by Salmoni and colleagues (Salmoni et al., 1984; Schmidt, 1991) is the abundant use of KR during acquisition encourages the learner to ignore important intrinsic information (e.g., kinesthetic) which will facilitate their performance when learning is assessed during the delayed retention and transfer tests. A consequence of failing to process this intrinsic feedback is the inability to internally develop an error-detection mechanism, which in turn would benefit the performer when learning is assessed, during a no-KR retention or transfer trial (Wulf & Shea, 2004). The guidance hypothesis supports the notion that frequent KR schedules can have both positive and negative effects on a learner's performance. During acquisition, when KR is presented after each trial, the beneficial aspects of frequent KR will yield superior performance. However, when KR is withdrawn (e.g., retention and transfer tests), performance is inferior compared to when KR is available. According to the guidance hypothesis, an optimal KR schedule needs to be implemented during acquisition in order for the learners to effectively utilize intrinsic feedback, develop error-detection capabilities and avoid dependency on KR during acquisition (Salmoni et al., 1984).

1.4 Closed loop Theory

The closed loop theory proposed by Adams (1971) is a cognitive theory of skill acquisition, which emphasizes the role of feedback in the modification of a performer's movements. This theory has two key components: a memory trace, which selects and initiates an appropriate response; and a perceptual trace, which acts as a record of the movement made over many practices (Adams, 1971; Schmidt & White, 1972). During and after an attempt of the movement, KR enables the performer to compare the completed movement with the perceptual trace. The trace acts as a reference of correctness so when the system detects an error or a difference between the actual and the expected feedback, then the subject can correct the movement accordingly. This record of movement, or perceptual trace, improves as a function of KR, as Adams (1971) contends, KR after every trial is essential during the learning phase. A limitation to Adams' (1971) theory is that it was formulated after slow moving tasks and was then generalized to fast moving tasks. Adams (1971) believed that a strong perceptual trace would improve error detection learning, thus, providing KR after every trial would strengthen this perceptual trace.

1.5 Schema Theory

Following Adams (1971) closed loop theory; Schmidt (1975) proposed a new theory of motor learning, known as the schema theory, to resolve some of the limitations of Adams (1971) closed loop theory. The schema theory (Schmidt, 1975) is based on the notion that every time an individual performs a movement, four pieces of information will be stored: the initial conditions, the response specifications for the motor program, the sensory consequences of the movement, and the outcome of the movement. The interaction of these four sources of information was used by the performer to build the two main components of the schema theory: the recall schema, and the recognition schema, similar to the memory trace and perceptual trace, respectively, in Adams (1971) closed loop theory. The recall schema is used to develop a motor program to perform the movement and is based on the relationship between the desired movement outcome and the initial conditions prior to the movement. The recognition schema is based on the relationship between the expected sensory consequences of a movement and the actual outcome (Schmidt, 1975). The strength of the recognition schema increases with the quality and quantity of intrinsic feedback and KR received on each trial, which is similar to the perceptual trace from the closed loop theory. Consistent with Adams (1971), Schmidt (1975) believed that KR was necessary after all trials however, errors were assumed to be detrimental to learning (Adams, 1971). Schmidt (1975) believed that errors would update the error labelling system, to improve the ability to accurately label future errors and strengthen the schema for the response recognition.

1.6 Challenge Point Framework

Practice is widely considered the single most important factor responsible for the permanent improvement in the ability to perform a motor skill (Adams, 1964; Annett, 1969; Fitts, 1964; Guadagnoli & Lee, 2004; Magill, 2001; Marteniuk, 1976; McDonald & Kugler, 1991; Newell, Schmidt & Lee, 1999). If all other factors are held constant, then skill improvement is generally considered to be positively related to the amount of practice (Guadagnoli & Lee, 2004). The Challenge Point Framework (Guadagnoli & Lee, 2004) provides a theoretical basis to conceptualize the effects of various practice conditions in motor learning. It has been proposed that with practice, there is reduced information available to the participant because better expectations are formed (e.g., practice is equivalent to redundancy, therefore less uncertainty) (Marteniuk, 1976). Task difficulty has two broad categories: Nominal task difficulty and functional task difficulty. Nominal task difficulty is due to the characteristics of the task only. Conversely, functional task difficulty is defined as the interaction between the performer's current skill level, the characteristics of the task, and the characteristics of the practice environment (Guadagnoli & Lee, 2004). Performance of a task with low nominal difficulty will be expected to be high in all groups of performers (e.g., all skill levels). However, beginner performance will be expected to decline rapidly as nominal difficulty increases, whereas intermediate and skilled performance will decline less rapidly, and expert performance is expected to decline only at the highest nominal difficulty levels (Guadagnoli & Lee, 2004). At low levels of functional difficulty, the potential available information is low for performers in all skill levels. As functional task difficulty increases, the potential information available increases exponentially for beginners and less rapidly for intermediate and skilled performers (Guadagnoli & Lee, 2004). For experts, the potential information available increases only at the highest levels of functional task difficulty.

The framework relates practice variables to the skill level of the individual, task difficulty, and information theory concepts. Motor tasks represent different challenges for performers of different abilities (Guadagnoli & Lee, 2004). Increases in task difficulty may increase learning potential, however, increased task difficulty is also expected to decrease performance. Thus, an optimal challenge point exists where learning is maximized and compromises to performance during practice are minimized. Since task difficulty is negatively associated with performance level, there is a performance-learning paradox (Guadagnoli & Lee, 2004). Depending on the skill level of the performer, increases in functional task difficulty results in decreased performance expectations but an increase in the available interpretable information. Learning depends on the amount of interpretable information. Although increases in task difficulty may increase learning potential, only so much information is interpretable, and task performance is expected to decrease. With increased practice it is assumed that one’s information-processing capabilities will increase (Marteniuk, 1976). Therefore, the optimal challenge point will change as the individual’s ability to use information changes, requiring further changes in functional difficulties to facilitate learning (Guadagnoli & Lee, 2004).

The most common findings comparing feedback frequencies, schedules, or both, has been that high KR frequencies or more immediate presentation of KR during acquisition trials produces better performance than do lower KR frequencies or less immediate presentation of KR

(Guadagnoli & Lee, 2004). However, this trend is reversed for retention performance (Salmoni et al., 1984). For tasks of high nominal difficulty, more frequent or immediate presentation of KR, or both, will yield the largest learning effect (Guadagnoli & Lee, 2004).

The acquisition of motor skills through various KR schedules has been studied extensively in the motor learning literature. An attempt to optimize learning through various KR schedules such as self-control, providing KR on relatively good or poor trials, bandwidth KR, summary KR, normative feedback and error estimates are areas of recent inquiry. A summary of existing literature follows.

1.7 Self -controlled practice

In most training situations that involve the learning of a motor skill, the instructor determines the details and frequency of the training protocol. However, recent arguments have shown that motor skill learning can be enhanced considerably if the learner is given some control over their practice conditions (Chen et al., 2002; Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky et al., 2008a; Chiviacowsky et al., 2008b). Patterson and Lee (2010) concluded that providing a learner the opportunity to self-control the frequency and location of information retrieval is a robust learning variable. Wulf, Raupach and Pfeiffer (2005) also concluded that giving learners the opportunity to decide (e.g., self-controlled condition) when and how often they observed a skilled model was more effective then a yoked condition, when performance was assessed during a retention test. Commonly in the self-controlled literature, a yoked condition is a group of participants that replicate the practice schedule of their self-controlled counterparts, however, without the choice. The purpose of the yoking procedure is to control the scheduling of feedback, because the frequency and timing of feedback are identical in both the self-controlled and yoked groups. Thus, the group differences observed during the retention and transfer tests (in which no KR is presented) can be attributed to the fact that one group (self-control) had control over the scheduling of their feedback, where as the yoked group did not. When learners are afforded the opportunity to individualize a portion of practice, it has been demonstrated that self-control participants facilitated greater learning than their yoked counterparts (Patterson & Carter, 2010). Recently, the benefits of self-controlled practice in the acquisition of motor skills have been examined in healthy younger adult populations and more recently in healthy children (Chiviacowsky et al., 2008a; Chiviacowsky et al., 2008b; Sanli & Patterson, 2009).

Janelle et al. (1995) examined whether allowing participants to control their receipt of performance feedback (KP) would be more beneficial in learning an underhand ball toss task compared to KP that was presented according to a pre-determined or random schedule. Sixty younger adults practiced in either a no feedback control condition, a 50% KP condition (e.g., feedback every other trial), a summary KP group (five trial summary length), a self-controlled KP group or a yoked condition. Participants completed an underhand ball toss to a target located on the floor. The participants that controlled their feedback demonstrated more effective learning of the movement form than the yoked participants (indexed by absolute error scores). Janelle et al. (1995) found that the participants in the self-controlled condition only requested feedback on an average of 7% of the total trials, and concluded the self-control condition did not become reliant on KP. Although it was not directly measured, Janelle et al. (1995) speculated the self-control condition was able to utilize intrinsic sources of information in the absence of performance feedback to learn the motor task.

Janelle et al. (1997) conducted a study to extend the findings of Janelle et al. (1995). Janelle et al. (1997) examined the influence of self-controlled KP on the acquisition of a motor skill compared to a yoked condition, a summary KP condition and a KR only condition. Participants threw a standard tennis ball at a target located on the floor using their non-dominant hand. Similar to Janelle et al. (1995), Janelle et al. (1997) determined that participants in the self-controlled KP condition outperformed all other experimental conditions during the retention period of the experiment. The relative frequency that KP was required by the self-control condition decreased over the acquisition phase with KP being requested on an average of 11.5%

of the total acquisition trials. Janelle et al. (1997) concluded that participants in the self-controlled KP condition processed information more efficiently based on being actively involved in the individualization of their practice context. Janelle et al. (1997) suggested that learners afforded the opportunity to individualize their practice environment increases motivation to learn because the learner has the freedom to implement different strategies during practice, a luxury that may not be available with an externally defined augmented feedback schedule.

Chen et al. (2002) investigated whether similar learning effects would be found for learning a five-digit key pressing sequence between a self-controlled KR schedule and an experimenter-induced KR schedule. Participants were randomly assigned to the self-control condition, the experimenter-defined condition, or one of the two yoked conditions for each KR manipulation. The self-control condition had complete control of their KR schedule whereas in the experimenter induced condition, participants were presented with a reminder asking if they wanted KR regarding their last completed response. The immediate and two day retention tests revealed that participants who actively decided when to receive and not to receive KR were more accurate (indexed by |CE|) than their yoked counterparts in achieving the timing goal of the task. In accordance with the conclusions of Janelle et al. (1997), Chen et al. (2002) suggested that participants in the self-control conditions were free to engage in various individualized learning strategies during skill acquisition. This increased responsibility to learn may have implicitly increased the intrinsic motivation of these participants, which in turn had an advantageous effect on their cognitive processes, thus facilitating learning.

Chiviacowsky and Wulf (2002) also examined the learning differences between participants with self-controlled KR schedules compared to a yoked condition. The participants in this experiment were required to learn a four-digit key pressing sequence with three relative timing goals and an absolute timing goal. Chiviacowsky and Wulf (2002) did not find any differences in retention performance between the self-control and yoked conditions, however, the self-control condition performed better (indexed by AE) than their yoked counterparts on a delayed transfer test utilizing a longer timing goal. Chiviacowsky and Wulf (2002) included a questionnaire in their experiment in hopes of acquiring a better understanding of the underlying mechanisms associated with the effectiveness of self-controlled practice. At the end of the acquisition phase, all participants completed a multiple choice KR questionnaire. Participants in the self-control condition were asked when and why they asked for feedback and when they did not ask for KR. The yoked condition participants were asked if they thought they received KR after the correct trials and if not, when they would have preferred to receive KR. The questionnaire data revealed that the majority of participants in the self-control condition preferred to receive KR after a perceived good trial. Interestingly, the majority of yoked participants believed they did not receive KR after the right trials, and they would have also preferred to receive KR after a perceived good trial. It was also determined that the subjective measures of the self-control condition corresponded to their behavioral measures (AE) when errors on KR trials were found to be lower than no-KR trials during the acquisition. Chiviacowsky and Wulf (2002) proposed that an inherent motivational factor may be responsible for the learning benefits of self-controlled practice, as it is easier to repeat a successful movement rather than correct for errors after a poor trial. As a result, this may have motivated participants to be actively engaged in their learning process to produce successful responses.

Chiviacowsky and Wulf (2005) facilitated our understanding of the learning benefits derived from a practice environment where the learner is provided control by manipulating when the participant decided to receive feedback or not, either prior to the trial or after the trial. Participants practiced the same four-digit key-pressing task from Chiviacowsky and Wulf (2002) with the same relative timing goals and absolute timing goal. The participants who decided whether KR was needed after a trial performed with less relative timing error on a retention test compared to the group that decided prior to completing the trial. However, this performance difference did not reach statistical significance. When participants were required to generalize their learning to a novel variation of the task, the experimental group that decided after a trial to receive KR during acquisition performed with significantly less relative timing error. The results of this study led Chiviacowsky and Wulf (2005) to conclude that error estimation processes are necessary to assess a just completed response, and may have an important role in the learning benefits associated with self-controlled practice.

Patterson and Carter (2010) examined the advantages of a self-controlled KR schedule for learning three different five-digit key pressing sequences each with a different associated movement goal time. Participants in the self-control condition decided if KR was required after each trial while participants in the yoked condition replicated the KR schedule of a self-control participant, without the choice. The self-control condition was significantly more accurate (indexed by %|CE|) with respect to movement goal times than their yoked counterparts in both retention and transfer tests. Participants also completed a questionnaire regarding feedback preference as used in Chiviacowsky and Wulf (2002). A preference for feedback after perceived good trials was found for all three different sequences. Patterson and Carter (2010) concluded that participants in the self-control condition adopted a generalized learning strategy for the three different key pressing sequences.

Patterson et al. (in press) examined the impact of decreasing the proportion of self-control trials during the acquisition of a five-digit key pressing sequence. Participants were required to complete the key pressing sequence as close as possible to the associated timing goal. Participants were randomly assigned to one of three self-control conditions (SELF-SELF, ALL-SELF or FADED-SELF) that differed in the number of control trials experienced during acquisition (50% or 100% of trials). Participants in the SELF-SELF condition controlled their KR schedule for all 90 acquisition trials whereas the ALL-SELF condition received 100% KR for the first 45 trials followed by 45 self-control trials. For the FADED-SELF condition, the frequency of KR was reduced over the first 45 practice trials (100% KR for trials 1-15; 33% KR for trials 16-30; and 20% KR for trials 31-45) followed by 45 self-control trials. The remaining 30 participants were randomly assigned to one of three respective yoked conditions (YOKED-YOKED, ALL-YOKED or FADED-YOKED) and replicated the KR schedule of a self-control counterpart. In retention and transfer, no significant differences were found between the three self-conditions. Consistent with Chen et al. (2002) and Patterson and Carter (2010), the self-control conditions performed more accurately (indexed by |CE|) and more consistently (indexed by VE) in retention. In addition, the self-control conditions also performed more accurately in transfer, consistent with Chiviacowsky and Wulf (2002, 2005). Patterson et al. (in press) concluded that a self-controlled KR schedule was beneficial for learning the key-pressing task and the proportion of control trials experienced during acquisition did not differentially impact motor learning in younger adults.

