PERCEPTIONS OF PERFORMANCE SUCCESS AND MOTOR LEARNING

by

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Abstract

Though acknowledged to play a role in motor learning, motivation was thought to mainly exert temporary energizing effects on performance. More recently, motivational-related factors have been shown to impact motor learning more directly. Perceptions of success, somewhat independent of actual success and errors in practice, have impacted what learners retain over time. The aim of my thesis was to study how motor learning is affected by the subjective perceptions of errors and success over the course of learning and to test between competing theories and mechanisms which might underlie such advantages. In Studies 1-3, I manipulated dart-throwing practice difficulty by varying distance progressions (near-to-far/easy-to-difficult or far-to-near) and target size (large or small). These manipulations had no impact on performance or learning in all three studies, despite the fact that in Studies 2 and 3, perceptions of success had changed (i.e., perceived self-efficacy and competency). Due to the saliency of veridical error feedback (i.e., actual landing position), which could have moderated the effects of target size manipulations and the variability inherent in dart throwing accuracy, in Studies 4 and 5 I switched to study learning on a balance task. I manipulated the criteria used for feedback about success (accuracy) and compared groups that differed on the stringency of this criteria (fixed across practice or increasing/decreasing). Neither absolute changes to feedback, nor changes in the stringency affected behavioural measures of learning. Study 5 was a replication and extension of a well-cited study claiming benefits for comparative (better or worse than average), success-related feedback. Despite our ability to successfully change competency perceptions and intrinsic motivation, I did not replicate the behavioural results in terms of improved learning. Overall, these studies do not support predictions emanating from current theories about errors, success and learning (i.e., OPTIMAL theory and reinvestment theory). For success manipulations to impact learning behaviours, it is likely that tasks or groups are required where motivation to do well is low to start and/or no other performance indicators are present. Given these current data, I would recommend that efforts be directed to learning improvements through changes to actual behaviours, rather than perceptions.

Lay Summary

Motor learning has been shown to be enhanced when error perceptions are reduced or when success perceptions are elevated through practice manipulations, even if actual performance is unaffected. The aim of my thesis was to study how learning is affected by the subjective experience of errors or success over the course of practice and to test potential mechanisms which might explain such effects. I manipulated practice during learning of dart-throwing and balance tasks, such that participants practiced with easy versus difficult versions of the task, or performance feedback indicating good or poor performance. Although actual success and perceptions of competency were affected as expected by the manipulations, contrary to other reports in this research area, behavioural indices of motor learning were not. We concluded that perceptions of success are not as impactful on motor learning as suggested and practitioners should look for more direct behavioural changes to bring about learning.

Preface

The studies in this thesis were conducted in the Motor Skills Laboratory at the School of Kinesiology, University of British Columbia (UBC). Approval to conduct these studies was obtained from UBC's Behavioural Research Ethics Board. Studies 1-3 (Chapters 2-4) were approved under Ethics Certificate H12-03325 "Errors in motor learning – Darts". Studies 4 and 5 (Chapter 5) were approved under Ethics Certificate H14-01923 "Balance Study – Feedback".

I was responsible for the bulk of the experimental design, data analysis and written report, as well as approximately 60 % of the data collection. My thesis supervisor, Dr. Nicola Hodges, helped me on the experimental design and data analysis, and edited all the chapters of this thesis. The members of my supervisory committee, Drs. Romeo Chua and Lara Boyd, advised on the progress of my studies, and gave valuable input. Research assistants that worked at the Motor Skills Laboratory provided essential help with data collection for Studies 1 and 3 (Anthony Sze, Daniel Ho and Jamie Hawke) and Studies 4 and 5 (Emily Brewer and Teresa Chang).

A version of Chapter 3 (Study 2) has been published in Frontiers in Psychology: Ong, N. T., Lohse, K. R., & Hodges, N. J. (2015). Manipulating target size influences perceptions of success when learning a dart-throwing skill but does not impact retention. *Frontiers in Psychology*, *6*: 1378. I conducted all the data collection, analysis and wrote most of the manuscript under Dr. Hodges' guidance. Drs. Hodges and Lohse, and I contributed to the design of the study.

A version of Chapter 5 (Studies 4 and 5) has been published in the Journal of Motor Behavior: Ong, N. T., & Hodges, N. J. (2017). Balancing our perceptions of the efficacy of success-based feedback manipulations on motor learning. *Journal of Motor Behavior*. doi: 10.1080/00222895.2017.1383227. Research assistants, Emily Brewer and Teresa Chang, and I were equally involved in data collection for Studies 4 and 5. I completed the majority of the data analysis and manuscript composition with editing assistance from Dr. Hodges. Dr. Hodges and I contributed to the design of Studies 4 and 5.

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List of Symbols

d	Cohen's d
n	number of participants
p	p-value
η^2_p	partial eta squared
r	Pearson's correlation coefficient

List of Abbreviations

AE	absolute error
ANOVA	analysis of variance
CE	constant error
CI	contextual interference
CSAI-2	Competitive State Anxiety Inventory
EDA	electrodermal activity
EMG	electromyography
F	F ratio
HR	heart rate
IMI	Intrinsic Motivation Inventory
KR	knowledge of results
M	mean
Mdn	median
MPF	mean power frequency
RE	radial error
RM	repeated measures
RMSE	root mean square error
SD	standard deviation
SE	standard error
SMS	Situational Motivation Scale
TOT	time-on-target
VE	variable error

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Throughout my PhD, I received valuable assistance from a number of people at the University of British Columbia. First and foremost, my research supervisor, Dr. Nicola Hodges, mentored, encouraged and helped me every step of the way. I still do not know how she does it – stay abreast on multiple lines of research, manage a productive laboratory, supervise/co-supervise a dozen or more graduate students and research assistants at a time, teach in the university and handle a load of administrative work, consult with the national women's soccer team, attend to the needs of her family and still train and play in a local soccer league. Thank you, Dr. Hodges. You are an inspiration.

Many thanks also go to Dr. Keith Lohse, who generously provided technical and statistical assistance, as well as input on study design; Drs. Romeo Chua and Lara Boyd, who offered much appreciated feedback on data analysis and the overall progress of my thesis; research and technical assistants that helped with the crucial programming, data collection, extraction and other miscellaneous processes: Graeme Kirkpatrick, Ruslan Amarasinghe, Anthony Sze, Daniel Ho, Jamie Hawke, Emily Brewer and Teresa Chang; my peers who were a source of academic and social support throughout my PhD: Brendan Cameron, Melanie Lam, Jarrod Blinch, Desmond Mulligan, Paul Campagnaro, David Hendry, Tom Coppola, Beverley Larssen, April Karlinsky, Chris Forgaard, Shawn Hetherington and Brennan Chan.

Dedication

Without the support and understanding of my family (especially my sisters in Singapore who care for our parents), I wouldn't have had this opportunity to seek further education so far away from home. Their blessings gave me the opportunity for adventure in Vancouver, to meet amazing people from all over the world, and experience the fantastic outdoors of South Coast BC. I am grateful for my parents, sisters, brothers-in-law, nephews and niece, cherished lifelong friends in Singapore and those I've met in UBC through St. John's College and the Varsity Outdoor Club.

To the memory of Stephanie Grothe and her unwavering optimism in life that reminds me... there's a positive side to everything.

1 Introduction

"To err or not to err?" Researchers and practitioners have long questioned the optimal method of instruction with regards to error committal. While instructing, coaches and teachers have to decide between provision of guidance or prescriptive information leading to error-reduced practice, or constructing a discovery, trial-and-error type of practice leading to the experience of more errors than in guided learning (see Ohlsson, 1996). The choice of instruction seems to depend largely on the goal of learning and type of task to be learned, although as will be apparent from this review, an error-strewn or error-reduced practice can impact learning beyond more traditional notions of a change in current performance. In this introduction I will first briefly discuss errors in learning from a more traditional, information processing perspective. Following that, I review the impact of errors, and importantly the subjective experience of error or success on motivation and perceived competency/efficacy, and highlight the reciprocal relationship between the latter two constructs. Finally, I discuss the topic of reward with respect to perceptions of success (and failure), and how it might affect the retention of skills through motivational processes that impact memory and more specifically, motor skill consolidation.

1.1 Rationale for Encouraging Errors

1.1.1 Schema theory

Indirect support for error committal in motor learning may be extrapolated from Schmidt's schema theory (1975). To produce a particular variant of a motor skill or "generalized motor programme" (GMP), it was said that specific parameters (e.g., absolute timing, absolute force) were to be assigned to invariant features (e.g., relative timing, relative force) of the GMP. A rule or schema is thought to capture the relationship between factors, such as initial conditions, sensory feedback, and outcome consequences, pertaining to the parameters assigned to the GMP during skill practice. Exploring the relationship between multiple assignments of parameters and these factors is believed to strengthen the exactness of the schema.

Based on the principles of schema theory, motor learning researchers have examined variations of skill practice that involved constant practice of one variant (applying the same parameters) of a motor skill, such as making a regulation free throw in basketball, or variable

practice of the skill (applying different parameters), such as making free throws at different distances to the basket. According to schema theory, variable practice that leads to more errors in performance would result in the formation of a more precise and appropriate schema than constant practice, which would likely minimize error in performance but result in a less accurate schema. This is known as "acquisition-retention reversal", i.e. poor or good practice performance respectively leading to reversed good or poor retention performance. Indeed, researchers showed that even variable practice that did not involve the test variant of a motor skill led to an acquisition-retention reversal (e.g., Shea & Kohl, 1991). Other than a more robust retention, variable practice also allows greater generalizability of skill, enabling more accurate productions of motor skill variations that were never performed (e.g., Catalano & Kleiner, 1984).