The superiority of self-controlled practice environments have been demonstrated in the contexts of controlling the frequency of augmented feedback (Chen et al., 2002; Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky et al., 2008a; Chiviacowsky et al., 2008b; Janelle et al., 1995; Janelle et al., 1997; Patterson & Carter, 2010), the use of assistive devices (Hartman, 2007; Wulf & Toole, 1999), the frequency of observing a model (Wrisberg & Pein, 2002; Wulf et al., 2005), and the organization of practice repetitions (Keetch & Lee, 2007; Sanli & Patterson, 2009; Wu & Magill, 2004). In summary, Wulf (2007) suggested the possible learning benefits of self-controlled practice could be related to this condition having enhanced motivation to learn the task, which in turn, results in deeper information processing and ultimately improves performance during retention and transfer tests.

1.8 Augmented feedback schedules: Good vs. poor KR

Chiviacowsky and Wulf (2002) conducted a sequential timing task in which one group of learners (self-control) were provided feedback whenever they requested it, whereas the other group (yoked) had no influence on the feedback schedule. The purpose of the study was to investigate whether self-controlled feedback was superior for learning compared to a yoked condition. Absolute and relative timing errors assessed motor performance of the participants in acquisition and retention. A self-report questionnaire was administered to both the self-control and yoked groups. The majority (67%) of the self-controlled condition participants reported they asked for feedback after a *perceived* good trial, which was consistent with the absolute constant error measures. It was concluded the participants in the self-controlled condition were more accurate in the novel sequential timing task than their yoked counterparts. It should also be noted that the self-controlled learners did not request feedback randomly, rather they had a strategy, they used feedback to confirm their performance on a given trial (e.g., good trials).

In a follow-up study Chiviacowsky and Wulf (2007), examined the impact of providing KR after *good* trials compared to after *poor* trials on learning a motor task. Participants in the *good* feedback condition received feedback on their best three trials within a six-trial block whereas the *poor* feedback condition received feedback on their worst three trials within a six-trial block. Participants were required to throw a beanbag at a concealed target located on the floor using their non-dominant hand. The target was circular, had a radius of 100cm, with 10 concentric rings each worth a specific value ranging from 10 to 100 points. If the beanbag landed on the target, 100 points were awarded, point values decreased as the throws became less accurate. Accuracy was used to measure the effects of KR during acquisition and then again during no-KR retention tests. During the acquisition phase, the KR *poor* group demonstrated lower accuracy scores when compared to the KR *good* condition. On the no-KR retention test, the KR *good* group had higher accuracy scores compared to the *poor* KR group. The authors concluded that it was more beneficial to provide KR after relatively *‘good’* trials compared to *‘poor’* trials during the acquisition of a novel motor task. Chiviacowsky, Wulf, Wally and Borges (2009) conducted a follow-up study, which replicated the experiment by Chiviacowsky and Wulf (2007), using the same task and experimental design, but used 65-year old adults as participants compared to the 21-year old participants in the 2007 study. Chiviacowsky et al. (2009) concluded that older adults also have superior performance when KR is provided after relatively successful trials compared to unsuccessful trials.

In a study conducted by Patterson and Azizieh (2011), the impact of being aware compared to not being aware of the KR content (e.g., KR after relatively *good* compared to relatively *poor* trials) was examined to determine if being aware of the KR content would differentially impact motor learning. Participants were randomly assigned to one of four conditions: KR after relatively *good* trials – aware; or KR after relatively *good* trials – unaware; KR after relatively *poor* trials-aware; KR after relatively *poor* trials- unaware. Participants in the *good-aware* and *good-unaware* feedback condition received feedback on their best three trials within a six-trial block whereas the *poor- aware and poor-unaware* feedback condition received feedback on their worst three trials within a six trial block. The participants were instructed to practice a modified linear-slide task with a defined spatial goal. Feedback was the actual distance of end position of the slider (e.g., 135cm). Participants in the aware conditions were informed of the KR type (e.g., *good* vs. *poor* feedback). A typical feedback screen appeared "your three best trials were: 112.8cm, 105.0cm, 102.9cm". Participants in the *good unaware* feedback condition received feedback on their best three trials within a six trial block whereas the *poor aware* feedback condition received feedback on their worst three trials within a six trial block. Participants in the unaware conditions (e.g., *good* vs. *poor* feedback) were informed that they would receive feedback. A typical feedback screen appeared "Goal: 133.0cm, 112.8cm, 105.0cm, 102.9cm". During retention, the aware groups independent of *good or poor* feedback demonstrated superior learning. Patterson and Azizieh (2011) speculated that the aware conditions demonstrated superior learning compared to those in the unaware condition as a function of the increased precision of KR relative to the findings of previous research.

KR has been the subject of enormous research efforts in the past few decades (Adams, 1971, 1964; Newell, 1977; Salmoni et al., 1984) determining KR as one of the most important practice variables when learning a movement skill. Many different KR schedules have been utilized such as bandwidth KR, summary KR, normative feedback and error estimation. A review of this literature will follow.

1.8.1 Augmented feedback schedules: Bandwidth KR

Bandwidth KR involves the presentation of precise quantitative KR on only those trials in which a preset criterion of accuracy is not met. However, when the criterion is met, only a general statement referring to this success (e.g., qualitative KR) is given to the participants (Lai & Shea, 1999). The type of feedback presented to the subject is directly related to the learner's performance. A criterion of accuracy is set prior to the onset of acquisition, and precise feedback is offered in regards to error magnitude only on the trials that accuracy was not met. However, when feedback is not given, the learner is informed this is a sign of a successful performance (Lee & Carnahan, 1990).

Smith, Taylor and Withers (1997) instructed participants to practice a golf chipping task with KR or error correcting transitional information, given under 0, 5, or 10% bandwidth conditions. Participants in the error correcting transitional information condition received verbal cues and no outcome information. The verbal cues were designed to focus attention on areas of importance and were based on four subcomponents: the shot, the backswing, the impact, and the follow-through (e.g., focus on keeping your eye on the ball) (Smith et al., 1997). Participants in the 0% bandwidth condition served as the control group and received feedback after every trial. However, participants in the 5 and 10% bandwidth conditions only received feedback when the ball's landing point deviated from the target line by more than 5 or 10%. Reduced relative frequencies of KR reduce the amount of guidance available. Although increased guidance can be beneficial for acquisition performance (Salmoni et al., 1984; Schmidt et al., 1989), it has been found to reduce retention performance (Schmidt et al., 1989). The retention results are in line with the guidance hypothesis, as those who received transitional information only when outside a 10% performance bandwidth received the lowest relative frequency of feedback during acquisition and achieved the best retention performance. Transitional information was more useful than KR in reducing error during acquisition. Also, evidence has been presented (Smith et al., 1997) which suggests that bandwidth KR findings do generalize to complex tasks. Bandwidth

KR has been shown to improve motor learning by increasing the participant's error detection method. However, an optimal bandwidth needs to be in place for the learning advantages to take place, much the same as an optimal summary KR schedule.

1.8.2 Augmented feedback schedules: Summary KR

Summary feedback is a source of augmented feedback provided after a series of no-KR trials summarizing the performance of the previous trials (Schmidt &Wrisberg, 2004). For example, a basketball coach teaching a player how to shoot the ball into the net from the three-point line. The coach would record each of the 15 attempts, and after the player's last attempt, the coach would show the player the results in graphical or visual feedback. However, in this scenario, the performer would have the outcome of their response occluded. The potential benefits of summary feedback were first discovered by Lavery (1962), in a simple laboratory task that required participants to strike a small ball with a special hammer to propel it up a ramp to a target. All participants performed the skill the first day with no feedback; then for the next five days, they received different schedules of feedback scheduling. One group received feedback immediately after each practice attempt, the second condition received summary feedback following 20 attempts, and the third condition received both types of feedback; immediately after each practice attempt and summary feedback after the completion of 20 practice trials. Following the five days of practice, all groups were tested with no-KR available on each of the next four days, as well as one month later, and again three months later. During acquisition it was concluded that the summary group performed the worst when compared to the conditions that received feedback immediately and that received both types of feedback; immediate and summary. Conversely, during retention, the summary feedback condition out-performed the immediate and both feedback conditions. It was concluded that summary KR may yield poor performance during acquisition; however, superior learning has been demonstrated during retention.

Schmidt, Lange, and Young (1990) explored the effects of different lengths of summary feedback on a timing skill. Participants practiced a baseball-batting task and received feedback about their timing accuracy after 1, 5, 10, or 15 attempts. During the no-KR retention test, the five-attempts summary feedback demonstrated the best learning. Schmidt et al., (1990) stated that the number of performance attempts practitioners should summarize in their feedback statements depends on the complexity of the task they are acquiring. For simple tasks, such as those in Lavery's (1962) experiment, a relatively large number of no-KR trials can be completed before KR is then presented to the learner (e.g., 20 or more). However, for more complex tasks (Schmidt et al., 1990), fewer attempts (e.g., five) should be summarized. Generally, as the complexity of the task increases, the length of the summary is shorter. The review of summary KR studies revealed that the length of summary KR on performance interacts with task complexity. When subjects perform a simple task, increasing summary-KR length appears to be beneficial to learning. However, as task complexity increases, a trade-off may occur between performance accuracy and consistency, thus, as the complexity of the task increases, the length of the summary should be shorter (e.g., five) (Schmidt et al., 1990).

1.8.3 Augmented feedback schedules: Normative Feedback

Augmented feedback in motor learning literature is assumed to have both informational and motivational functions (Schmidt & Lee, 2005; Schmidt & Wrisberg, 2008). The motivational function of feedback is thought to energize task interest and encourage continued effort, persistence, and attention to accomplish the goal. However, motivational aspects in motor learning have been relatively neglected or have been assumed to exert generally temporary effects on performance or indirect effects on learning (Schmidt & Lee, 2005). Normative feedback involves social comparison, comparing one's performance and attributes to those of others. Lewthwaite and Wulf (2009) had participants practice a novel balance task (stabilometer) and gave veridical feedback (feedback about their actual performance after each trial) scores after each trial. In addition to the veridical feedback, two groups received false normative feedback about the “average” score of others on that trial. Average feedback scored indicated that participant’s performance was either above (better group) or below (worse group) the average, respectively. A control group received veridical feedback about trial performance without normative feedback. Learning as a function of social-comparative feedback was determined in a retention test without feedback, following two days of practice. Participants in the better and worse groups were provided with the “average” score of a group, calculated based on the participant’s own score on a given trial with either and consisted of a score that was either 20% above (“better” group) or 20% below (“worse” group) the participant’s score. The conviction that one’s performance was better than average was associated with more effective skill learning than the belief that one’s performance was below average. Importantly, positive normative feedback also enhanced learning compared with no normative feedback (control condition), which resulted in similar levels of learning as the negative normative feedback condition. The performance advantages of the “better” group were still seen when feedback was withdrawn in retention. The “better” group continued to outperform both the “worse” and the control groups on the delayed retention test, suggesting that normative feedback indeed led to different degrees of skill learning. The motivational influences on performance were also examined in a post-experimental questionnaire. Lewthwaite and Wulf (2009) concluded that participant’s preferred feedback when it indicated that their performance was better than average, compared with feedback that noted below-average performance. Especially on the second day of practice, participants in the “better” group rated the “usefulness” of the normative feedback higher (9.2/10) than did participants in the “worse” group (7.1/10). Therefore, the task of motor learning has been shown to have both informational and motivational properties, as participants in the present study who received “better” scores out performed the “worse” and control condition.

1.9 Error-Estimation

Guadagnoli and Kohl (2001) conducted a study in which participants were required to strike a padded force transducer with one blow from the right fist, attempting to reproduce a predefined (target) force. Participants were randomly assigned to one of two KR conditions (100% or 20%) and one of the two estimation conditions (100% or 0%). Participants in the 100% KR condition received KR after every acquisition trial. The 20% condition received KR after every fifth trial. Participants in the 100% estimation condition were required to estimate their force-production error immediately after each response, before receiving KR about that response. Participants in the 0% estimation condition were not required to error estimate. Participants completed 10 blocks of 15 consecutive trials (total of 150 trials) for acquisition. Then returned for a 1-block, 15-trial, no-KR retention test. During retention participants were not required to error-estimate. Guadagnoli and Kohl (2001) revealed that when participants estimated response errors during acquisition, 100% KR frequency condition enhanced retention performance (decreased error and increased consistency) to a greater extent than the 20% KR frequency condition. Participants who were provided 100% KR frequency but were not required to error estimate had the worst performance during retention. In comparison, the 20% KR condition was not required to error estimate, performed better than those who estimated less (0%), and did worse than those who estimated more (100% KR estimation).

In summary, augmented feedback has been regarded as one of the most important variables for motor skill learning (Magill, 2004; Schmidt & Lee, 2005). Previous motor learning research on the role of KR examined the predictions of the guidance hypothesis, which received its name from the negative role of feedback guiding the performer to the correct movement. It was determined that the learner may become too dependent on the augmented feedback presented and bypass the processing of other important intrinsic feedback sources (e.g., error-correction mechanism) when the feedback is withdrawn (e.g., in a retention or transfer test) (Salmoni et al., 1984; Schmidt, 1991). Numerous studies were conducted using a variety of KR manipulations, to encourage the learner to rely on their intrinsic feedback. This includes a reduction of feedback frequency, such that feedback is provided on a certain percentage of trials during practice (Guadagnoli & Kohl, 2001). Other studies have used bandwidth KR manipulations, where quantitative KR is provided only when errors are larger than the predetermined value, while qualitative KR is provided when errors are within the bandwidth (Lai & Shea, 1999; Smith et al., 1997). Summary KR manipulations have been used where KR is presented for individual trials or as an average, respectively, is delayed until a set of trials has been completed (Schmidt &Wrisberg, 2004; Schmidt et al., 1990). The effects of self-controlled feedback have been examined, where the learner has the opportunity to decide when to receive feedback. Chiviacowsky and Wulf (2002) revealed that learners preferred to receive feedback after they thought they had a relatively successful trial but not when they thought their performance was relatively poor. Furthermore, the effect of awareness level (e.g. higher KR precision) was examined when feedback was presented after relatively good or relatively poor trials. Patterson and Azizieh (2011) concluded that awareness was more important than the type of feedback presented (e.g., good vs. poor), as performance was equivalent between the good and poor conditions. In future experiments, it might be interesting to increase the KR precision by increasing the complexity of the task. For example, would the benefits of KR when estimating performance also be found if task complexity was increased (thus, increasing the cognitive effort needed to accurately perform the task). Also, would the benefits of KR differ when the learners are novice, intermediate and experts at the task? For example, a golf putting task, where the learner had to putt the golf ball to a predetermined distance, and the distance varied across the experimental conditions. It might also be interesting to have participants receive different types of feedback (e.g., good vs. poor) and have a condition that estimates their performance, on a modified slide linear slide, where participants must aim for a predetermined target distance (Patterson & Carter, 2010). This may increase the cognitive effort, and also increase the motivation of the individual to successfully reach the target distance.

CHAPTER 2: INTRODUCTION

2.1 Introduction

Practice is generally considered to be the single most important factor responsible for the permanent improvement in the ability to perform a motor skill (Adams, 1964; Annett, 1969; Fitts, 1964; Guadagnoli & Lee, 2004; Magill, 2001; Marteniuk, 1976; Newell et al., 1991; Schmidt & Lee, 1999). If all other factors are held constant, then skill improvement positively relates to the amount of practice (Guadagnoli & Lee, 2004). Recently, much attention in the motor learning literature has been directed towards examining practice environments, such as self-controlled practice, characterized as affording the learners an opportunity to individualize a portion of their practice schedule (Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky et al., 2008a; Chiviacowsky et al., 2008b; Hartman, 2007; Janelle et al., 1995; Janelle et al., 1997; Keetch & Lee, 2007; Patterson & Carter, 2010; Patterson et al., in press; Patterson et al., 2009; Patterson & Lee, 2010; Sanli & Patterson, 2009; Wrisberg & Pein, 2002; Wu & Magill, 2004; Wulf et al., 2005; Wulf & Toole, 1999). Self-controlled learners are generally more cognitively invested to learn the motor skill because they are actively involved in the learning process (e.g., requesting feedback), which requires a higher level of cognitive effort. Self-control practice contexts have proven to be an effective variable facilitating motor skill learning (Janelle et al., 1997; Janelle et al., 1995). For example, when learners had the opportunity to decide when they wanted to receive KR, it has been demonstrated that self-control facilitated greater learning when compared to their yoked counterparts (Hartman, 2007). The yoked counterparts replicate the practice schedule individualized by participants in the self-control condition, however, they are not afforded the opportunity to request feedback. Although the KR schedules are identical between the participants in the self-controlled and yoked condition, providing learners the opportunity to decide when to receive feedback was more beneficial than an externally controlled (yoked) feedback schedule. The robustness of self-controlled training protocols has been demonstrated in practice contexts such as receiving augmented information in regards to movement outcome (Chen et al., 2002; Chiviacowsky & Wulf, 2002, 2005; Chiviacowsky et al., 2008a; Chiviacowsky et al., 2008b), learning through observation or modeling (Chiviacowsky & Wulf, 2002, 2005), and the use of assisted devices (Hartman, 2007; Wulf & Toole, 1999).

In a study by Chiviacowsky and Wulf (2002), it was revealed that learners preferred to receive KR after they perceived they had a relatively successful trial compared to a perceived unsuccessful trial. The positive effects of motor learning associated with preferring feedback after successful trials has been demonstrated in sequential timing tasks (Chiviacowsky & Wulf, 2002) and beanbag tossing tasks (Chiviacowsky & Wulf, 2007). While this preference seems to contradict the common notion that KR should be more effective after less successful trials, more recent literature has illustrated that KR after successful trials has, in fact, been shown to be more effective (Chiviacowsky & Wulf, 2005) compared to presenting KR after poor trials. However, a limitation to this research was the fact that participants were unaware of the type of KR (good trials vs. poor trials) they were receiving (Chiviacowsky & Wulf, 2005, 2007). To address this limitation, a more recent study showed that being aware of the KR content (good or poor trials) facilitated the greatest learning benefits, independent of the type of feedback (good trials vs. poor trials) received. Patterson and Azizieh (2011) revealed that independent of providing KR after relatively good or poor trials, the groups that were *aware* of their KR content demonstrated superior learning when compared to the groups that were *unaware* of their KR content (e.g., good vs. poor KR).

In previous motor learning literature, it has been established that some amount of KR is necessary for the learning of a new motor action (Newell, 1991; Schmidt & Lee, 1999). In early information-processing perspectives, it has been suggested that KR was primarily used in two complementary ways: (a) A learner needs KR to test the correctness of the previous response, and (b) each tested response contributes to a better memory of that response, and this reproduces more correct responses (Adams, 1971, 1964; Schmidt, 1975). After the completion of a trial, it has been suggested the learner estimates how successful they were, and then assesses the correctness of their estimation by comparing this to the KR received after a trial (Guadagnoli & Kohl, 2001). Adams' (1971) closed loop theory of motor behavior proposes two memory components: the memory trace and the perceptual trace. The memory trace is used to select and initiate a motor response. The role of the perceptual trace was to determine the extent of the movement and develop a reference of correctness. Therefore, the perceptual trace is strengthened as a function of KR. Therefore, early perspectives of KR use for motor learning (Adams, 1971, 1964; Schmidt, 1975), predicted that 100% KR frequency would yield the greatest learning effects. Contrary to this notion, previous research has demonstrated that when participants are required to estimate response errors during acquisition performance, they produce better retention performance than participants who do not error estimate (Swinnen et al., 1990). Guadagnoli and Kohl (2001) revealed that when participants estimated response errors during acquisition, 100% KR frequency condition enhanced retention performance (decreased error and increased consistency) to a greater extent than the 20% KR frequency condition. Participants who were provided 100% KR frequency but were not required to error estimate had the worst performance during retention.

Augmented feedback in motor learning literature is assumed to have both informational and motivational functions (Schmidt & Lee, 2005; Schmidt & Wrisberg, 2008). The motivational function of feedback is thought to energize task interest and encourage continued effort, persistence, and attention to goal accomplishment through evidence of performance progress. However, motivational aspects in motor learning have been relatively neglected or have been assumed to exert generally temporary effects on performance or indirect effects on learning though support for continued practice (Schmidt & Lee, 2005). Lewthwaite and Wulf (2009) examined the informational and motivational properties of performance. It was concluded that participants receiving "better" feedback outperformed the "worse" and control condition. Also, the "better" condition reported the feedback received to be more useful on the second day of practice.

In summary, it has been well documented that self-controlled learners demonstrate superior learning when compared to their yoked counterparts. Cognitive effort plays an important role for self-controlled learners as they are actively engaged in the learning process. Self-controlled learners have reported a specific strategy, that is, a preference for KR after *perceived* good trials. Further research has examined the benefits of providing KR after successful trials (e.g., good trials) compared to unsuccessful (e.g., poor trials) trials (Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2009). More recently, the impact of being aware compared to being unaware of KR content was examined to determine if this would differentially impact motor learning. It was concluded that the aware conditions independent of KR content (e.g., good vs. poor feedback) had greater performance during retention than the unaware conditions.

2.2 Statement of the research problem

Previous experiments examining the impact of providing KR on good trials only (Chiviacowsky & Wulf, 2007) and participant awareness all have similar limitations, the learners were not actively engaged in the learning process, which has previously been shown to facilitate learning. Thus, it is unclear whether increasing the cognitive effort in a KR condition whereby participants are being provided KR on either relatively good or poor trials would further enhance learning of a novel motor task. Previous research has shown that cognitive effort is enhanced when a learner is forced to interpret his or her own intrinsic feedback. Specifically, requiring participants to use their error-detection mechanism (e.g., intrinsic feedback) to estimate their best or worst trials in a block before KR is presented is predicted to enhance learning compared to providing KR on relatively good or poor trials alone, without active error detection. Currently, this is identified as a gap in knowledge. The results of Lewthwaite and Wulf (2009) concluded that participants that received “better” feedback were more motivated to successfully complete the task compared to participants in the “worse” and control conditions. However, the results of this study are currently limited to normative feedback, therefore, the motivational properties that function as a result of KR precision requires additional attention. Therefore, the purpose of this thesis is to address these identified gaps in knowledge in the motor learning literature.

CHAPTER 3: METHODOLOGY

3.1 Participants

Fifty-six younger adults (*M* age = 22, *SD* = 1.1) participated in the experiment. All participants were recruited from the undergraduate and graduate population at Brock University. All participants provided informed consent before participation, and were naïve to the purposes of the experiment. Participants were randomly assigned to practice in either the good – estimate (G-E) (*n*=14), poor -estimate (P-E) (*n*=14), good – no estimate (G) (*n*=14), or poor - no estimate (P) (*n*=14) condition. The estimate and non-estimate conditions consisted of an equal number of males and females. Measures of motivation and feedback preference were collected for all participants using the motivation questionnaire (see Appendix A) and the feedback questionnaire (see Appendix B).

3.2 Apparatus

Throughout the acquisition and retention periods of the experiment, participants were seated behind the home position of the apparatus (see Appendix C). The home position refers to the location on the apparatus where the slide was located before the beginning of each trial. The apparatus was secured to a table that was 243.8 cm (length) by 50.2 cm (width) by 60.3 cm (height). The total length of the apparatus railing was 261.6 cm with the railing located 30.5 cm above the table surface. The rail was divided into two separate areas: a warm-up area, where participants could move the slide back and forth before releasing it and the scoring area. The slide was 12.1 cm (length) by 17.1 cm (height), weighing 455g and had a large knob for the participants to grip. The two areas were divided by a wooden barrier that was located 50 cm from the home position, this was termed the release line. The wooden barrier was 78.7 cm (height) by 45.7 cm (wide) and had an opening equal to the size of the slide. The wooden barrier prevented the participants from viewing the scoring zone and final resting position of the slide. At the end of the apparatus railing, opposite to the home position, a Vernier Motion Detector (see Appendix D) was positioned on a customized mount. The motion detector functioned at an ultrasound frequency of 50 kHz with an accuracy of 2 mm within a range of 0.5 to 6 m. The motion detector was connected to the BTD port on the Vernier LabPro (see Appendix E). The LabPro is an instrument for data collection and was connected to the serial port of a computer. The LabPro is 21.5 cm (length) by 8.2 cm (width) by 3 cm (height). The LabPro received commands from the computer to activate the motion detector and to transmit the motion detector's reading on each trial to the customized software program installed on the computer.

It was important to ensure the relative friction of the apparatus does not change throughout testing because this would confound the results. Therefore, to determine that the relative friction did not change throughout testing, a pulley-system was constructed and attached to the apparatus. The pulley-system consisted of a cable wire (215 cm) attached to a weight (505 g) at one end. At the opposite end, the cable wire was attached to a fishing clip that was clipped to the slide when relative friction as being assessed. The weight attached to the pulley-system ensured the same amount of force was always used to move the slide along the apparatus railing. The motion detector determined the distance the slide travelled and the value was recorded in the customized software program.

3.3 Experimental task

The experimental task was a modification of a linear slide task that required participants to push and release a slide along a confined pathway to a pre-determined distance (133 cm) as accurately as possible. Participants used their non-dominant hand to perform the task as a method of increasing the novelty and complexity of the task. Participants needed to accurately calibrate their force through their interpretation of intrinsic feedback to successfully perform the task. Participants were required to wear a pair of Mastercraft Standard Earmuffs to eliminate auditory feedback from the apparatus. The wooden barrier prevented the participants from viewing the scoring zone and final resting position of the slide. Participants completed a total of 72 trials during the acquisition period, and 12 no-KR trials in an immediate (15minute) and delayed (one day later) retention test, respectively.

3.4 Procedure

All participants were randomly assigned to one of the four experimental conditions: good – estimate (G-E), poor - estimate (P-E), good – no estimate (G), and poor - no estimate (P). Participants in all groups were informed that, at the end of each block of six trials, they would receive KR on three of those trials (similar to Chiviacowsky & Wulf, 2009). Participants were allowed to look at the target before each set of six trials. Customized software was used to control the timing of the trials and KR presentation. Participants had 6s to complete a trial. KR was displayed on the computer monitor and presented for 5s. The KR display consisted of the trial number and the actual end position of the slider. The content of the three KR trials was based on the participants three best (G or G-E) or three worst trials (P or P-E) of the 6 trial block. Identifying the three best or three worst trials of the block was determined by the customized software program. All participants completed 72 acquisition trials (12 blocks of 6 trials), and 12 trials in the immediate (10 minutes after completion of the last acquisition trial) and delayed (24 hours after the last acquisition trial) retention test, respectively. No KR was presented during the retention period. Upon completion of the delayed retention period, participants completed a transfer test consisting of 12 trials of a novel distance (165 cm) with no KR.

In the present study, participants in the G-E (see Appendix F) and P-E (see Appendix G), conditions were required to estimate either their three best or worst trials of the 6-trial block before receiving their respective KR. Participants had 10-seconds to estimate their three best or worst trials. For example, upon completion of the 6-trial block, participants in the G-E condition would estimate their three most accurate trials, then they would view the task goal: 133cm, and the following ‘your three best trials were 125cm, 130cm and 129cm’ (see Appendix H & I). At this point participants were required to differentiate between their perceived good and actual good trials. If the participant correctly estimates which trial (s) were good or poor, depending on the respective condition, a red box will highlight the correctly guessed trial, indicating to the participant that they had correctly estimated. The KR will be presented for 5s.

Participants not estimating their accuracy to the goal distance sat silently for 10-seconds then viewed the same feedback screen (either their three best or three worst of the 6 trial block) for 5-seconds (see Appendix J). To ensure consistency in the acquisition trials between conditions, the condition that did not estimate sat silently for 10-seconds and then viewed the feedback screen for 5 seconds (e.g., an elapsed time of 15-seconds which is consistent with the other two conditions estimating their performance). For example, participants viewed the task goal: 133cm, and the following ‘your three best trials were 125cm, 130cm and 129cm’. The KR was presented for 5s (see Appendix K). Participants in the not estimating poor condition viewed the task goal: 133cm, and the following ‘your three worst trials were 112cm, 105cm and 102cm’. The KR was presented for 5s (see Appendix L).

The acquisition period began with participants reading through a series of instruction screens outlining the goal of the motor task and their respective KR condition. Upon completion of the instruction screens, participants completed one familiarization trial of the motor task. The participants then completed their first motivation questionnaire, prior to the beginning of the study. At the completion of the questionnaire all questions were answered at this time. A typical experimental trial began the same way for all experimental conditions with the word ‘Ready?’ in the centre of the computer screen for a total of 3 seconds. Following this screen, participants viewed the word ‘Go’ in the centre of the computer screen, signaling the participants to complete their motor response within 6 seconds. Upon completion of the trial, participants were prompted by a ‘Trial Complete’ message for 3 seconds. For the first five practice trials in the 6 trial block, KR was not be provided to the participants. On the no-KR trials, participants viewed the ‘Trial Complete’ message, followed by the ‘Ready?’ screen for 3 seconds. Upon completion of the 6th trial in every block (12 blocks total, thus a total of 12 KR presentations), participants received KR on their three best or three worst trials, respective of KR condition for 5 seconds. Similar to Chiviacowsky and Wulf (2009), participants were aware of the trials they were receiving KR within the 6 trial blocks. Importantly, the only factor distinguishing the experimental conditions was whether or not they were estimating their KR content.