1.1.2 Cognitive effort

The acquisition-retention reversal has also been reported in the contextual interference (CI) literature, examining the effects of blocked practice against random practice conditions (for reviews see Lee, 2012; Lee & Simon, 2004, Magill & Hall, 1990). When learning several motor skills, overall performance tends to be more accurate on a blocked schedule of practice ("blocked practice", performing all trials of one skill before switching to the next skill) than a random schedule ("random practice", interspersing the practice trials of all skills so that each skill is typically not repeated more than once). Random practice is believed to generate greater CI compared to blocked practice due to more frequent switches between skills. However, on retention or transfer tests, these performance effects are normally reversed (again the acquisition-retention reversal), suggesting that the presence of greater interference and error in practice leads to more long lasting learning benefits. It was postulated that random practice was more likely to promote cognitive processing and understanding of each skill ("elaborative processing hypothesis") or/and heighten cognitive effort in organizing plans of actions during practice ("forgetting and reconstruction hypothesis"; see Schmidt & Lee, 2011). In general, it is said that conditions that make practice more challenging or difficult, and potentially more "errorful" (error-strewn), are more beneficial to motor learning (Lee, Swinnen & Serrien, 1994).

There is some counter-evidence to the claim that random practice conditions facilitate learning because they promote more cognitive effort. It has been suggested that random practice

conditions may somewhat counter-intuitively induce a form of implicit learning (Rendell, Masters, Farrow & Morris, 2011), defined as the capacity to learn without awareness of the products of learning (e.g., Reber, 1967; Willingham & Goedert-Eschmann, 1999). Hence, participants who learn implicitly accrue little explicit knowledge relevant to task performance while procedural knowledge is gained and demonstrated through performance improvement. After random and blocked practice of an Australian Rules Football kicking and handball skill over 4 weeks (Rendell et al., 2011), a random practice group did not perform worse than a blocked practice group during acquisition (a result not consistent with the majority of the CI literature), but showed significant learning benefits on the kicking task in retention (a result consistent with most CI literature). In further assessment of learning, the random practice group showed no decrement in accuracy (in fact an improvement in performance) for the kicking task when tested under attention demanding conditions, and tended to report fewer task relevant rules and hypotheses than the blocked practice group. This combination of results led the authors to conclude that random practice benefited motor learning through implicit processes, rather than heightened cognitive processing. It was thought that random practice limited accrual of explicit knowledge because of the frequent switches between tasks, preventing deeper processing of information due to attentional overload. However, there were other outcomes in the study that were incongruent with this conclusion. The inter-trial probe reaction times reported for the random group were greater than the blocked practice group during practice. This is typically considered as evidence that the former group was engaged in more attentionally-demanding, cognitive processes during the inter-trial period (e.g., Abernethy, Hanna & Plooy, 2002; Kahneman, 1973; Starkes, 1987). The lack of practice performance differences in the random and blocked practice groups suggests that there was insufficient CI in the practice of these tasks to cause a significant decrement to the random group's performance. There were only two tasks practised in this study, compared to three tasks tested in other studies examining CI (e.g., Hall & Magill, 1995; Lee & Magill, 1983; Shea & Morgan, 1979), and the repetition constraint for random practice (same task not repeated more than 3 times) was more liberal than the typical constraint (same task not repeated more than once), likely leading to lower interference than seen in other studies.

Another line of research which supports the proposal that tasks high in cognitive effort and processing are good for long-term learning is related to augmented feedback in motor

learning, such as the frequency and timing of augmented feedback (or knowledge of results, KR, which is feedback about outcome success). Augmented feedback plays a guidance role and benefits practice performance because errors are highlighted and corrected. However, when given too soon or too frequently, it can be detrimental to learning, eliciting an acquisition-retention reversal discussed earlier in studies of variability of practice and CI. For example, more frequent KR (e.g., 100 % KR) is detrimental to learning relative to less frequent KR (e.g., 50 %; Sullivan, Kantak & Burtner, 2008; Winstein & Schmidt, 1990). Withholding KR or providing summary feedback only after several trials has a similar effect to decreased frequency of augmented feedback, compared to providing KR on immediate conclusion of every trial (e.g., Schmidt, Young, Swinnen & Shapiro, 1989; Swinnen, Schmidt, Nicholson & Shapiro, 1990).

According to the guidance hypothesis (Winstein & Schmidt, 1990), the prescriptive aspect of KR prevents individuals from processing their own intrinsic feedback, thus impairing error detection and correction processes. The result is that learners become overly dependent on the extrinsic KR feedback and are unable to apply appropriate adjustments or corrective strategies when this source of feedback is unavailable. Therefore, high frequency of KR leading to low experience of errors in practice has negatively impacted retention. When participants have been asked to estimate their error on each trial before receiving KR on 100 % of the trials, the negative retention effects of practising with a high frequency of KR was reversed (e.g., Guadagnoli & Kohl, 2001). Here, engaging in effortful activities related to detection of error was useful for learning. Delaying or withholding augmented feedback results in learning benefits, which are often elicited at the expense of practice performance, and are in opposition to views in favour of "errorless" (i.e. error-reduction) protocols. In conjunction with other principles of learning, such as contextual interference and the schema theory, the guidance hypothesis of augmented feedback supports error committal and conscious processing of error in aiding motor learning.

1.2 Rationale for Error Minimization

1.2.1 Frequency of correct responses

Reverse support for error committal in motor learning is offered by Adams' closed-loop theory (1971). It was postulated in this theory that a perceptual trace is laid down in memory for every

trial of a skill performed. In initial learning when an individual does not possess prior, correct experience of a motor skill, the perceptual trace of the correct movement is weak as there are relatively few correct movement traces compared to incorrect traces. By later stages of learning, when an individual has accumulated a relatively large number of correct perceptual traces to incorrect ones, the correct perceptual trace is strong and skill execution is more likely to be accurate. Therefore, based on Adam's closed-loop theory, a high frequency of correct movements is to be encouraged during motor skill practice, for effective learning and accurate reproduction of a skill.

Proponents of error minimization also refer to neurobiological work on associative or Hebbian learning (Hebb, 1949) to support their case. During learning (or conditioning), when a neuron fires and elicits activity in another, or when a stimulus elicits a certain pattern of neural activity, the synaptic connections between these neurons strengthen so that the stimulus input will tend to elicit the same pattern of neural activity on subsequent occasions. Repeat elicitation of pairings will be strengthened, regardless of outcome efficacy. Accordingly, synaptic pairings associated with incorrect performances are undesirable for learning. Both Adams' closed-loop theory and Hebbian learning validate the conventional wisdom that 'bad' habits are hard to break and would therefore encourage the use of errorless protocols in motor learning.

1.2.2 Implicit motor learning

Distinct from guided or prescriptive errorless learning whereby participants learn in an explicit mode, i.e., are consciously aware of knowledge relevant to the skill they have acquired while making few errors (hence explicit errorless learning), in implicit errorless motor learning participants acquire the task with few errors and without conscious task-relevant knowledge. Hence the extent of implicit learning in participants is typically reported by comparisons against the effects of explicit learning in other participants. One method used to quantify the extent of explicit learning is by the amount of explicit, task-relevant knowledge accrued. Participants are interviewed for verbalizable, task-relevant rules and hypotheses they had generated and tested on the skill (Frensch & Rünger, 2003). In patients with amnesia, errorless rather than errorful learning has consistently produced benefits for acquiring new motor skills or information (e.g., Page, Wilson, Shiel, Carter & Norris, 2006; Squires, Hunkin & Parkin, 1997), even if patients

can neither recollect the learning experience nor verbally report explicit knowledge relevant to the skill.

Implicit learning methods have been used to train participants in motor learning research. It has been found to be particularly useful for preventing performance decrements when participants perform under high stress (e.g., "yips" or choking) or under task demands that exceed attentional capacity (e.g., Masters, 1992). One method used to induce implicit learning was to train individuals on a primary motor task while simultaneously engaging them in a cognitively demanding secondary task (i.e., dual-task practice). Performing the additional cognitive task prevented the build-up of explicit, task-relevant knowledge about the primary motor task, functioning like a blockage to declarative memory (akin to memory-impairment experienced by amnesic patients). According to reinvestment theory, performers choke under pressure because of the tendency to revert the control of an automatized motor skill (one that is well-learnt and performed with minimal attentional demands) back to declarative, step-by-step explicit control (Masters & Maxwell, 2008). In a number of studies, Masters and colleagues have shown that by preventing the acquisition of explicit, task-relevant knowledge, performers were inoculated against disruptions to performance, as they had no conscious access to knowledge that they may 'reinvest' under pressure or additional cognitive loads (Masters & Poolton, 2012).