To assess whether the KR conditions differentially impacted participant motivation, participants completed a motivation questionnaire previously utilized by Lewthwaite and Wulf (2009) prior to the acquisition period to determine baseline motivation levels, mid-point motivation levels and following the acquisition period to examine the impact of various feedback conditions on participant motivation. The questionnaire required participants to self-report how motivated they were to learn the task as a function of their KR condition and feedback. For most items on the questionnaire, participants were asked to circle a number, ranging between 1 and 10 that best reflects their perceived motivation upon completion of the acquisition period. The numbers ranged from 1, “not at all (skilled, motivated, useful, etc.)”, to 10, “very (skilled, motivated, useful, etc.)” (Lewthwaite & Wulf, 2009) (see Appendix B). A second questionnaire was administered after the acquisition period to determine if participants had the choice, when would they have preferred to receive feedback. Participants were instructed to circle the answer that best reflects their perception (See Appendix B). (Patterson & Azizieh, 2011; Chiviacowsky & Wulf, 2009).

3.5 Data analysis

For the acquisition and retention periods, the dependent measures of interest was absolute constant error (|CE|) and variable error (VE). |CE| was used as a measure of performance accuracy while VE was used as an index of performance consistency (Schmidt & Lee, 2011). For the acquisition phase, the means for |CE| and VE were grouped separately into 12 blocks of six trials, respectively. For acquisition |CE| and VE were analyzed separately in a 2 (feedback type: good, poor) x 2 (estimating: estimate, non-estimate) x 12 (blocks) ANOVA with repeated measures on the last factor. For the retention tests, |CE| and VE were collapsed into one block of 12 trials for each retention test (immediate and delayed) and subjected to a 2 (feedback type: good, poor) x 2 (estimating: estimate, non-estimate) x 2 (blocks: immediate, delayed retention test) ANOVA with repeated measures on the last factor. For the transfer test, |CE| and VE was collapsed into one block of 12 trials and subjected to a 2 (feedback: good, poor) x2 (estimating: estimate, non-estimate) ANOVA. To assess questionnaire data, a mean and standard deviation of responses was calculated, each question could range from 1 = “not at all” to 10 = “very”. Questionnaire responses were analyzed with separate one-way ANOVAs. All one-way ANOVAs were followed by Bonferroni-corrected comparisons, where appropriate.

StatSoft Inc conducted all statistical analyses using Statistica version 7.0. A significance level of $p < .05$ was used for all statistical analyses and statistically significant interactions involving more than two means were analyzed using the Tukey’s HSD post hoc analysis. Effect sizes were reported as partial eta squared (η_p^2) where appropriate.

3.6 Experimental Predictions:

The following predictions were made for all experimental periods:

1. Independent of KR content, the performance-estimating conditions were expected to perform more accurately (e.g., less |CE|) and more consistently (e.g., less VE) than the non-estimating conditions in all experimental phases (Guadagnoli & Kohl, 2001).
2. Independent of performance-estimation, no differences were expected between conditions receiving KR on good trials or KR on poor trials during

all experimental phases based on accuracy (|CE|) and consistency (VE) measures (Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2009).

3. Participants in the performance estimating conditions would report higher motivation scores than those not estimating their performance, based on expected increased cognitive effort invested during the acquisition period (Lee et al., 1994; Lewthwaite & Wulf, 2009) compared to those not estimating.
4. The KR content provided (e.g., good or poor trials) would not differently impact the success in performance estimation during all experimental phases (e.g., estimating good trials or poor trials; indexed by proportion of trials guessed correctly) (Patterson & Azizieh, 2012).

CHAPTER 4: RESULTS

4.1 Absolute constant error (|CE|)

4.1.1. Acquisition

The means for |CE| for experimental conditions are displayed on the left side of Figure 1. There was a significant main effect for block, $F\ (11, 572) = 24.85$, $p < .05$, $\eta_p^2 = 0.32$ and a block x estimate interaction, $F\ (11, 572) = 2.64$, $p < .05$, $\eta_p^2 = 0.048$. The post hoc analysis for the block main effect showed that block 1 was performed with greater |CE| compared to blocks 2-12, block 2 demonstrated greater |CE| than blocks 4-12, block 3 demonstrated greater |CE| than blocks 5 and 8-12, and block 4 demonstrated greater |CE| than block 11. Results of the post-hoc analysis for the interaction showed that block 1 was performed with greater |CE| compared to blocks 2-12, and block 2 demonstrated greater |CE| than blocks 4-12 for the estimate conditions. For the non-estimate conditions, block 1 was performed with greater |CE| than blocks 5-12, block 2 demonstrated greater |CE| than blocks 9-12, and block 3 demonstrated greater |CE| than blocks 7-12. Results also revealed a significant difference between block 1 of the estimating conditions compared to blocks 7, 9-12 of the non-estimating conditions. There was no statistically significant difference between the estimating groups at blocks 1-12. The main effect for feedback content, $F\ (1, 52) = 2.67$, $p = .11$; and estimate, $F\ (1, 52) = 0.06$, $p = .81$; were not statistically significant. The feedback content x estimate interaction, $F\ (1, 52) = 0.002$, $p = .97$; feedback content x block interaction, $F\ (11, 572) = 0.91$, $p = .53$; and the feedback content x estimate x block interaction, $F\ (11, 572) = 0.59$, $p = .84$; were also not statistically significant.

4.1.2. Retention

The means for |CE| for experimental conditions are displayed in the middle of Figure 1. There was a main effect for retention test, F (1, 52) = 8.51, p <.05, η_p^2= 0.14, feedback content, F (1, 52) = 4.21, p <.05, η_p^2= 0.07, and a retention test x feedback content x estimation interaction, F (1, 52) = 6.85, p <.05, η_p^2=0.12. Results of the post hoc analysis for the main effects showed the immediate retention test (15-minute) (M = 15.86, SE = .76) was performed with less |CE| than the delayed retention test (24-hours) (M = 18.33, SE = .84), and the good KR conditions (M = 15.70, SE = .96) demonstrated less |CE| than the poor KR conditions (M = 18.50, SE = .96). Results of the post hoc analysis for the retention test x feedback content x estimate interaction showed the good non-estimate condition had greater |CE| than the poor non-estimate condition during the immediate retention. There was no statistically significant differences identified between the groups (i.e., good/poor estimate and good/poor non-estimate) during the immediate or delayed retention test. Finally, the main effect for estimate, F (1, 52) = 0.97, p=.33, was not statistically significant nor was the retention test x estimate interaction, F (1, 52) = 0.07, p=.8; feedback content x estimate interaction, F (1, 52) = .07, p= .8; or feedback content x retention test interaction, F (1, 52) = 0.84, p=.36.

4.1.3. Transfer

The means for |CE| for experimental conditions are displayed on the far right side of Figure 1.There was a main effect for feedback content, F (1, 52) = 7.19, p <.05, η_p^2= 0.12 with the good KR conditions (M = 18.66, SE = 1.23) performing with less |CE| than the poor KR conditions (M = 23.31, SE = 1.23). The main effect for estimate, F (1, 52) = 1.05, p=.31, and the feedback content x estimate interaction, F (1, 52) = 1.04, p=.31, was not statistically significant.

4.2 Variable error (VE)

4.2.1. Acquisition

The means for VE for all experimental conditions are displayed on the far left side of Figure 2. There was an estimate x block interaction, F (11, 572) = 2.14, $p< .05$, η_p^2=.04. The post hoc analysis indicated that block 1 in the non-estimate conditions (M = 19.15, SE = 1.37) was more variable than block 3 (M = 12.58, SE = 1.32) in the estimate conditions. There was no statistically significant difference between the estimating conditions at any of the acquisition blocks (1-12). The main effect for feedback content, F (1, 52) = 0.66, p=.42; estimate, F (1, 52) = 1.64, p=.21; and block, F (11, 572) = 1.19, p=.29; were not statistically significant. The feedback content x estimate interaction, F (1, 52) = 0.83, p=.37; feedback content x block interaction, F (11, 572) = 0.28, p=.99; and the feedback content x estimate x block interaction, F (11, 572) = 0.75, p=.69; were also not statistically significant.

4.2.2. Retention

The means for VE for all experimental conditions are displayed in the middle of Figure 2. The main effect for estimate, F (1, 52) = 4.65, $p< .05$, η_p^2=.08, was statistically significant with the estimate conditions (M = 17.83, SE = 1.11) demonstrating less variability compared to the non-estimate conditions (M = 21.22, SE = 1.11). The main effect for feedback content, F (1, 52) = 0.66, p=.42; and retention test, F (1, 52) = 0.001, p=.97; were not statistically significant. The feedback content x estimate interaction, F (1, 52) = 0.19, p=.67; feedback content x retention test interaction, F (1, 52) = 0.78, p=.38; estimate x retention test interaction, F (1, 52) = 0.0008, p=.98; and the feedback content x estimate x retention test interaction, F (1, 52) = 2.45, p=.12; were also not statistically significant.

4.2.3. Transfer

The means for VE for all experimental conditions are displayed on the far right side of Figure 2. The main effect for feedback content, F (1, 52) = 0.20, p=.65; and estimate, F (1, 52) =

0.44, *p*=.51; were not statistically significant. The feedback content x estimate interaction, *F* (1, 52) = 1.61, *p*=.21, was also not statistically significant.

4.3 Proportion of correctly estimated trials as a function of feedback type

4.3.1. Acquisition

The proportion of correctly estimated KR trials as a function of feedback content (i.e., good / poor estimate condition) for all experimental conditions during the acquisition period are displayed on the far left side of Figure 3. The main effect for feedback content, *F* (1, 26) = 1.8, *p*=.19; and block, *F* (11, 286) = .95, *p*=.5; were not statistically significant. The feedback content x block interaction, *F* (11, 286) = 1.02, *p*=.43; was also not statistically significant.

4.3.2. Retention

The proportion of correctly estimated KR trials for all experimental conditions during the retention period are displayed in the middle of Figure 3. The main effect for retention test, *F* (1, 52) = 4.63, $p < .05$, η_p^2=.08, was statistically significant. The immediate retention test had a greater proportion of correctly estimated trials (*M* = .65, *SE* = .03), than the delayed retention test (*M* = .73, *SE* = .03). The feedback content, *F* (1, 52) = 1.14, *p*=.29; and estimate, *F* (1, 52) = .33, *p* = .57; were not statistically significant. The feedback content x estimate, *F* (1, 52) = 1.14, *p*=.29; retention test x feedback content, *F* (1, 52) = 1.43, *p*=.24; retention test x estimate, *F* (1, 52) = .51, *p*=.48; and retention test x feedback content x estimate, *F* (1, 52) = .16, *p*=.69; were also not statistically significant.

4.3.3. Transfer

The proportion of correctly estimated KR trials for all experimental conditions during the transfer period are displayed on the far right side of Figure 3. The main effect for feedback content, *F* (1, 52) = 3.67, *p*=.06; and estimate, *F* (1, 52) = .11, *p*=.74; were not statistically significant. The feedback content x estimate interaction, F (1, 52) = .32, p=.58; was also not statistically significant.

4.4 Specificity of practice

To examine whether there was a specificity of practice effect as a function of the trials being estimated during the acquisition period (good or poor), we examined whether participants in the *good-estimate* condition were more successful at estimating their good trials than their poor trials. Likewise, we were interested in determining if participants in the *poor estimate* condition were more successful at estimating their poor trials than their good trials during the retention and transfer periods.

4.4.1. Immediate Retention

The means of the estimated KR trials during the immediate retention test are displayed in Figure 4. The main effects of retention test, F (1, 55) = .0004, p=.98; and feedback content, F (3, 55) = .72, p=.54; were not statistically significant. The feedback content x retention test interaction, F (3, 55) = .48, p=.7; was also not statistically significant.

4.4.2. Delayed Retention

The means of the estimated KR trials during the delayed retention test are displayed in Figure 4. The main effects of retention test, F (1, 55) = .56, p=.46, η_p^2=.01; and feedback content, F (3, 55) = .67, p=.57, η_p^2=.04, were not statistically significant. The feedback content x retention test interaction, F (3, 55) = .61, p=.61, η_p^2=.03, was also not statistically significant.

4.4.3. Transfer

The means of the estimated KR trials during the transfer test are displayed in Figure 4. The main effect of transfer test, F (1, 55) = .61, p=.44, η_p^2=.01; and feedback content, F (3, 55) =

1.2, p=.32, η_p^2=.061736, were not statistically significant. The feedback content x transfer test interaction, F (3, 55) = .64, p=.59, η_p^2=.03, was also not statistically significant.

4.5 Motivation

The purpose of the self-reported motivation questionnaire was to assess differences in motivation as a result of practicing the motor task throughout acquisition. The questionnaire was created by Lewthwaite and Wulf (2009) and was modified to have participants self-report their motivation just prior to the acquisition phase. The complete questionnaire was administered at the middle (i.e., 36 of 72 trials completed) and end (all acquisition trials completed) of the acquisition period, to have participants self-report their motivation and preference for KR. The complete results of the questionnaire are displayed in Table 1. All experimental conditions had a similarly high self-reported motivation level. When motivation was assessed at mid-point (i.e., 36 of 72 trials completed) the poor non-estimate showed a slight decrease in motivation, meanwhile motivation for the other experimental conditions remained similar to each other, with a slight increase. When motivation was assessed at the end (all acquisition trials completed) the same trend, a slight decrease in self-reported motivation levels have been identified with the poor non-estimate condition. The good estimate condition self-reported a slightly higher motivation level compared to the other experimental conditions and their mid-point assessment. The poor estimate and good non-estimate conditions had similar motivation levels as reported from the mid-point assessment. These are evident trends for each of the experimental conditions, however there was no statistically significant difference between the experimental conditions and between the time periods assessed.

The means for the self-reported motivation scores throughout acquisition for all experimental conditions are displayed on Figure 5. The main effect for feedback content, F (1, 52) = 2.10, p = .15; and estimate, F (1, 52) = 1.45, p = .23; were not statistically significant. The feedback content x estimate interaction, $F(1, 52) = .25$, $p = .62$; was also not statistically significant. Therefore, self-reported motivation measures did not change as a function of practice for all experimental conditions.

4.6 Feedback preference

Participants were asked at the end of the acquisition period to self-report when they would have preferred to receive feedback. The results of the feedback preference questionnaire illustrated that the majority of participants preferred to receive feedback after successful trials only, *good-estimate* (57%), *poor-estimate* (65%), *good non-estimate* (50%) and *poor non-estimate* (36%). The *good* and *poor non-estimate* conditions both had 7% of participants adopt a strategy not listed on the questionnaire (e.g., after 3 trials [successful or unsuccessful] and closer than 10cm).