Although the dual-task training method was effective for inducing implicit learning, this form of training impeded progress in skill acquisition (more than the normal progression seen in single task training) and could potentially de-motivate learners (see Section 1.4). To overcome these constraints, Maxwell, Masters and colleagues (Maxwell, Masters, Kerr & Weedon, 2001) devised an errorless practice protocol that encouraged a more implicit mode of learning without causing unnecessary delays in improvement associated with high attentional loads in dual-task methodologies. By manipulating the order to which task difficulty progressed during practice, easy-to-difficult progression groups experienced fewer errors in practice compared to difficult-to-easy progression groups. The former groups also reported fewer explicit task-relevant rules and hypotheses, and learning appeared to be more robust over time and when tested under transfer conditions that evoked pressure or cognitive load (Capio, Poolton, Sit, Eguia & Masters, 2013a; Capio, Poolton, Sit, Holmstrom & Masters; 2013b; Lam, Maxwell & Masters, 2010; Masters & Maxwell, 2008; Poolton, Masters & Maxwell, 2005). For example, in one study, an

easy-to-difficult practice group performed with less error (fewer target misses; named errorless group) in practice and in retention (Maxwell et al., 2001). The primary task performance for this errorless group also did not deteriorate during a dual-task test involving a secondary cognitive task, implying that performance of the primary task did not require the full cognitive capacity of this group. Meanwhile, greater error was made by the difficult-to-easy group (named errorful group), and interference was shown in this errorful group during dual-task performance, indicating that this group was performing the primary task at full (or close to full) cognitive capacity. Masters and colleagues have also provided evidence that the timing of explicit knowledge accrual affects later performance, particularly under dual-task conditions (Poolton et al., 2005). Early explicit knowledge (manipulated through instruction provision) was worse for performance in subsequent dual-task conditions, than later-given explicit instruction, even though both groups performed an easy-to-difficult or an errorless (as considered by the authors) practice protocol. The authors argued that the absence of early instructions for the latter group prompted implicit learning and greater automaticity in the primary task, despite the subsequent provision of explicit instructions/knowledge later in practice. In addition to error rates, it also seems likely that these task difficulty progressions would affect individuals' perceptions of success and motivation, although to date this has not been directly measured. The hypothesis that success perceptions and motivation may provide an additional or alternative account for this errorless learning phenomenon was explored in Study 1.

Another version of task difficulty progression was administered on children learning beanbag throwing with changes to target size (going from small-to-large or large-to-small), rather than target distance (Capio et al., 2013a, 2013b). Participants in the easy-to-difficult (large-to-small target) progression were less errorful during practice (i.e. made more target hits) and in retention and secondary task tests at the same target distance than those who practiced a difficult-to-easy (small-to-large target) progression. As there was no online control of the ball once it left the participant's hand, the "objective" target centre was always 5 m from the participants at a height of 0.8 m from the ground, regardless of target size. The only differences across practice blocks were subjective difficulty and the subjective interpretation of outcome success when targets were hit. Again, it was concluded that the costs of difficult-to-easy target progressions were primarily due to the additional cognitive effort and explicit rule and hypothesis testing associated with this type of practice progression. An outstanding question is

whether greater subjective success would result in more robust learning effects were the same level of objective performance achieved by the opposing groups in practice. In the errorless protocols above, the easy-to-difficult group experienced less error in acquisition than the opposite progression group. Thus the retention data generally reflected this poorer acquisition performance. In Studies 2 and 3, we administered an errorless practice protocol without progression in task difficulty. By assigning participants to practise on either an easy or large target (errorless group) or a difficult or small target (errorful group), we maximized the difference in error or success rates experienced between the groups. The objective error, in reference to the centre of the target, should not be different between the groups in practice (see details in Section 1.4.2 on task difficulty), as they should always be aiming for the centre of the target.

1.3 Goal of Learning

With due consideration to theory and empirical evidence for and against error minimization, it seems apparent that the goal of learning would be an important consideration for instructors and coaches when structuring practice and providing instruction. Singer (1977) indicated that guided instruction (i.e., prescriptive, errorless learning) would be most beneficial for the learning of 'closed' skills, where the environment of skill execution is predictable and stable. If the goal of learning is to produce only one variant of a motor skill accurately and consistently, practice protocols, such as constant and blocked practice, leading to minimal errors is likely to enhance parameterization for the specific skill variation (see Keetch, Schmidt, Lee & Young, 2005 on "especial skills"). On the other hand, errorful, trial-and-error type practice conditions would benefit 'open' skills (i.e. skills performed in constantly changing or unpredictable environments) so that learners are more adaptable to change in environmental conditions. If the goal of learning is to be able to apply different parameters to a GMP in a variety of contexts, self-discovery and errors should be encouraged during motor practice.

Although we may glean much information from making errors, such as what not to do and what corrections to make, frequent and large-magnitude errors may cause doubts in one's competency and potentially diminish motivation towards practice. While subjective perceptions or interpretations of performance success are normally tied to objective error outcomes (e.g.,

absolute error in spatial accuracy or movement time), these perceptions are not only influenced by information on objective absolute error. Other factors, such as self and social/normative comparisons, goal-setting and outcome expectations, also influence subjective interpretations of success. In addition to studying the informational impacts of error in practice, potential psychological or motivational impacts of success should be considered.

In the following sections I briefly review the self-determination theory of motivation (Deci & Ryan, 2000) and the OPTIMAL theory (Wulf & Lewthwaite, 2016; Lewthwaite & Wulf, 2017), and present behavioural research pertaining to practice manipulations that have modified learners' perceptions of success/competency and affected motor learning. Next, links between success/competency perceptions, memory consolidation processes, rewards and neurophysiological research related to reinforcement learning and dopaminergic systems are discussed. Finally, the research plan and brief rationale for the five studies I have conducted are described.

1.4 Effect of Success on Motivation and Learning

The psychological construct of motivation refers to the direction, intensity and persistence of effort in a certain behaviour (Vallerand & Thill, 1993 as cited in Crocker, 2007). Whilst acknowledged to play an important role in motor performance and learning, motivation was thought to exert temporary energizing effects on performance or influence motor learning through the extra practice that motivated learners were engaged in (Lewthwaite & Wulf, 2010b). More recently, with the absolute amount of practice controlled for, researchers examined more permanent impacts of motivation on learning, and the study of motivational processes started to gain some ground in the information-processing dominated field of motor learning and control (Lewthwaite & Wulf, 2012). For instance, we now know that perceptions of autonomy or competency (see self-determination theory and OPTIMAL theory in the next section) affect what is learned and retained (e.g., Chiviacowsky & Wulf, 2002; Saemi, Porter, Ghotbi-Varzaneh, Zarghami & Maleki, 2012; Trempe, Sabourin & Proteau, 2012; Wulf, Chiviacowsky & Lewthwaite, 2010, 2012). Given these findings, we might expect competency judgments to covary with the learner's experience of errors, such as objective error, perception of success in relation to a goal/criterion, perception of success in relation to others (social comparison), or

perception of success due to performance improvement (self-comparison). We also know that reward and positive feedback can directly impact motor learning through motivational processes.

1.4.1 Motivation towards competence/efficacy

According to Deci and Ryan's self-determination theory of motivation and personality (2000; 2008; Ryan & Deci, 2000), human beings are inherently driven to satisfy three basic psychological needs; competence – a need to feel effective in one's interactions with the environment and experience opportunities to express one's capabilities; autonomy – a need to experience one's own behaviour as originating from the self; and relatedness – a need to feel a sense of belonging and connectedness with others. Hence, individuals are motivated towards actions/behaviours that satisfy these needs and reciprocally, motivation towards particular actions that leads to satisfaction of needs is further enhanced when these needs are fulfilled. The psychological need for competency is particularly relevant to the study of errors and success in motor learning. An individual's perception of competency is essentially the concept of self-efficacy, which is defined as the belief or confidence in one's capabilities to organize cognitive resources and execute courses of action required to meet situational demands (Wood & Bandura, 1989). In a number of studies, self-efficacy has been operationally defined as "task-specific confidence" (e.g., Hutchinson, Sherman, Martinovic & Tenenbaum, 2008; Zimmerman, 2000). According to Bandura (1997), there are four sources informing self-efficacy beliefs: mastery experiences, vicarious experiences, verbal persuasion (feedback) and physiological and affective states. Mastery experiences (i.e., experience of success/error) and verbal persuasion (e.g., social comparative feedback) are particularly relevant to perceptions of competency or self-efficacy and will therefore be discussed in greater detail than the other sources of self-efficacy below.

Perceptions of competency or self-efficacy influences an individual's motivation – i.e., choice of activities, effort, persistence – and performance (Bandura, 1997). Hence someone who is strongly efficacious towards a task would tend to persist longer, exert more effort and achieve better performance on the task. For instance, intrinsic motivation was mediated by perceived competency in a stabilometer (also "stabiliometer" or stability platform) balancing task, with positive feedback increasing both perceived competency and intrinsic motivation, while negative feedback decreased them (Vallerand & Reid, 1984). Similar to the bidirectional relationship

between psychological needs and motivation, self-efficacy is largely influenced by past mastery experiences (Bandura, 1997, 1998). Self-efficacy beliefs (and past achievements) appear to be positively correlated and/or predictive of performance and goal attainment in various domains including: cognitive/academic tasks (e.g., Pajares, 1996; Schunk & Swartz, 1993; Shell, Murphy & Bruning, 1989), work settings (e.g., Stajkovic & Luthans, 1998) and in motor skill learning (e.g., Bandura & Cervone, 1983, Jourden, Bandura & Banfield, 1991; Mitchell, Hopper, Daniels, George-Falvy & James, 1994; Stevens, Anderson, O'Dwyer & Williams, 2012).

1.4.2 Task difficulty

When faced with two versions of a task, one more difficult than the other, participants tend to perform better on the easier than the difficult task (e.g., Sanli & Lee, 2014; Stevens et al., 2012). Evidence is less clear as to whether the easy or difficult practice transfers better to a task of which difficulty is between the two practice versions (Holding, 1962). In an earlier section on implicit learning (see 1.2.2), studies involving task-difficulty practice progression (easy-to difficult or difficult-to-easy) were described. For example, in a beanbag throwing task, even though objective difficulty of the task did not change (i.e., the target centre was always 5 m away), progressing from an easy (large target) to difficult (small target) positively impacted practice, retention and dual-task performance in comparison to a difficult-to-easy progression (Capio et al., 2013a, 2013b). Visual illusions have also been used to impact perceived target difficulty and success, influencing both golf putting performance in practice (Witt, Linkenauger & Proffitt, 2012), and in retention (Chauvel, Wulf & Maquestiaux, 2015). The Ebbinghaus illusion of surrounding the putting (circular) target with larger circles made the target appear smaller, while surrounding the target with smaller circles caused it to be perceived as larger. Participants that putted to the perceived larger hole were more accurate in putting performance towards the end of practice and in retention than participants that practised on the perceived smaller hole (Chauvel et al., 2015). Reports of self-efficacy were greater in the perceived larger than perceived smaller hole group, suggesting that the visual illusion's impact on motor learning was mediated by psychological factors related to competency perceptions (rather than, or perhaps in addition to, more implicit learning and less error correction).

Without modifying the visual stimuli of the practice environment, other researchers have not reported immediate performance benefits when participants were tasked with an easy vs. difficult goal criterion. In a visuomotor adaptation protocol, where participants adapted their aiming to circular targets in a virtual environment that rotated visual feedback representing hand movement to the actual hand movement, the goal criterion was manipulated such that one group had to aim directly to the centre of a target, whereas a second group was allowed to aim to the edge of the target, thereby making their goal easier to achieve (Trempe et al., 2012). The group with the easier goal criterion experienced greater success than the difficult goal criterion group. Though actual objective performance was not different between the two groups, the easy-goal group showed significant savings during readaptation (i.e., retention) the next day, whereas the difficult-goal group did not. Because the only discernable difference between the groups was the frequency of successful trials experienced during practice and participants' quality rating of their practice performance, the authors suggested that success perceptions moderated what was consolidated over the retention interval. It was postulated that arousal levels or perceptions of success might have modulated consolidation processes (see Section 1.6). However, arousal was not assessed and no direct measure of success was collected during practice, and because no measure of explicit/strategic knowledge was taken, it remains possible that the poorer retention of the difficult-goal group was due to a more explicitly-driven manner of learning in comparison to the easy-goal group, that therefore impacted readaptation (which is more in line with the reinvestment hypothesis of Maxwell and colleagues, 2001).

Goal criterion was also manipulated in a coincident-anticipation timing task, without the alteration to environmental stimuli imposed by visuomotor adaptation tasks (Chiviacowsky, Wulf & Lewthwaite, 2012). Timing error was provided on some trials in the form of milliseconds the response button was pushed before or after stimulus arrival. One group was informed that a good trial was when absolute timing error was less than 4 ms (Difficult criterion group), and for another group the criterion of a good trial was more lax (Easy criterion group), it was less than 30 ms. Throughout practice, the groups were not different in objective performance, yet learning disadvantages surfaced during retention for the Difficult criterion group. At the end of practice, the Difficult criterion group also gave lower ratings of perceived competency, self-efficacy and task interest/enjoyment than the Easy group. Similar to the study by Trempe et al. (2012), motivational processes due to increased perceptions of success and

competency might have impacted consolidation processes and aided retention. Yet, like Trempe et al, this study did not measure changes in self-efficacy and perceived competency over practice, and the two self-efficacy probes were with regards to attaining absolute timing outcome of less than 30 ms and 50 ms, which were identical to and easier than the easy criterion respectively. If self-efficacy was obtained for more difficult targets (closer to 4 ms), the Difficult criterion group might have been more efficacious than the Easy criterion group. A greater range of attainment for measure of self-efficacy, such as suggested by Bandura (2006), would provide a less biased measure of the construct. I adopted this approach in the studies detailed in this thesis.

1.4.3 Positive feedback

Another method of manipulating perceptions of success and competency in motor learning is to selectively provide only feedback on the best or the worst performances, such as the best or worst three of six trials, with participants unaware of the manipulation (Abbas & North, 2018; Badami, VaezMousavi, Wulf & Namazizadeh, 2012; Carter, Smith & Ste-Marie, 2016; Chiviacowsky & Wulf, 2007; Saemi et al., 2012). Outcome error was often visually occluded or not clearly determined, resulting in considerable reliance on augmented feedback. Overall performance benefits have been reported for participants receiving "better" feedback on more accurate practice trials in tossing and golf-putting activities (Badami et al., 2012; Chiviacowsky, Wulf, Wally & Borges, 2009; Saemi et al., 2012). Even when practice error was not different between groups receiving better or "worse" feedback, the better feedback group outperformed the worse feedback group in retention (Chiviacowsky & Wulf, 2007). Further examination of selective feedback provision indicated greater reports of self-efficacy and self-confidence for the better feedback groups relative to the worse feedback groups.

Perceptions of competency have been influenced by social comparative feedback, which has been provided in addition to veridical outcome feedback in studies of motor learning. Whether provided on each trial or as summary feedback after a block of practice trials, positive social comparative feedback indicating that the individual is performing better than average has benefited performance and learning (e.g., Ávila, Chiviacowsky, Wulf & Lewthwaite, 2012; Chiviacowsky & Drews, 2016; Gonçalves, Cardozo, Valentini & Chiviacowsky, 2018;

Lewthwaite & Wulf, 2010a; Pascua, Wulf & Lewthwaite, 2015). For instance, participants in a stabilometer balancing task received veridical error feedback and fabricated "group average" feedback (social comparative feedback) on each trial, indicating that they were performing ~ 20 % better than their peers (Lewthwaite & Wulf, 2010a). The advantages of receiving such ego-comparative information were observed almost immediately compared to a negative social comparative feedback group (receiving fabricated feedback that their performance was worse than others) and a control group (only receiving veridical outcome feedback). The superior performance demonstrated by the positive group persisted in a retention test. In a related study by Ávila and colleagues (2012), summary positive social comparative feedback was provided after each practice block of 10 beanbag-tossing trials. While performance benefits were not observed for the positive social comparative group relative to controls, there was a delayed benefit for the former in retention and in post-practice reports of perceived competency. Besides the purported motivational effect of competency-related perceptions on learning, task mastery and positive social comparisons can impact learning through reward mechanisms (discussed later in Section 1.5).

1.4.4 OPTIMAL theory

Considering the impact of task difficulty, feedback and other practice manipulations on performance perceptions and motor learning, Wulf and Lewthwaite (2016) proposed the OPTIMAL (optimizing performance through intrinsic motivation and attention for learning) theory of motor learning, building on the theory of self-determination theory and research literature on reward. The OPTIMAL theory underscores the importance of improving motivation (by meeting the psychological needs of competence and autonomy), and adopting an external attentional focus to boost motor learning. Practice conditions, such as selective provision of feedback associated with better performance trials, positive social comparison feedback, and reduction in objective/subjective task difficulty as discussed earlier, that promoted enhanced expectations or anticipatory beliefs about future outcomes (e.g., self-efficacy) enhanced motivation and motor learning. Other practice manipulations, such as instructions influencing participants' conceptualization of ability as malleable (rather than fixed; Drews, Chiviacowsky & Wulf, 2013; Wulf & Lewthwaite, 2009), and self-modelling whereby learners watched videos of themselves only performing the skill(s) correctly (Clark & Ste-Marie, 2007) also resulted in

enhanced competency perceptions and learning. In addition to single practice interventions, learning benefits have also been demonstrated through the combination of two or more success-related or attentional focus manipulations, providing support for the OPTIMAL theory (e.g., Levac, Driscoll, Galvez, Mercado & O'Neil, 2017; Pascua, Wulf & Lewthwaite, 2015; Wulf, Chiviacowsky & Cardozo, 2014; Wulf, Lewthwaite, Cardozo & Chiviacowsky, 2018). According to the OPTIMAL theory, motivation and attention facilitate goal-action coupling through strengthening of neural activity and connectivity, and dopaminergic activity that reinforces learning/consolidation (also see Sections 1.2.1, 1.5 and 1.6). Besides neurophysiological influences, the theory also asserts that motivation and attention enhance learning through psychological factors, such as positive affect and goal setting, and cognitive factors, such as improved concentration and working memory.

1.5 Effect of Reward on Learning

Rewards are desirable outcomes that motivate certain behaviours, induce positive affect, and reinforce learning (e.g., Berridge & Robinson, 2003; Schultz, 1997, 2001). Traditionally, the use of rewards in educational settings was chiefly to motivate learners towards behaviour that aided learning, such as extra practice and effort. According to Thorndike's law of effect (1927), any behaviour that is rewarded (i.e., followed by a pleasant outcome) is more likely to be repeated in future. Likewise, in motor behaviour, actions or decisions leading to rewarding outcomes are more likely to be repeated. Rewards are typically in the form of monetary incentives (e.g., prize money, remuneration) or social rewards such as positive social or normative comparisons (e.g., placing first in a competition, higher ranking than peers), and praise for effort or improvement in performance.