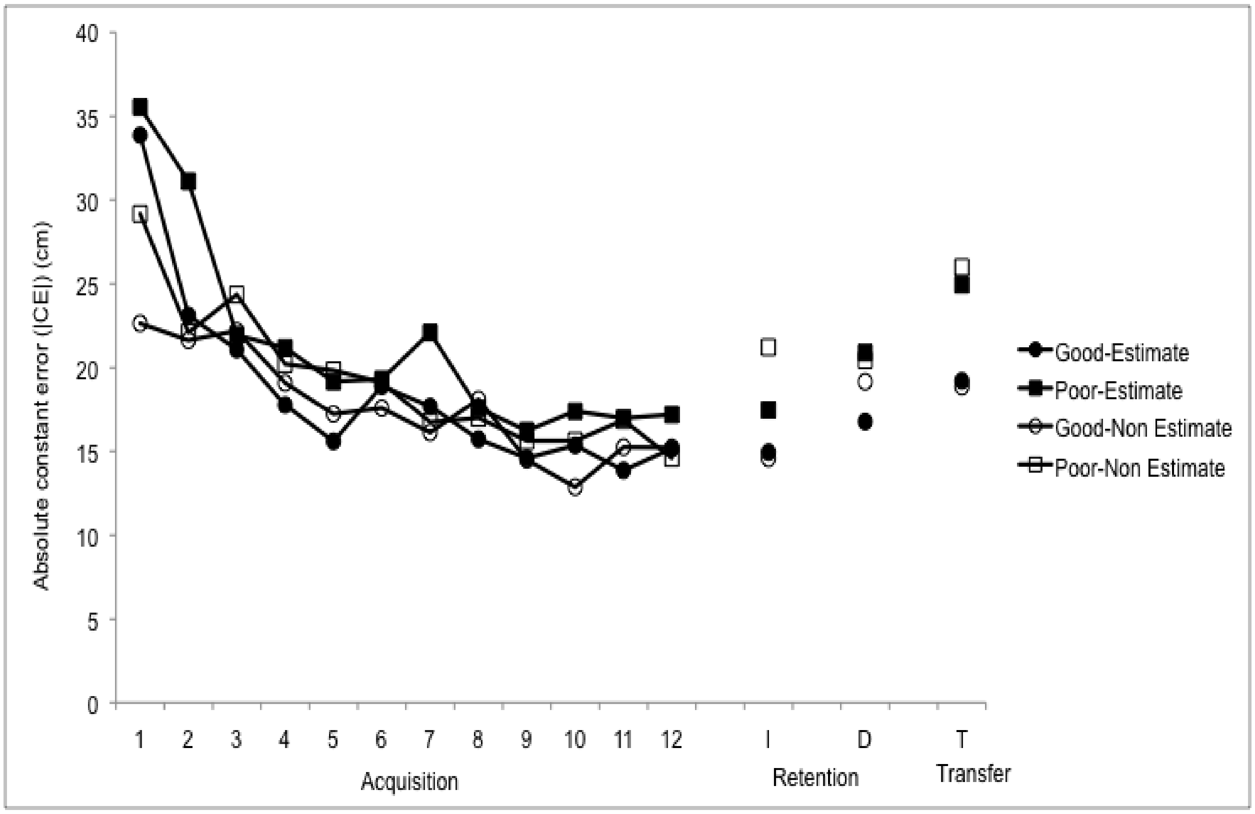

Figure 1. Absolute constant error (|CE|) for all experimental conditions for the acquisition (blocks 1 to 12) (immediate [15-min] and delayed [24-hr]), and transfer periods of the experiment.

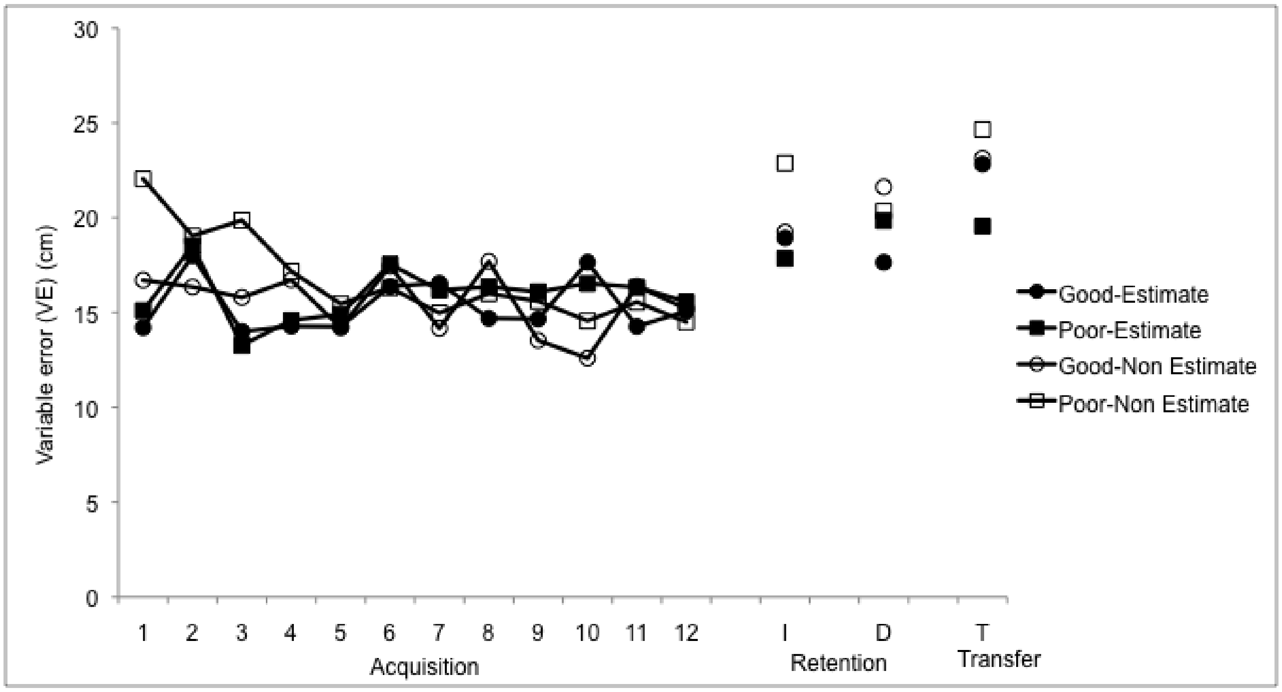

Figure 2. Variable error (VE) for all experimental conditions for the acquisition (blocks 1 to 12), retention (immediate [15-min] and delayed [24-hr]), and transfer periods of the experiment.

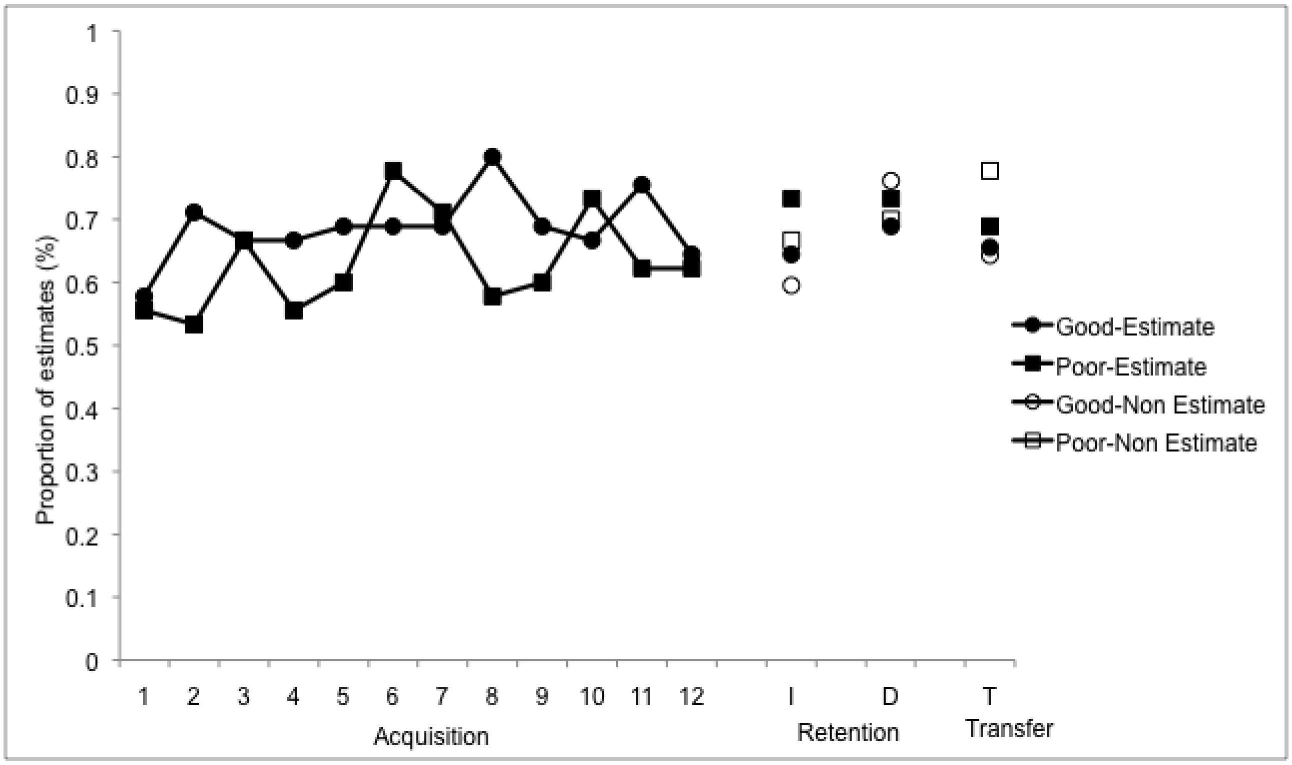

Figure 3. Proportion (%) of correctly estimated KR trials as a function of feedback type for all experimental conditions for the acquisition blocks (1 to 12), retention (immediate [15-min] and delayed [24-hr]), and transfer periods of the experiment.

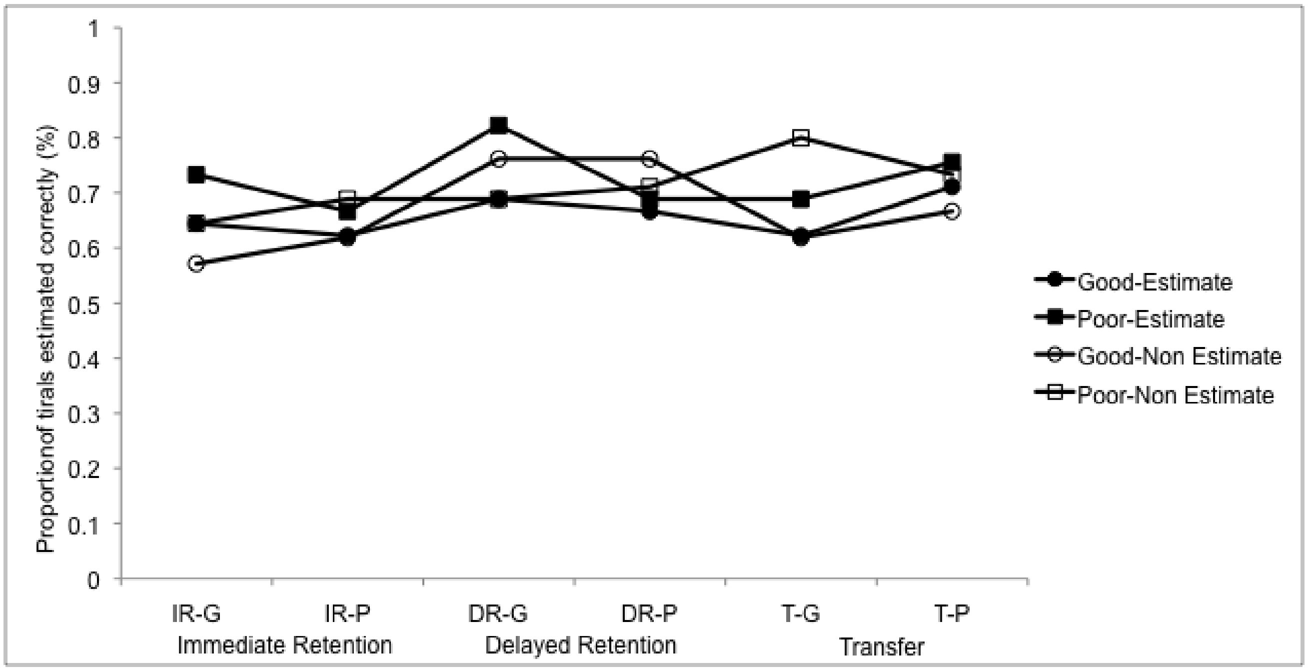

Figure 4. Proportion (%) of estimated KR trials as a function of feedback type for all experimental conditions for the retention (immediate [15-min] and delayed [24-hr]) and transfer periods of the experiment.

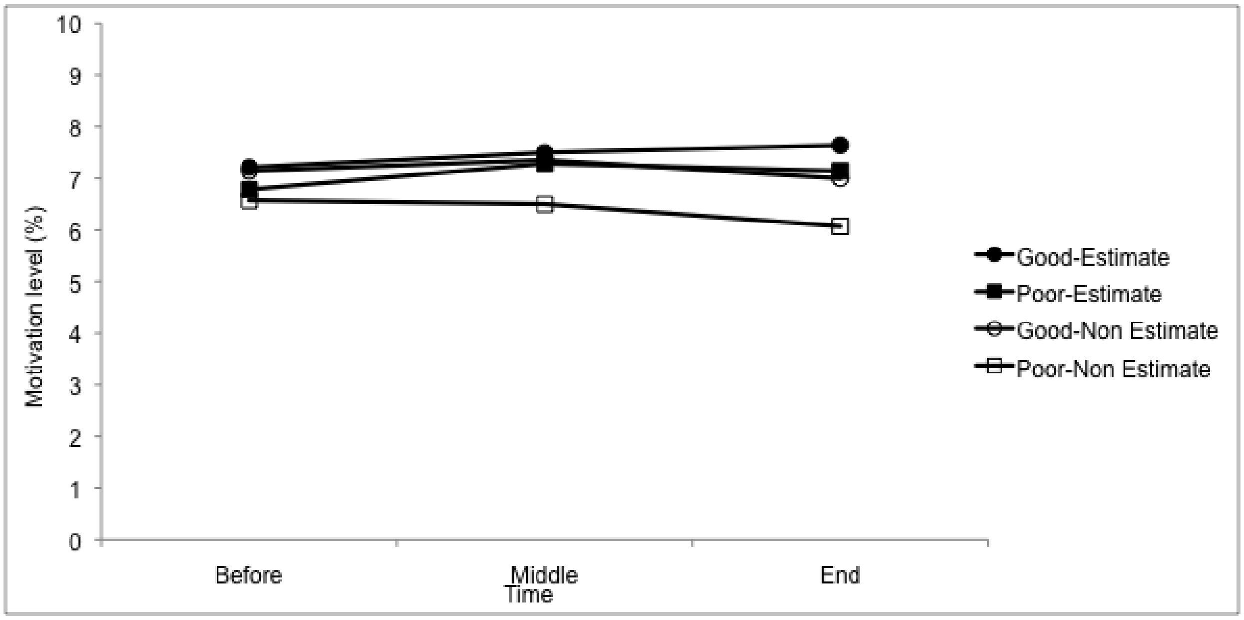

Figure 5. The self-reported motivation levels (%) prior to the acquisition phase (before), at mid-point (i.e., 36 of 72 trials completed) and end (all acquisition trials completed) of the acquisition period.