Verbal persuasion in the form of performance-contingent feedback or reward also contributes to learners' self-efficacy for a task, especially if the information comes from a credible source, such as a coach, therapist or the experimenter in a research study. This informational aspect of feedback and reward improves perceived competency and intrinsic motivation, whereas rewards that are seen as controlling or the cause of one's behaviour can impede learning through diminished intrinsic motivation (e.g., Deci, Koestner & Ryan, 1999). Positive comparative feedback (or social reward) compared to none has generally resulted in

enhanced self-efficacy (e.g., Ávila et al., 2012; Hutchinson et al., 2008; Lewthwaite & Wulf, 2010a; Wulf et al., 2012), motivation and positive affect/arousal (e.g., Cioffi, 1991; Hutchinson et al., 2008), and benefits to performance (e.g. Hutchinson et al., 2008; Lewthwaite & Wulf, 2010a; Schunk, 1983), retention (e.g., Abe, et al., 2011; Ávila et al., 2012; Lewthwaite & Wulf, 2010a) and transfer of learning (e.g., Wulf et al., 2010). There is evidence that the dopaminergic system is involved in reinforcement learning, and it is likely that successful and rewarding events, as well as the anticipation of future rewards, facilitate learning through positive dopaminergic signaling that outcomes are better than expected (see Holroyd & Coles, 2002). Accordingly, when outcomes are worse than expected, negative dopaminergic signaling inhibits learning. Though we may expect negative comparative feedback and low perceptions of success to negatively impact learning, rather mixed findings have been reported for the effects of negative comparative feedback on performance and learning. Some studies have shown that negative comparative feedback lowered self-efficacy beliefs compared to a control or positive feedback groups (e.g., Bandura & Jourden, 1991; Hutchinson et al., 2008; Lamarche, Gammage & Adkin, 2011), yet there were instances where negative comparative feedback was found to have little impact on self-efficacy or behavioural measures of learning (e.g., Lewthwaite & Wulf, 2010a). In Study 5, I study the impacts of both positive and negative comparative feedback on learning.

Where the neurobiology of reward and reinforcement learning were studied, a number of brain areas and pathways have been implicated, including the nucleus accumbens, ventral tegmental area, striatum, amygdala, anterior cingulate cortex and a number of dopamine pathways (e.g., mesolimbic, mesocortical) (Hollerman, Tremblay & Schultz, 1998; Kawagoe, Takikawa & Hikosaka, 1998; Smith, Bennett, Bolam, Parent & Sadikot, 1994; Suri & Schultz, 1999; Williams & Goldman-Rakic, 1993). In particular, mesocortical, dopaminergic projections to the primary motor cortex impacted novel motor skill learning in rodents (Hosp, Pekanovic, Rioult-Pedotti & Luft, 2011). Surgical lesion of these dopaminergic neurons appeared not to impact existing motor skills but blocked learning of new motor skills.

Dopamine neurons also show phasic activations corresponding to rewards and reward-predicting stimuli, and appear to be crucial for learning (Schultz, 1998). In animal studies of classical and operant conditioning, researchers observed that animals that were impaired or

blocked in dopamine function did not learn stimulus-reward associations or behaviour that would lead to reward (e.g., pressing a lever for food in Wise & Schwartz, 1981), or experienced accelerated extinction of learning (e.g., Dickinson, Smith & Mirenowicz, 2000). Diminished effects of reward on learning were evident in the event of lesions or blockades by dopamine antagonists to brain regions and neural networks associated with reward (Brozoski, Brown, Rosvold & Goldman, 1979; Calabresi et al., 1997; Otani, Blond, Desce & Crepel, 1998).

1.6 Consolidation Processes

Like rewards, consolidation processes are also linked to neurobiological evidence alluding to the importance of dopamine for memory consolidation and learning. Consolidation generally refers to the "offline" neurobiological processes that take place outside of practice/training that stabilize or enhance memory (e.g., Brashers-Krug, Shadmehr & Bizzi, 1996; Robertson, Press & Pascual-Leone, 2005; Shadmehr & Holcomb, 1997). In contrast, motor learning more generally refers to the relatively permanent improvement in capacity for skilled movement that is due to both online (during practice) and offline processes. During memory consolidation, neurobiological processes stabilize a memory trace in two distinct time frames (Karni et al., 1998). The fast (synaptic) consolidation involves synaptic protein synthesis and strengthening of synaptic transmissions that are active during an event (i.e., during skill performance). The slow (systems) consolidation, which can last for weeks, involves reorganization of neural network such that memories, which were encoded and dependent on the hippocampus for retrieval, are relieved of this dependency and moved to the neocortical system for long-term storage (Dudai, 2004; Squire & Alvarez, 1995). Both types of consolidation are necessary to induce permanent change to memory and motor skills.

Motivation towards desirable outcomes (e.g., high achievement or monetary reward) is known to trigger greater release of dopamine, which enhances the processes of consolidation. At the cellular level, dopamine (and dopamine receptor activation) influences synaptic plasticity via long-term potentiation (LTP) and long-term depression (LTD) between neurons (see reviews by Jay, 2003; McGaugh, 2000; Wadden, Borich & Boyd, 2012). Dopamine-dependent LTP and LTD are found in the hippocampus, dorsal striatum, amygdala and frontal cortex – brain regions which are involved in learning (e.g., Bethus, Tse & Morris, 2010; Li, Cullen, Anwyl & Rowan,

2003; Otani, Daniel, Roisin & Crepel, 2003; Rossato, Bevilaqua, Izquierdo, Medina & Cammarota, 2009).

There is empirical evidence suggesting that achievement of performance stability within a practice session is important for eliciting consolidation gains or robust retention of learning. Within practice, stability is achieved when the performance curve begins to level out. This is termed asymptotic or saturated performance. Using an enumeration task, where participants had to decide quickly and accurately if the number of letters in a letter string were odd or even, between-practice session gains were only seen if individual participants practiced until they achieved asymptotic performance (Hauptmann, Reinhart, Brandt & Karni, 2005). Another group of researchers further reinforced the necessity of both reaching and continuing to practise at saturation for a newly acquired visuomotor rotation (again, a virtual environment whereby visual feedback representing hand movement is rotated in relation to actual hand movement) to be inoculated against interference from immediate practice of an opposing rotation (Krakauer, Ghez & Ghilardi, 2005).

Post-practice events also hamper or aid consolidation of motor skills. Immediate practice of a counter-rotation after first adapting to an opposite direction visuomotor rotation usually induces retrograde interference, whereby there is a significant reduction in retention of the first rotation (e.g., Krakauer, 2009). A non-invasive electromagnetic procedure that interferes with local brain function (like a temporary brain lesion), known as the repetitive transcranial magnetic stimulation (rTMS), disrupted memory consolidation when applied to the primary motor cortex immediately after practice of fast, rhythmic finger movements on the non-dominant hand (e.g., Muellbacher et al., 2002). In sleep-related memory consolidation research, the lack of sufficient sleep (e.g., Walker, Brakefield, Morgan, Hobson & Stickgold, 2002) or rest (e.g., Press, Casement, Pascual-Leone & Robertson, 2005) after skill practice has also been shown to interfere with consolidation processes (e.g. Stickgold, 2005; Walker & Stickgold, 2006; *c.f.* Brawn, Fenn, Nusbaum & Margoliash, 2010). For example, when learners were sleep-deprived on the first night after a practice session, they showed less pronounced offline improvement in a motor sequence task at a 48-hour delayed retention test, compared to learners who had two regular nights of sleep after practice (Fischer, Hallschmid, Elsner & Born, 2002). Interestingly, post-practice rewards and emotionally arousing stimuli also impact memory consolidation (e.g.,

Nielson & Bryant, 2005; Nielson, Yee & Erickson, 2005; Sugawara, Tanaka, Okazaki, Watanabe & Sadato, 2012). After learning a word list, participants in experimental groups that were given a small monetary reward (Nielson & Bryant, 2005) or viewed an arousing video involving surgery (Nielson et al., 2005) showed better recall and recognition of the word list in a delayed retention test compared to controls.

In summary, motor learning researchers are just starting to understand how motivation and success perceptions affect motor learning in the context of errors and perceptions of performance. It is not clear how motivational processes interact with cognitive/information processing activities during skill acquisition to change what is learnt and retained. Given that all learning is defined at some level with respect to errors, knowing how to optimize the experience of errors is critical to optimizing learning.

1.7 Research Plan

The overall aim of my thesis is to study how motor learning is affected by the subjective experience of errors (and success) during practice and to explore the mechanisms that underlie the learning effects produced by practice interventions that alter these experiences. In the thesis I refer to manipulations of error perceptions as manipulations of success perceptions, as performance outcomes impact how trials are perceived, interpreted and ultimately judged as successful. The research questions and completed studies are listed below. I have also included summary tables of each study in Appendices 1- 5.

- Study 1: Manipulation of task-difficulty progression does not impact performance or learning of a dart-throwing task.
- Study 2 (published): Manipulating target size influences perceptions of success when learning a dart-throwing skill but does not impact retention (Ong, Lohse & Hodges, 2015).
- Study 3 (in preparation): Target size manipulations affect error-processing duration and success perceptions but do not impact behavioural indices of performance and learning.
- Studies 4 & 5 (published): Balancing our perceptions of the efficacy of success-based feedback manipulations on motor learning (Ong & Hodges, 2017).

In Study 1, we first attempted to replicate the errorless learning advantage shown with task-difficulty progressions of practice (Capio et al.; 2013a, 2013b; Maxwell et al., 2001; Savelsbergh, Cañal-Bruland & van der Kamp, 2012) as there were mixed findings on the advantages of progressing from easy-to-difficult compared to the reverse progression (detailed in Study 1; Lee et al., 2015; Sanli & Lee, 2014) and potential motivational influences had not been tested. Upon replicating the errorless learning advantage, we had planned to recruit two additional groups that would practise the dart-throwing task on the same easy-to-difficult and difficult-to-easy task progressions, with these groups additionally receiving positive social comparative feedback during the first half of practice to improve early perceptions of success. If enhanced success perceptions offset any potential costs associated with the degree of errors experienced early in practice, then we expected the difficult-to-easy plus comparative feedback group to show enhanced performance in retention compared to the difficult-to-easy (no comparative feedback) group. Although positive comparative feedback might generally enhance retention for both groups, the effects were not expected to be as prominent for the easy-to-difficult group, who should feel more efficacious early in practice as a result of the easy target distances.

After testing (n =12-13/gp), we were unable to replicate the errorless learning advantage with task-difficulty progressions. The groups were undifferentiated in practice outcome error/success, and reports of self-efficacy, motivation, anxiety and explicit knowledge generation. Hence our planned social comparative feedback groups were not recruited. Because we did not observe elevated practice errors in the difficult-to-easy (supposed errorful) group compared to the easy-to-difficult (errorless) group using this method of task progressions, we altered the methods in Study 2 and improved on our scoring criterion. As the method of scoring in Study 1 involved a one-dimensional measure of outcome success (points on a dart board radiating out from the centre), in Study 2 we measured errors in the rectangular coordinate system, measuring both x and y directional error, which allowed assessment of both bias and consistency in dart-throwing as recommended by Fischman (2015; Hancock, Butler & Fischman, 1995).

Study 2 was designed to distinguish the groups on outcome success in practice by assigning participants to groups that practised dart-throwing at a difficult (large) or an easy

(small) target. The large target group was expected to make more target hits than the small target group, even though they faced the same objective difficulty in regards to throwing distance. Study 2 would also extend the work on task difficulty effects on perceptions and motor learning (e.g., Chiviacowsky et al., 2012; Trempe et al., 2012). Trempe and colleagues presented evidence suggesting that the subjective perception of success in a visuomotor adaptation task affected how well the skill was retained over a retention interval, despite a lack of differences in actual error during practice.

As expected, the large and small target groups in Study 2 differed on target-hit success rate during practice. However, the groups did not differ with respect to objective error (radial error in relation to the centre of the target) in practice, or in self-efficacy when reporting on their self-efficacy for hitting the centre of the target. We considered several methodological reasons for the lack of effects and followed up with the same dart-throwing task for Study 3 with minor modifications to the task and procedures. For Study 3 (which was chronologically the final study of my thesis), two groups of participants practised dart-throwing to a difficult (small) horizontal band or an easy (large) band target with similar procedures to Study 2 except the modifications to overall task difficulty and overall practice success rates for both groups. These changes were made in order to differentiate the groups on motivation, perceived competency and success. Additional psychophysiological measures (i.e., electrodermal and electromyography activity), and kinematic data, were collected to elucidate potential differences in movement characteristics or control processes.

As we were unable to replicate the errorless learning advantage of easy-to-difficult practice progressions in Study 1, where the groups were not different in measures of learning, self-efficacy and motivation, we speculated that a difficult-to-easy practice progression might enhance, rather than diminish, success perceptions and motivation. This may be due to reductions in error across practice for the difficult-to-easy group and what is likely conceived as a relatively large improvement over time compared to the opposite progression. In addition, due to the saliency of actual error in dart-throwing (i.e., nearness to the bulls-eye/centre of the target), other available sources of error/feedback that could potentially moderate target size effects and perceptions of success, we switched to a stabilometer (raised horizontal platform) balancing task in Studies 4 and 5. We anticipated that a continuous (60 s duration) motor task

would potentially make participants more reliant on augmented feedback (end of trial KR) as an indication on how well they performed the task.

In Study 4, we assigned participants to four groups; two groups received time-on-target feedback on their balance performance based on fixed goal-criteria (either easy or difficult) and two groups on changing goal-criteria (easy-to-difficult vs. difficult-to-easy). The changing goal-criterion afforded greater relative improvement or progress for the difficult-to-easy group that started practice with a difficult goal, while the easy-to-difficult goal group experienced less error and greater success early in practice but little-to-no improvement across practice trials as the task became more difficult. Although the groups received performance feedback and their self-efficacy ratings were aligned with their respective feedback groups and goal assignment, there were no behavioural differences amongst the groups in practice or retention performance.

Study 5 was conducted as a follow-up to Study 4, where we attempted to replicate the findings reported by Lewthwaite and Wulf (2010a). Rather than simply relying on performance metrics indicating high or low error, which were still subject to different interpretations by individuals, participants received social comparative feedback in Study 5. As such, the feedback was interpreted for the participant, with respect to their performance in relation to others. We first recruited two groups, which received veridical error feedback on the task, with one of the groups additionally receiving positive social comparative feedback. Because the groups were again not different on our primary outcome (balance error) and psychosocial measures of motivation and perceived competency, we recruited two further groups which this time did not receive any veridical outcome feedback about trial success/error, and with one of these groups receiving negative social comparative feedback about their performance. Significantly higher motivation, competency and success perceptions in the control group (without any feedback) did not lead to a performance and learning benefit over the negative social comparative feedback group.

In summary, five studies were conducted to test how perceptions of success impacted behavioural measures of performance and learning, psychological measures related to motivation and feelings of competency, and process measures of arousal (Studies 3 and 5), mean power frequency (Study 5) electromyography and movement kinematics (Study 3). Despite the

replication built into the studies and attempts to manipulate errors and perceptions of performance through changing task-difficulty progression, target size, perceptions of improvement, perceptions of relative success or lack of success compared to others, there were a general lack of behavioural effects associated with errors and heightened perceptions of competency. These studies are reviewed in the following chapters where I discuss potential methodological reasons for the data and relate the findings to concepts concerning consolidation, implicit motor learning and the OPTIMAL theory.

2 Manipulation of Task-Difficulty Progression Does Not Impact Performance or Learning of a Dart-Throwing Task (Study 1)

2.1 Introduction

In considering optimal practice conditions or methods for acquiring motor skills, it might seem like common sense for a novice to proceed by starting with practice on a simple or easy version of a task. Were task difficulty to far exceed the competency level of a novice performer, such challenging conditions are likely to render practice ineffective (Guadagnoli & Lee, 2004). An easy-to-difficult task difficulty progression to skill acquisition is a widely accepted approach to instruction. It is thought to afford successful skill performances and appropriate movement form, potentially lowering the likelihood of injury or drop-out from subsequent engagement (Herbert, Landin & Solmon, 2000). Support for this progressive approach to practice was recently shown in what are termed "errorless" learning protocols, where an easy-to-difficult progression reduced performance error and was believed to do so by promoting more implicit learning than the reverse progression. In this study we attempted to replicate the errorless learning effect and further test the mechanisms underpinning the potential advantage of an easy-to-difficult progression. I was particularly interested in the cognitive-affective explanation related to heightened perceptions of success as an explanation for these errorless learning advantages (OPTIMAL theory, Wulf & Lewthwaite, 2016; Lewthwaite & Wulf, 2017).

One of the most influential concepts that have emerged on practice organization in motor learning is the notion of contextual interference (CI). Defined as the amount of "interference generated due to the context in which the skills were being practiced" (Schmidt & Lee, 2011, p. 371), the main tenet of CI is that practice conditions promoting greater CI degrades practice performance, but is more effective for learning than practice conditions that promote low CI. Participants that practised three barrier knock-down tasks in a blocked order, whereby all trials of one task were completed before moving on to practice on the next task ("blocked practice"), were superior in practice performance to participants that practised the same tasks in a randomized order, whereby each task was not successively repeated more than once in the practice schedule ("random practice"; Shea & Morgan, 1979). In retention, this trend was typically reversed, indicating superior learning for random practice over blocked practice. A

common thread in well-tested hypotheses of the CI effect is that practice conditions with greater CI place greater difficulty or cognitive processing demands on the learner, hence generating more robust or meaningful memory representations of the practiced skills (Lee, 2012; Li & Wright, 2000).

Another prominent theory related to practice organization is the schema theory (Schmidt, 1975). Variations of a motor skill are thought to be produced by assigning specific parameters (e.g., absolute force or absolute time) to a generalized motor programme (GMP) associated with a particular class of actions. Abstract memory representations that specify a rule, concept or generalization, known as schemas, are formed and refined based on information on initial conditions, parameters assigned, outcome feedback and sensory feedback pertaining to movements performed. Selection of different parameters and practice in different contexts (known as variable practice) strengthens the schema and enhances learning through improved parameterization of movements. In an early study of variability of practice in a force-matching task, variable practice with different forces including the criterion led to better retention performance than constant practice on the criterion force (Shea & Kohl, 1991).