Table 1

Self-reported motivation, feedback and KR preferences for all experimental conditions before acquisition, at mid-point (i.e., 36 of 72 trials) and at the end. Each question could range from 1 (not at all) to 10 (very).

Questionnaire Item	Group			
	Good-Estimate (*n*=14)	Poor-Estimate (*n*=14)	Good-Non Estimate (*n*=14)	Poor-Non Estimate (*n*=14)
How motivated are you to learn this task?				
Questionnaire (before acquisition)	Average responses			
	7.2 (72%)	6.8 (68%)	7.1 (71%)	6.6 (66%)
How motivated were you to learn this task?				
Questionnaire (Mid-point [36 of 72 trials])	Average responses			
	7.5 (75%)	7.3 (73%)	7.4 (74%)	6.5 (65%)
How much did you enjoy practicing this task?				
	Average responses			
	6.6 (66%)	5.6 (56%)	6.1 (61%)	5.1 (51%)
Did you find the feedback useful?				
	Average responses			
	7.3 (73%)	7.2 (72%)	8.9 (89%)	6.9 (69%)
Did you find the feedback motivating?				
	Average responses			
	7 (70%)	7.1 (71%)	8.1 (81%)	6.3 (63%)
Would you have preferred not to receive feedback?				
	Average responses			
	2 (20%)	3.3 (33%)	2.1 (21%)	1.8 (18%)
How motivated were you to learn this task?				
Questionnaire (End of acquisition)	Average responses			
	7.6 (76%)	7.1 (71%)	7 (70%)	6.1 (61%)

	Average responses			
	7.7 (77%)	7.2 (72%)	7.8 (78%)	6.4 (64%)
Would you have preferred not to receive feedback?				
	Average responses			
	1.4 (14%)	3.2 (32%)	2.2 (22%)	2.1 (21%)
If you had a choice, when would you have preferred to receive feedback?				
Questionnaire (end of acquisition)	Number of responses			
After only successful (e.g., good) trials	8 (57%)	9 (65%)	7 (50%)	5 (36%)
After only unsuccessful (e.g., poor) trials	0 (0%)	2 (14%)	3 (21.5%)	2 (14%)
Randomly	1 (7%)	1 (7%)	0 (0%)	2 (14%)
After good and poor trials equally	5 (36%)	2 (14%)	3 (21.5%)	4 (29%)
Other	0 (0%)	0 (0%)	1 (7%)	1 (7%)

CHAPTER 5: DISCUSSION

The purpose of the present thesis was to determine if requiring learners to use their error-detection mechanism (i.e., intrinsic feedback) to estimate their best or worst trials (high cognitive effort) would facilitate superior learning compared to those not estimating their performance (low cognitive effort). To address this gap in knowledge, the following predictions were made: First, independent of KR content, the performance-estimating conditions were expected to perform more accurately (e.g., less |CE|) and more consistently (e.g., less VE) than the non-estimating conditions in all experimental phases (Guadagnoli & Kohl, 2001). Second, independent of performance-estimation, no differences were expected between conditions receiving KR on good trials or KR on poor trials during all experimental phases based on accuracy (|CE|) and consistency (VE) measures (Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2009). Third, participants in the performance estimating conditions would report higher motivation scores than those not estimating their performance, based on expected increased cognitive effort invested during the acquisition period (Lee et al., 1994; Lewthwaite & Wulf, 2009) compared to those not estimating. Finally, the KR content provided (e.g., good or poor trials) would not differently impact the success in performance estimation during all experimental phases (e.g., estimating good trials or poor trials; indexed by proportion of trials guessed correctly) (Patterson & Azizieh, 2012). A discussion of the findings in relation to the experimental predictions follows.

5.1 Performance-estimation and motor learning

The main purpose of this thesis was to determine if requiring learners to use their error-detection mechanism (i.e., intrinsic feedback) to estimate their best or worst trials (increased cognitive effort) would facilitate superior learning compared to those not required to estimate their performance success. Based on existing literature, it was predicted that independent of KR content, participants in the performance estimating conditions would demonstrate superior performance (Guadagnoli & Kohl, 2001) compared to the non-estimating conditions (i.e., good or poor trials). This prediction was not supported. As the results indicated there was no significant differences found for accuracy between the performance-estimating and non-estimating conditions during retention and transfer. Guadagnoli and Kohl (2001) have suggested that participants required to estimate the magnitude of their performance success prior to receiving augmented feedback is advantageous in facilitating motor learning. The process of error estimation requires participants to create a response hypothesis about the outcome of their just completed motor action (Guadagnoli & Kohl, 2001). This protocol encourages the use of additional information sources (Schmidt & Lee, 2011) requiring participants to use KR to test their response hypotheses (Guadagnoli & Kohl, 2001).

Early information-processing perspectives have suggested that KR is primarily used for motor learning in two complementary ways: (a) A learner needs KR to test a hypothesis about the correctness of the previous response, and (b) each tested hypothesis contributes to a better memory of that response (Adams, 1971, 1987; Schmidt, 1975). Therefore, after the completion of a trial, the learner will explicitly estimate how successful they were on that trial. The learner then assesses the correctness of that estimation (i.e., hypothesis) by comparing it to the KR received. On the basis of that comparison, a response hypothesis, or plan, is derived for the next response. The response hypothesis is continually updated as the learner compares their response hypothesis and their estimates to the KR presented. Therefore, executing a motor response coupled with explicit error estimations embody response hypotheses that are either confirmed or updated with KR statements (Guadagnoli & Kohl, 2001).

Feedback representing a performer's success for a given set of responses has been long considered a critical factor in both motor performance and learning (Adams, 1987; Salmoni, et al., 1984). In the present study, during retention we believe that both the performance-estimation and non-estimation conditions were involved in the same process of generating a response hypothesis, independent of KR content. This is evident by the similar accuracy and variability scores between groups during retention. Independent of KR content, it was found that both the performance-estimation and non-estimation conditions performed similarly for performance estimation. These results extend Guadagnoli and Kohl (2001) as we suggest that a response hypothesis can be generated, and stored within working memory when KR is provided similar to a summary format, and independent of whether the participant is required to make their response hypothesis explicit.

Previous studies required participants to estimate the success of their previous response during the acquisition period only. Participants provided their error estimation immediately after their response, and before KR was provided. Using a 100% KR relative frequency schedule, it was demonstrated that participants who estimated response errors performed better on retention tests than participants who did not estimate response errors (Hogan & Yanowitz, 1978; Swinnen, Schmidt, Nicholson, & Shapiro, 1990). However, in previous studies, subjects were not required to estimate their error during retention tests (Guadagnoli & Kohl, 2001). Therefore, it was unknown whether error estimation abilities demonstrated during acquisition would persist in the retention period (Swinnen, et al., 1990). The results of the current study found similar performance in retention and transfer periods, as performers demonstrated the ability to accurately predict their good and poor trials over the course of the retention period, therefore, extending Guadagnoli and Kohl (2001) study. The skill of estimating one’s performance persisted independent of KR content, as performers were forced to interpret intrinsic feedback and generate a response hypothesis, which increased the challenge of the task during the no-KR trials. Previous research only required error-estimation during acquisition (Guadagnoli & Kohl, 2001) our results extend to the retention and transfer period (no-KR trials) and suggest a persistence of performance-estimating ability. Reasons for the performance-estimation success between those required and those not required to estimate their performance in the acquisition period is discussed next.

The first explanation to consider why the performance-estimating conditions had similar accuracy measures (|CE|) and proportion of trials guessed correctly as the non-estimating conditions during all experimental phases is based on the *tested response hypothesis* (Adams, 1971, 1987; Schmidt, 1975). According to this hypothesis, for motor learning to occur, learners must use KR to amend future responses on the basis of the information gathered from the just-completed response. The strength of the memory that controls the motor action develops a positive response in relation to KR (i.e., tested response hypothesis) (Adams, 1971). Adams also noted that when KR is withdrawn, the learner can strengthen only what has been learned from the previous responses with KR. Therefore, based on early perspectives of KR, learners develop a strengthened memory based on the feedback presented. In the current study, participants were primed to the information that would be contained in their KR display (good or poor trials) and in some cases, required to estimate (good or poor trials). The performance-estimating conditions were *explicitly* required to estimate their three 'good' or 'poor' trials after each six-trial block as a function of their experimental condition. The enhanced performance (decreased accuracy and increased consistency) of participants in the current study extends Guadagnoli & Kohl (2001) by having participants performance-estimate based on a predetermined criterion (good or poor trials) over a 6-trial delay. The results indicated that both the performance-estimating and non-estimating conditions engaged in similar cognitive processes (i.e., tested response hypothesis) and as a result, both performed with greater accuracy and consistency during retention and transfer. The results of the present study support the acquisition results of Guadagnoli and Kohl (2001), and extend those findings based on the retention and transfer results of the present experiment of the performance – estimating condition.

A second explanation to consider why the performance-estimating conditions demonstrated similar scores for accuracy as the non-estimating conditions is the process in which participants were engaged (i.e., implicit vs. explicit). Implicit learning is typically defined as the acquisition of knowledge about the underlying structure of a complex stimulus environment by a process which takes place naturally, simply and without conscious operation, while explicit learning is characterized by more conscious operation where the individual makes and tests hypotheses (Ellis, 1994b). We believe that the non-estimating conditions were engaged in the same cognitive process (i.e., implicitly learning) as the performance-estimating conditions. Graf & Mandler (1984) described implicit memory as arising from the process of being primed, whereby subjects are measured by how they have improved their performance on tasks for which they have been subconsciously prepared. In the present study, participants were explicitly informed of the KR content that would be presented (i.e., good or poor trials). One interpretation of this finding is that both the performance-estimating and non-estimating groups were engaged in the same process (i.e., explicitly learning), yielding similar accuracy results during retention and transfer. All groups were primed to the KR received (i.e., good or poor KR), and were explicitly monitoring their performance, however, the performance-estimation groups had the opportunity to verbalize their *"response hypothesis"* (Adams, 1971). That is, priming individuals to specific KR content (i.e., good or poor trials) encouraged individuals to explicitly engage, thereby improving motor learning. We propose that both, the performance-estimation and non-estimation conditions generated a response hypothesis during acquisition, such that when KR was withdrawn (retention and transfer phases) learners retrieved their response hypothesis and interpreted their intrinsic feedback in reference to their response-hypothesis, leading to motor skill acquisition.

A third explanation for the similar results between the performance-estimating and non-estimating conditions is based on the notion of feeling of knowing (FOK). According to the accessibility model proposed by Koriat (1993, 1995), individuals retrieve partial information in regards to a required response (fragments of the target may be retrieved but remain below the level of conscious awareness), whether or not that answer is the correct one, will influence this feeling (feeling of knowing). This feeling, is a way of measuring the accessibility of the knowledge one has, correct or incorrect (Koriat, 1993). FOK judgments are based on the overall accessibility of partial information activated during the search for the target information, within working memory.

The accessibility hypothesis suggests that memory will be accurate when the ease of processing (accessibility) is correlated with outcome behaviour (Koriat, 1993). It is suggested that both the performance-estimation and non-estimating conditions based their performance estimations during the retention and transfer period on a FOK to retrieve the proprioceptive information stored in memory, as a result of the summary KR schedule. As a result, both conditions engaged in the FOK judgments based on the fact learners were encouraged to interpret their sensory feedback, intrinsic to the task in reference to either their perceived good or poor trials to enhance accurate retrieval of their response hypothesis (Adams, 1971). The results suggest that learners developed an internally generated error-detection mechanism, as accuracy of performance estimation was maintained during the retention and transfer tests. We believe learner's also utilized their FOK judgments during the retention period when KR was no longer available (i.e., retention and transfer tests). In future studies, the use of questionnaires assessing FOK judgments and confidence level (CL) would be a fruitful endeavor. Confidence level questionnaires assess the participant's perceived confidence in regards to the accuracy of their FOK.

5.2 KR content and motor learning

One of the purposes of this thesis was to examine the possible learning differences of receiving KR on good trials versus poor trials. Thus, it was of interest to determine if KR content would differentially impact the development of accuracy (|CE|) and consistency (VE) independent of performance estimation. Previous motor learning literature has examined the impact of providing KR after good trials compared to after poor trials when learning a motor task (Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2009; Patterson & Azizieh, 2012). The second prediction stated that no differences were expected between conditions receiving KR on good trials or KR on poor trials during the acquisition and retention period based on accuracy (|CE|) and consistency (VE) measures (Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2009). This prediction was based on the most current study conducted by Patterson and Azizieh (2012) who concluded that being aware of the KR content, not the type of KR content, was the modulating factor facilitating skill acquisition. This prediction was not supported based on the retention |CE| measures showing the KR good conditions demonstrating greater accuracy than the KR poor conditions, independent of performance-estimation. The most viable explanation for the benefits of receiving KR after good trials might be positive impact of KR on good versus poor trials. Receiving KR after good trials may reinforce the cognitive processes required to reproduce the correct motor response on upcoming and subsequent trials (Chiviacowsky & Wulf, 2002, 2005). The cognitive processes associated with reproducing a correct response has been shown to be less demanding and more advantageous for the learner compared to the cognitive demands associated with correcting an error (Chiviacowsky & Wulf, 2002, 2005).