Though one of the predictions of schema theory is that variable practice is beneficial for learning, the theory did not address task-scheduling effects (Shea & Wulf, 2005). These effects were examined in studies of contextual interference with multiple tasks of different GMPs (e.g., different types of skills, such as passing, dribbling, shooting), rather than multiple task variations of one particular GMP (e.g., shooting different distances). When task-scheduling was applied to variations of one GMP, although there was evidence that random, variable practice was better for learning than blocked, variable practice, the findings were relatively mixed (e.g., Hall & Magill, 1995; Sekiya, Magill & Anderson, 1996; Shea, Lai, Wright, Immink & Black, 2001). The explanation offered by Shea and Wulf (2005) for these inconsistent findings, is that parameter variations in practice may degrade, rather than benefit, learning for motor skills with unstable GMPs.

Other than a random or blocked order to task variations, ordering of task variations in an easy-to-difficult progression has also been compared to constant practice of a criterion task. Easy-to-difficult task progressions were found to benefit learning of a volleyball and tennis serve

more than constant practice (French, et al., 1991; Hebert, Landin & Solmon, 2000). However, it was not clear if learning was enhanced due to variability of practice or task-scheduling effects. These concerns were only addressed when Maxwell and colleagues (2001) replaced the constant practice group with a group that practised in a reversed, difficult-to-easy (far-to-near) task progression, resulting again in learning advantages for the easy-to-difficult (near-to-far) group. Compared to the reversed group, outcome error was reduced (hence termed "errorless" learning) for the easy-to-difficult group during practice and in retention, even though the amount of task variability was equal for both groups. Similar findings were also reported in a kicking study with target distance variation (Savelsbergh et al., 2012), throwing studies with target size variation (Capio et al., 2013a, 2013b), and a full-body step sequencing study where an easy-to-difficult progression was combined with an autonomy-supportive practice environment (Levac et al., 2017).

With fewer practice errors committed in an easy-to-difficult progression and learners generating less task-relevant knowledge, it was concluded that an easy-to-difficult progression promoted a more implicit mode of learning than the reversed practice (Maxwell et al., 2001). Implicit learning is thought to occur without conscious awareness of the products of learning. When implicit learning processes are dominant in practice, explicit control or conscious cognitive processing is minimized and the learner accrues less explicit, task-relevant knowledge, such as hypotheses, rules or strategies (Masters, 1992; Masters & Maxwell, 2004, 2008). Without access to task-relevant knowledge, performers are unable to "reinvest" in the performance of well-learned, 'automatic' skills and hence are less likely to revert to conscious, step-by-step motor control, reminiscent of unskilled performances in early practice. Reinvestment of skilled movements leads to notable disruptions, particularly when performance is assessed under pressure or cognitive task load. In addition to the amount of task-relevant knowledge generated by participants as a measure of explicit control or learning, interference caused by a secondary transfer task (dual-task condition) is often used to test attentional demands of tasks, with greater interference indicative of more explicit control in the primary task (Hardy, Mullen & Jones, 1996; Lam, Maxwell & Masters, 2009).

The timing of practice manipulations prompting implicit learning was shown to be a significant contributor to the advantages of easy-to-difficult progressions (Poolton et. al, 2005).

Two groups of participants practiced golf-putting in the same easy-to-difficult (near-to-far) progression. One group (early instruction) was given task-relevant instructions before practice began, while the other (late instruction) received the same instructions mid-practice. Though both groups reported similar levels of explicit knowledge post practice and there was no significant group difference in performance (i.e., number of successful putts) during practice and in retention, only the early instruction group showed a performance decrement during a secondary task test (see decrease in successful putts for the early instruction group between retention and secondary task test, Figure 2.1). Early task-relevant instructions prompted a more explicit mode of learning than late instruction, despite the same task-difficulty progression experienced by the participants. It was concluded that the absence of explicit instructions in the early period of an easy-to-difficult progression allowed implicit processes to dominate learning. This then freed working memory capacity for conscious processing of secondary task tones in the secondary test, without interfering in the primary task of golf-putting.

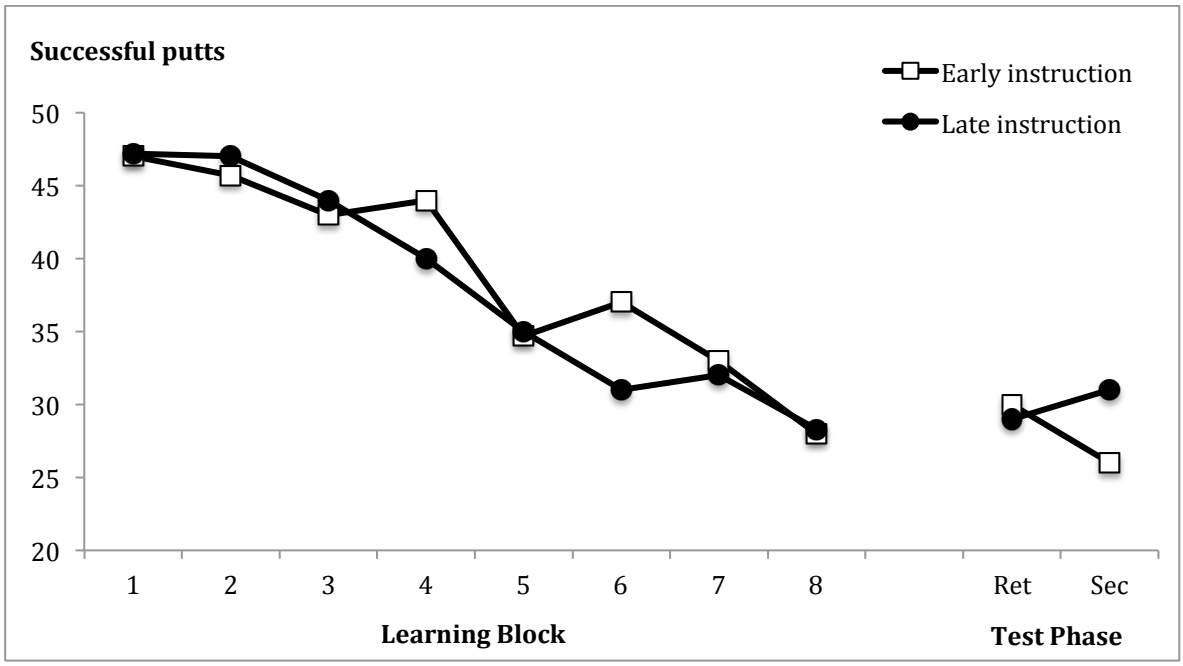

Figure 2.1. Data reproduced from Poolton et al. (2005). Number of successful putts made by the early instruction and late instruction groups as a function of practice (Learning Block 1-8), and test phase (Ret = retention, Sec = secondary transfer test).

Yet, the benefits of an easy-to-difficult practice progression appear to be mixed (cf. Lee et al., 2015; Sanli & Lee, 2014). In one of Sanli and Lee's (2014) experiments with a disc-propulsion task, the opposite pattern of results was observed. During practice, the easy-to-

difficult (near-to-far) group made, on average, more error (i.e. target misses) than the difficult-to-easy (far-to-near) group, although they were less errorful in the initial period of practice. There were no performance accuracy differences between the two groups in immediate and delayed retention and dual-task tests. The only post-practice difference was in transfer tests to a novel distance, where the difficult-to-easy group continued to be more accurate than the easy-to-difficult group. The authors argued that the initial "errorful" practice might have led to greater accrual of task-relevant explicit knowledge (although this was not verified in the study), and consequently enhanced transfer for the difficult-to-easy group. However, the lack of secondary task decrements for this difficult-to-easy group does not align with the explicit learning explanation. It may be that force-variability principles were at work, which might have benefited practice at harder tasks, requiring more force than easier tasks given the non-linear relations between force and accuracy.

Much emphasis has been placed on implicit learning or explicit control-related accounts of errorless learning, particularly for easy-to-difficult task progressions. Less consideration has been given to how these task-difficulty progressions might directly impact learning through perceptions, motivation, and processes of memory consolidation (see OPTIMAL theory below). The predominant theories of self-regulation (such as social cognitive theory, Bandura, 1991) predicted that when individuals believe they can achieve their task goal (i.e., individuals with high self-efficacy), they are more likely to exert more time and effort towards performance than those who are not self-efficacious. Self-efficacy is defined as "task-specific confidence" or the belief in one's capabilities to organize cognitive resources and execute courses of action required to meet situational demands (Wood & Bandura, 1989). While making fewer errors early in practice might promote a more implicit type of learning, self-efficacy and motivation may also be amplified due to the initial success associated with an easy-to-difficult task progression. Bandura also suggested that early beliefs of self-efficacy may be rather long-lasting, in that once an individual develops a strong self-efficacy for a task, subsequent performance failures may not lower or impact self-efficacy much. Therefore, greater initial self-efficacy elicited by easier task versions in an easy-to-difficult progression may be an influential factor for learning.