The third prediction stated, independent of performance-estimation, no differences were expected between conditions receiving KR on good trials or KR on poor trials during all experimental phases based on accuracy (|CE|) and consistency (VE) measures (Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2009). This prediction was not supported. The retention results of the current study showed a main effect for feedback content with the good KR conditions demonstrating less |CE| than the poor KR conditions. This was also supported during transfer, as the good KR conditions also performed with less |CE| than the poor KR conditions. There were no significant differences found between the good or poor KR conditions for VE. Independent of performance estimation, these findings suggest that receiving KR after good trials creates a greater success experience for learners than KR after relatively poor trials. This success experience might be more motivating for learners, in turn, enhancing the learning process. Aside from the informational role, KR has long been assumed to have motivational properties (Thorndike, 1927). More recent studies have confirmed this. Chiviacowsky & Wulf (2007) speculated that participants that received KR after relatively good trials had greater motivation to learn, and in turn, had greater performance during retention than participants that received KR after relatively poor trials. The learning advantage of feedback after good compared to poor trials contradicts the guidance hypothesis (Salmoni et al., 1984; Schmidt, 1991; Patterson & Azizieh, 2012). The guidance hypothesis states that error feedback is beneficial (receiving feedback based on poor trials) because it guides the learner to the correct response. Specifically, feedback after larger errors should be more beneficial than feedback after smaller errors. Results from the present study suggest that participants developed their error-detection mechanism capability, as evidenced by the improved accuracy and consistency throughout the retention and transfer periods. In addition, one could infer that error detection and correction abilities could also be the result of performance-estimation success, as evidenced by enhanced accuracy and consistency throughout the no-KR trials.

A second possible explanation to consider why the KR good condition had superior performance during retention and transfer compared to the KR poor condition, independent of performance estimation was the KR content difference (i.e., good vs. poor). It has been demonstrated that feedback after relatively good trials encourages the learners to repeat a successful movement rather than change the movement pattern to correct for errors (Chiviacowsky & Wulf, 2007). In fact, “maladaptive short-term corrections”, may be used by the group receiving KR after poor trials, viewed as a negative effect of frequent feedback (Schmidt, 1991). Maladaptive short-term corrections are defined as inappropriate corrections in the production of a motor skill resulting when relatively minor movement errors are corrected through the provision of augmented feedback (Schmidt, 1991). As feedback is given, the KR poor conditions attempted to correct for all errors, thus preventing learners from developing a stable movement representation, as evidenced by VE and |CE| during the acquisition period, when KR was available. As KR was only provided after every six trials, we believe participants receiving KR after poor trials made trial-to-trial changes (or no changes) based on their intrinsic feedback. It appears that participants receiving KR after poor trials during acquisition developed maladaptive short-term corrections evidenced by increased VE. As a result, the short-term corrections had a negative impact on retention and transfer performance during no-KR trials.

5.3 Motivation and motor learning

The benefits of receiving KR after good trials were expected to increase self-reported measures of motivation compared to those learners receiving KR after relatively poor trials. Previous research suggests that the motivational role of KR has long term learning benefits, rather than a temporary effect on motor learning (Lewthwaite & Wulf, 2009). When participant motivation is enhanced as a function of KR, learners are predicted to practice with more seriousness resulting in an indirect impact on learning (Schmidt & Lee, 2011). The fourth prediction stated, independent of KR content the performance-estimating conditions will possess superior motivation compared to the non-estimating conditions. This prediction was not supported. The results of the present experiment showed no significant differences for self-reported motivation measures between the performance-estimating and non-estimating conditions, independent of KR content during acquisition. In the present experiment, participants were required to self-report their motivation levels at three separate times throughout the acquisition period. The first measure of motivation was collected prior to the beginning of the acquisition period (i.e., 0 of 72 trials), at mid-point (i.e., 36 of 72 trials) and finally at the end (72 of 72 trials) of the acquisition period. All participants independent of performance-estimation and KR content reported high motivation at all points throughout acquisition to learn the task. A possible explanation to consider why motivation did not change as a function of experimental conditions was believed to be the novelty of the motor task. The task in the current experiment is considered novel as, none of the participants had previous experience with the task. We attribute this high motivation to participant satisfaction with the task and their respective experimental condition. It appears that all participants were able to learn the task, independent of experimental condition as a block effect for |CE| was found confirming that all participants did in fact learn the task.

A second explanation for the similar levels of motivation between experimental conditions throughout acquisition is that motivation in previous studies has only been inferred, and in fact, has never been measured. Chiviacowsky & Wulf (2007) suggested that the motivational properties of feedback might have a direct effect on learning. However, motivation was not assessed within this study. Our findings suggest that participants' self-reported motivation was not a significant factor dissociating the differences between the performance-estimating and non-estimating conditions. As all conditions self-reported similarly, high motivation levels to learn the task at all times during the acquisition period. It was important to explicitly examine the direct role motivation has on motor learning because previous studies have inferred there is a direct relationship. Showing heightened motivation throughout the skill acquisition period, independent of experimental condition, is a novel and important contribution of the present thesis, based on the fact previous research has suggested motivation was a function of KR content (Chiviacowsky & Wulf, 2007). Further research is suggested to examine if motivation levels remain similar during retention and transfer tests' as it may be a factor impacting motor performance. Motivational properties of feedback may have a direct relationship with the motivation to learn the task as a function of the practice content therefore, a more complete understanding of the various roles of feedback and how it affects motivation during motor learning is vital.

5.4 Performance - estimation and motor learning

One of the purposes of this thesis was to determine if KR content would differentially impact the success in performance-estimation. It was also of interest to determine if a specificity of practice (Adams, 1971) would be evident during retention and transfer as a function of performance-estimation, as a result of the KR content provided (i.e., good or poor KR). Specificity of practice is typically defined as learning a skill that is specific to the sources of afferent feedback used to guide the learner's movement during practice (Trembley & Proteau, 1998). It is usually evidenced by the performance on a no-KR trial where performance will be proportional to the similarity of those conditions to that of the practice conditions (Lee & White, 1990). The specificity of practice hypothesis suggests that learning is most effective when practice sessions include environment and movement conditions which closely resemble those required during performance of the task - replicating the target skill level and context for performance (Schmidt & Wrisberg, 2004). For example, if a specificity of practice was found in the present study, participants that received KR after only good trials would have demonstrated greater performance estimation success of good trials compared to estimating poor trials during the no-KR trials (retention, transfer). The fourth prediction stated that the KR content (i.e., good or poor trials) would not differentially impact the success in participant performance estimation during all experimental phases (i.e., estimating good or poor trials) (indexed by proportion of trials guessed correctly). This prediction was supported; KR content did not differentially impact performance estimation. Moreover, there was no specificity of practice effect found, as those that estimated their good trials during acquisition were no better at estimating their good versus poor trials during retention and transfer, and vice versa.

A possible explanation for the absence of a specificity of practice effect during retention and transfer between the performance-estimation and non-estimation conditions is based on context-dependent memory. Context-dependent memory is described as a phenomenon in which cognitive processing is affected in subtle, and often important, ways by the environmental stimuli in which an experience occurs (Wright & Shea, 1991). Environmental stimuli are classified along intentional and incidental dimensions (Wright & Shea, 1991). Intentional stimuli are those that are explicitly identified as essential to task acquisition (for example, if a participant was placed into the performance-estimation good KR condition, the intentional stimuli would be good KR), and incidental stimuli are those that have to potential to become associated with a specific task because of their selective presence in the learning environment (for example, the perceived poor KR as there is an association with the task as a function of the KR condition) (Wright & Shea, 1991). In the present experiment, the intentional stimulus identified to the participants was based on the specific KR content provided (i.e., good or poor KR). As the learning process progressed, the performer began to simultaneously process some of the incidental stimuli along with the intentional stimuli. In the present experiment, we believe that participants that were primed to good KR for example, were simultaneously processing the incidental stimuli (i.e., poor KR), as a result, had similar performance-estimation abilities to the participants that were primed for the poor KR. It appears that the stable relationship between intentional and incidental stimuli allowed the individuals to utilize this information and to assist in the execution of an appropriate response during the retention and transfer periods (Wright & Shea, 1991).

A second explanation is based on the tenets of the schema theory (Schmidt, 1975b). Schema theory suggests the recognition schema is responsible for storing the relationship between the past-outcomes and the past-sensory consequences to plan the current motor action. The expected sensory consequence is the expected proprioceptive feedback, which should result if the desired motor outcome is achieved. We believe that having participants engage in performance-estimation, increased awareness of their proprioceptive feedback, and as a result, heightened participant’s error detection ability as a function of increased awareness to their proprioceptive feedback. Schmidt & White (1972) showed that subjects increased their sensitivity to the direction of their errors with practice, and supported the notion that the schema for response recognition was increasing in strength (Schmidt, 1975). Previous research has examined error detection immediately after a response has been made. However, in the present experiment, participants were required to estimate their performance (i.e., good or poor trials) in which they were primed for at the completion of six trials. Although it has been shown that error detection improves over acquisition, the findings from the present thesis are consistent and extend Guadagnoli & Kohl (2001) study as the present experiment had a 5 trial delay prior to providing KR. This is an interesting finding, as the results of this experiment suggest that with trial delay, the recognition schema is still being strengthened.

CHAPTER 6: CONCLUSIONS

6.1 Future Research

Future studies examining error-detection abilities and cognitive effort should examine the differences found between performers that are explicitly aware of their KR conditions to those unaware of the KR received. Based on the findings of this thesis, it appears that all performers learned the task, indexed by increased accuracy and consistency during retention and transfer tests. Therefore, examining whether awareness of KR content would have a greater impact on motor learning may be fruitful for future studies. The current study has extended previous research by offering insight into motivation levels as a function of the practice condition. The use of questionnaires during retention and transfer tests might shed light onto the differences observed compared to the acquisition period. It would be beneficial to expand the questionnaires, if examining estimation abilities, to allow performers to rank how confident they are in their estimation abilities. Through the use of this expanded questionnaire, this will give insight into confidence levels associated with motivation which may be a factor modulating motor learning. Finally, future investigations of performance-estimation in motor learning should explicitly attempt to capture the mechanisms responsible for the learning benefits performance-estimation as this will extend our knowledge in the development of more effective rehabilitation, vocational, and recreational programs.

6.2 Practical Application

The current thesis has extended our knowledge and may benefit the development of more effective rehabilitation and recreational programs. One factor to consider when designing a rehabilitation program may be to have patients estimate how successful they are completing a task. For example, have post-reconstructive ACL patients estimate the degrees of flexion gained after each treatment. Based on the findings on the current thesis, we suggest that this may maintain a high level of motivation throughout treatment; as a consequence the patient is being subconsciously primed to successful accounts of their recovery. The practical importance of this thesis to benefit recreational programs may be to provide feedback after successful attempts during practice. For example, when learning a new dribbling technique in soccer, the coach should provide feedback when the performer has completed the technique successfully. Thus, reinforcing the correct motor response for upcoming trials.

6.3 Limitations

The current thesis had several limitations. One factor to consider in future investigations is the attention to focus on the questionnaires. Motivation was the subjective variable being measured in the self-reported questionnaires. All participants were required to self-report their motivation levels throughout the acquisition period. Two corresponding variables that could be added to the questionnaires is the feeling of knowing and confidence level measurements. With the combination of these measurements, the confidence and accuracy of the performers estimation may have a greater meaning during analysis. Another possible limitation in this study could have been including an unaware control condition. With the addition of this experimental condition, this would allow for a comparison of past research investigating whether being aware impacts success in performance-estimation. Previous research has shown that awareness is the modulating factor in motor learning, independent of KR content (Patterson & Azizieh, 2012). Future studies should investigate the differences in motor learning when performance-estimation and awareness are variables of interest.

6.4 Conclusion

The results of this thesis add to our theoretical understanding of the learning benefits of performance-estimation and good vs. poor KR in several different ways. Priming performers to specific KR content (i.e., good or poor trials) increased their ability to use intrinsic information to make accurate performance-estimations in no-KR retention tests, independent of KR content. The results of this study strengthen the growing body of evidence demonstrating the effectiveness of providing KR after good trials (Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2009), as the participants that received KR after relatively good trials had superior performance to those that received KR after relatively poor trials. The results of the current study are consistent with previous speculations regarding the long-term impact of motivation on motor learning. However, the benefits and longevity of motivation throughout the learning process is not well understood and consequently remains a fruitful area of further investigation.

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Appendix A

Motivation questionnaire (Lewthwaite & Wulf, 2010)

Please answer the following questions regarding your experience practicing the motor task.

	Questions	
Task-related responses	How motivated were you to learn this task?	1 | | | | | | | | 10 (not at all) (very)
	How much did you enjoy practicing this task?	1 | | | | | | | | 10 (not at all) (very)
Feedback-related responses	Did you find the feedback useful?	1 | | | | | | | | 10 (not at all) (very)
	Did you find the feedback motivating?	1 | | | | | | | | 10 (not at all) (very)
	Would you have preferred not to receive feedback?	1 | | | | | | | | 10 (not at all) (very)

Note: Responses for each question could range from 1 = “not at all” to 10 = “very”.

Appendix B

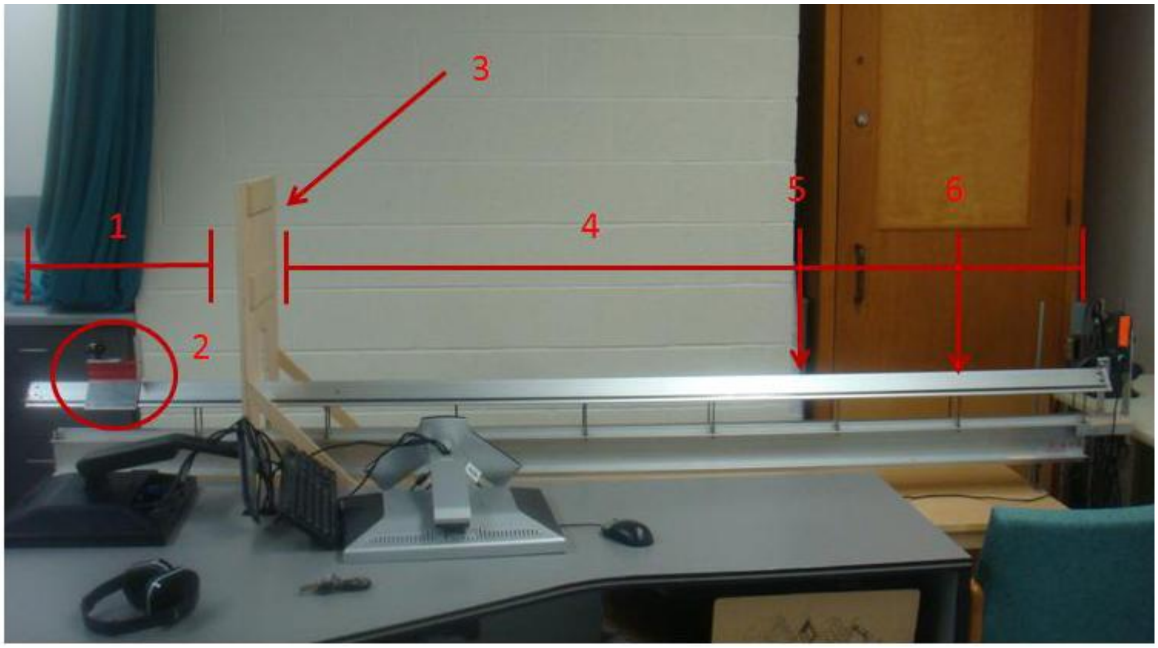
Feedback questionnaire:

Please answer the following questions regarding your experience practicing the motor task.

Identify (circle) the content of your feedback display during practice of the motor task.	Good trials only Poor trials only
If you had the choice, when would you have preferred to receive feedback? (please select one option from the list in the right hand column):	1. after only successful (e.g., good) trials 2. after only unsuccessful (e.g., poor) trials 3. randomly 4. after good and poor trials equally 5. other:__________________

Appendix C

Image of task apparatus



Note. 1 - Warm-up area; 2 - Slide; 3 - Wooden barrier; 4 - Scoring zone; 5 -Approximate acquisition and retention goal; 6 - Approximate transfer goal

Appendix D

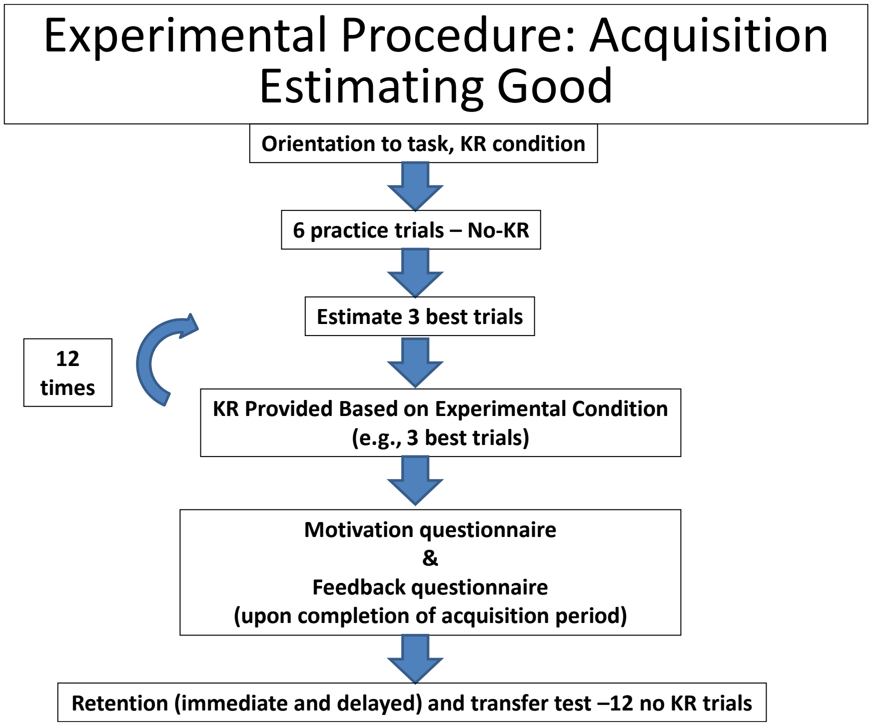
Image of Vernier Motion Detector

Appendix E

Image of Vernier LabPro

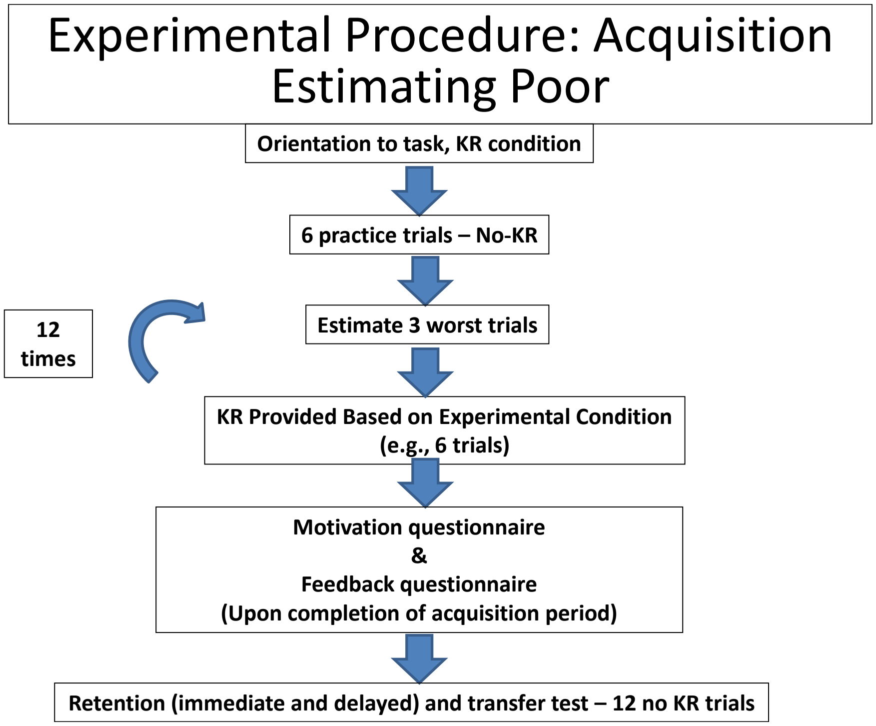
Appendix F

Acquisition: Estimating good



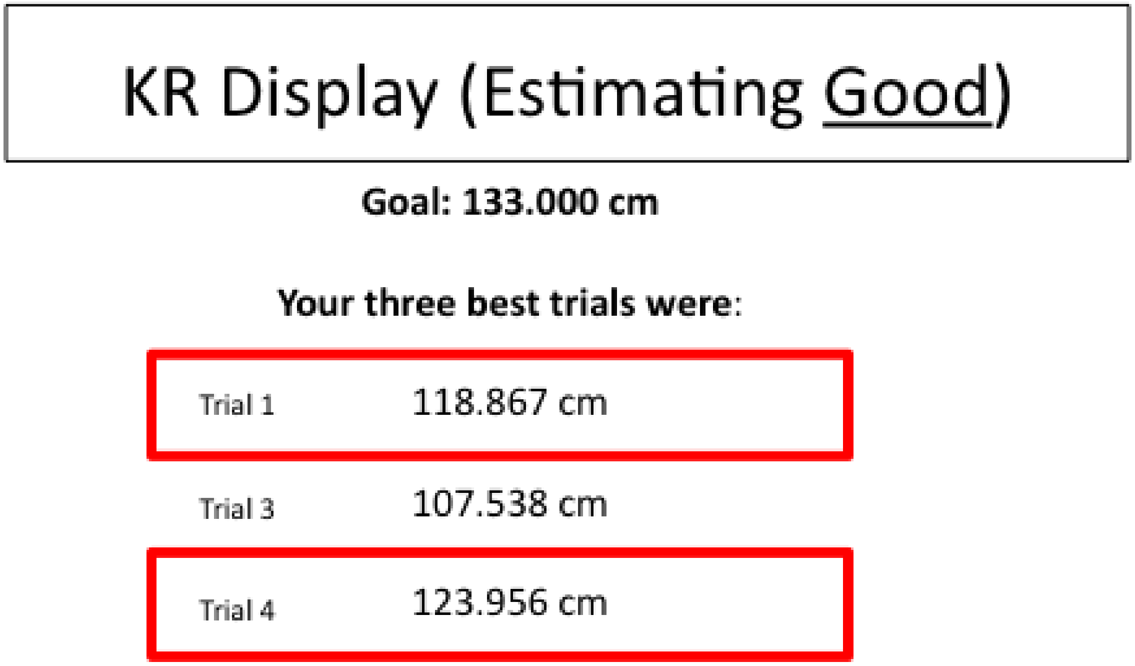
Appendix G

Acquisition: Estimating poor



Appendix H

KR display: Estimating good



KR Display (Estimating Good)

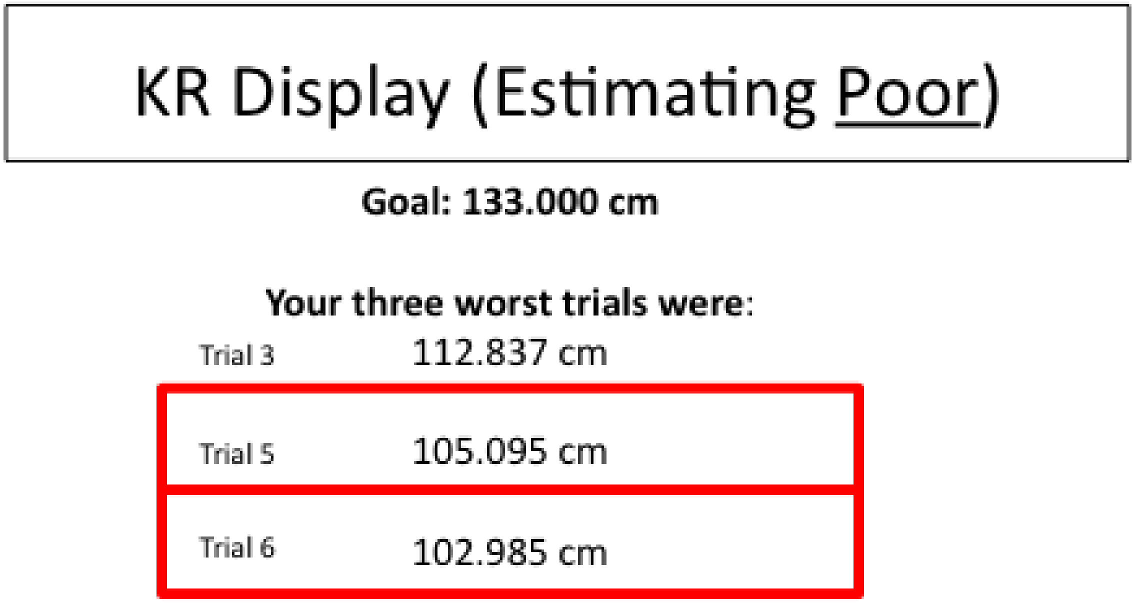
Goal: 133.000 cm

Your three best trials were:

Trial 1	118.867 cm
Trial 3	107.538 cm
Trial 4	123.956 cm

Appendix I

KR display: Estimating poor



KR Display (Estimating <u>Poor</u>)

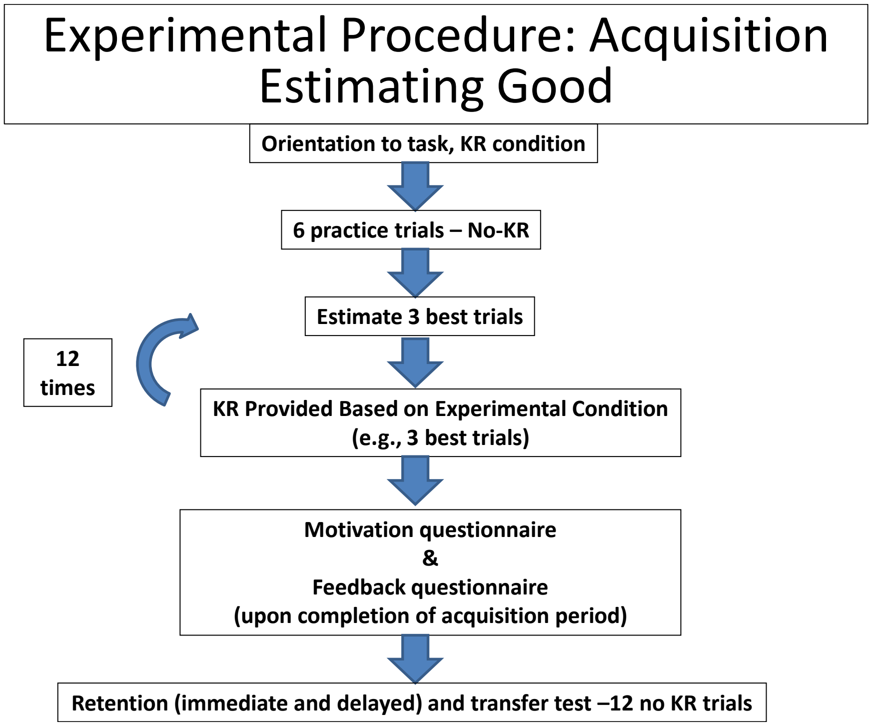
Goal: 133.000 cm

Your three worst trials were:

Trial 3	112.837 cm
Trial 5	105.095 cm
Trial 6	102.985 cm

Appendix J

Acquisition: Not estimating good and poor



Appendix K

KR display: Not estimating good

KR Display (Not Estimating Good)

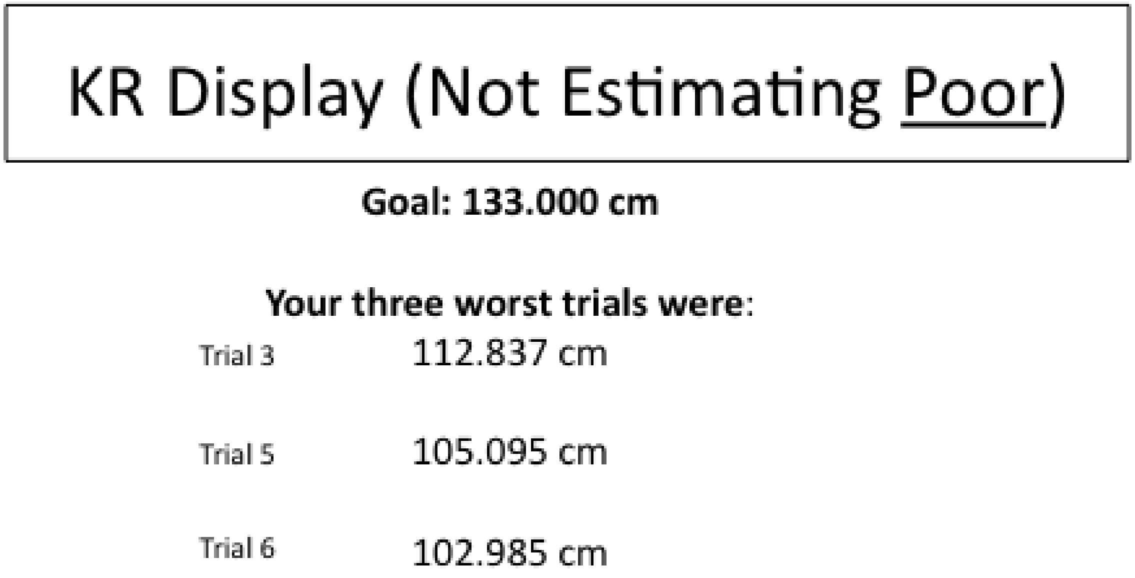
Goal: 133.000 cm

Your three best trials were:

Trial 3	112.837 cm
Trial 5	105.095 cm
Trial 6	102.985 cm

Appendix L

KR display: Not estimating poor



KR Display (Not Estimating Poor)

Goal: 133.000 cm

Your three worst trials were:

Trial 3	112.837 cm
Trial 5	105.095 cm
Trial 6	102.985 cm