A recent theory has been proposed to explain direct motivational and attentional influences on motor learning, and advantages related to perceptions of success and expectancies

for future success, termed the OPTIMAL theory (Wulf & Lewthwaite, 2016; Lewthwaite & Wulf, 2017). Here, overall perceptions of success and competency are thought to impact both performance—through increased effort/attention, goal-setting, task enjoyment, positive affect, or decreased self-regulatory processes—and retention, either as a result of enduring practice differences, or potentially a product of memory consolidation processes related to heightened "reward" and dopaminergic activity that aid memory in the retention interval (e.g., Holroyd & Coles, 2002; Wise, 2004). Although it is not clear whether early success, or potentially later or increasing successes (see Study 4 of my thesis) might facilitate learning in this way, through measurement of self-efficacy, we determine how these variables covary with task-difficulty progressions and impact learning in the present study.

Errorless learning practice strategies that lead to reduced errors and promote less cognitive processing on the part of the learner seem to be in contrast to strategies based on other motor learning principles that espouse challenge and cognitive effort, such as in conditions of high CI (cf. Rendell, Masters & Farrow, 2009), as precursors for long term retention of motor skills (e.g., Guadagnoli & Lee, 2004; Lee et al., 1994; Sherwood & Lee, 2003). Therefore, there is continued reason to test how progressions of task difficulty work to affect motor learning, not just via measures of explicit control processes, but also through measures of efficacy perceptions and motivation.

The aim in this study was to evaluate whether and how manipulations to task-difficulty progressions impacted both errors in practice and later retention and transfer (under dual-task conditions designed to probe implicit motor learning, an outcome prediction task in the absence of visual feedback, and a weight-transfer test examining adaptability to a novel version of the task). Importantly, in addition to measuring traditional indices associated with these errorful paradigms (i.e., explicit knowledge accrual and performance under dual-tasks), I also studied how success perceptions (i.e., self-efficacy, motivation-related perceptions, and anxiety) were impacted by these task-difficulty progressions and whether these might add to the implicit learning account, or offer an alternative explanation for any potential learning benefits associated with easy-to-difficult task progressions. A dart-throwing task was adopted to test these ideas, where novice participants were assigned to either an easy-to-difficult (i.e., near-to-far) or

difficult-to-easy (far-to-near) practice group. Task difficulty was manipulated through changes to the distance from the target.

If an easy-to-difficult practice progression resulted in less error than a difficult-to-easy progression, participants in the former might learn more implicitly (reporting fewer explicit rules/strategies), report greater ratings of self-efficacy and lower anxiety during practice. With respect to longer-term measures of learning, we anticipated that this easy-to-difficult group would perform with increased accuracy, self-efficacy and motivation in a delayed retention test, and in contrast to the difficult-to-easy group, would show minimal performance decrement in a secondary task test. However, we also expected that there would potentially be some benefits associated with increased processing of errors during practice, including better development of processes related to intrinsic feedback processing. Hence we included a transfer task to test these processes, whereby participants were asked to estimate the outcomes of their throws in the absence of feedback. We also included a transfer condition to a novel variation of the task (throwing with a weight on the arm), to assess whether there were potential advantages associated with more frequent error processing during practice that might promote transfer to unpractised task variations (Sanli & Lee, 2014; Schmidt, 1975).

2.2 Methods

2.2.1 Participants

Female novice dart players (*M* age = 24.9 yr, range: 18 – 33 yr) were recruited for this study. Participants reported that they were right-handed and inexperienced at darts (i.e., had not played darts on more than three occasions). They were pseudo-randomly assigned to the easy-to-difficult (n = 12) or difficult-to-easy (n = 13) group, with the constraint of matching the groups on pre-test performance accuracy (after the first 10 participants, 5/gp). Remuneration of $10.25/hr was paid to participants and informed consent was obtained in accordance with the Behavioural Research Ethics Board of the University.

2.2.2 Task and apparatus

A modified regulation size bristle dartboard was mounted with the centre of the bullseye at a height of 1.73 m from the floor. Affixed over the board surface was a customized target board, constructed from poster-board. The customized target board consisted of 8 concentric circles featuring a bullseye that matched the inner and outer bull of a regulation dartboard (3 cm diameter). Around the bullseye were 7 concentric zones (increasing in diameter by 6 cm, from 9 – 45 cm). The largest zone was the same diameter as the regulation dartboard. Each zone was assigned a score, descending from 8 points for bullseye, 7 points for the inner most concentric zone (closest to the bullseye) to 1 point for the outer most zone, see Figure 2.2.

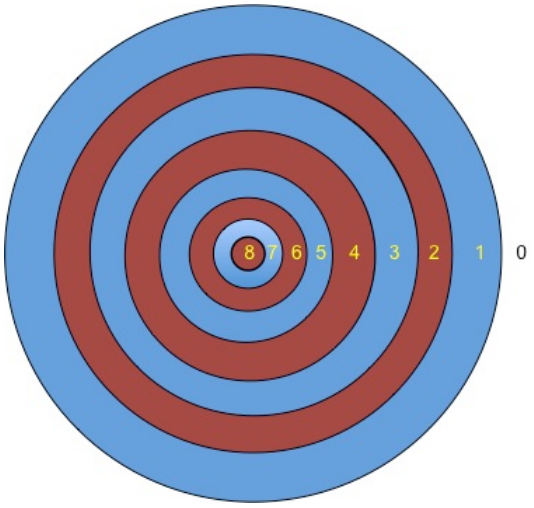

Figure 2.2. Schematic of poster-board with concentric zones and assigned accuracy scores.

Participants were instructed to throw and land darts (each 26 g) at the customized target board, with the goal of maximizing scores. No point was awarded when a dart landed outside the scoring zones (Figure 2.2). If a dart landed on the border of two zones, the higher score was awarded. Exact dart landing positions were recorded via a video camera located on a raised tripod behind the dart-thrower (but not for the first 10 participants). These videos allowed post-experiment analysis of outcome error and variability in the *x* and *y* dimensions.

As a measure of self-efficacy, participants were asked to indicate their confidence of hitting “close to bullseye” (defined as landing darts in scoring zones 6, 7 or 8) on at least one out

of the next three throws. The scale ranged from 0 to 100, with corresponding written descriptions; “0” (not at all), “10” (not sure), “40” (somewhat sure), “70” (pretty sure) and “100” (very sure; Zimmerman & Kitsantas, 1997). This scale was pinned ~1 m to the right of the dartboard. Using the same scale, the first 10 participants were assessed on two customized items at the end of the study; on their motivation to play darts again (“Given the opportunity, will you play darts again?”), and their perceived future ability in darts (“With some practice, do you think you will become a decent darts player?”). The remaining participants (*n* = 7-8/group) responded to two different customized 7-point (1 = “strongly disagree”, 7 = “strongly agree”) Likert scale items at the end of the study, to assess their motivation to improve during practice (“During practice I was motivated to improve.”), and motivation to play darts again (“I look forward to playing darts again.”). These participants also filled out the Competitive State Anxiety Inventory (CSAI-2; Martens, Vealey & Burton, 1990), and a modified version of the Situational Motivation Scale (SMS; Guay, Vallerand & Blanchard, 2000) at the beginning of each day.

For the secondary task transfer test, we constructed two audio sequences (~20 s/sequence) of interspersed high and low pitched tones (300 ms/tone; 1.2 s inter-stimuli interval) that were randomly generated. Participants’ task was to mentally count the number of high tones for each of the two sequences. In the outcome-prediction transfer task, vision was occluded using visual occlusion goggles (Translucent Technologies Inc., Canada), just before dart release (manually controlled by the experimenter using a custom hand-held switch). For the weighted-transfer test, a 450-g weight was Velcro-strapped onto the wrist of the participants’ throwing arm.

2.2.3 Procedure

The study was conducted over two days, separated by ~24 hours. Participants were instructed to avoid stepping over the throw line, and to adhere to an overhand throw, i.e., to maintain their throwing arm in the sagittal place of motion (the motion was demonstrated).

2.2.3.1 Day 1

On Day 1, three warm-up throws (data not recorded) were performed at the criterion distance of 275 cm from the target board. Participants that were recruited later (not the first 10 participants) completed the CSAI and SMS before beginning the short warm-up. After warm-up, a self-efficacy rating for hitting close to bullseye (i.e., scoring 6 points or more) on at least 1 out of the next 3 throws was obtained from participants. The pre-test (t=6) was also performed at the criterion distance of 275 cm. Following pre-test, dart-throwing practice was completed in 7 blocks of 30 trials each, at target distances: 200, 225, 250, 275, 300, 325 and 350 cm from the target board. On occasion, the darts did not stick to the board and rebounded. From pilot work, we established that 200 cm was the nearest distance to safely practise dart-throwing without being too close to a potential rebound. The other practice distances were chosen so that our procedures were closely matched to those of Maxwell et al. (2001). Participants assigned to the easy-to-difficult group completed the acquisition blocks in an increasing distance progression (i.e. 200 to 350 cm); the difficult-to-easy group progressed in a decreasing distance order (i.e. 350 to 200 cm). Darts were thrown in sets of 3. The experimenter collected the darts after each set, and read out the score for the set (max score = 24). At the start and mid-point of each acquisition block, a rating was again obtained on participants' self-efficacy level of hitting close to bullseye for at least 1 of the next 3 throws. A short break was encouraged in between each throwing distance.

Upon completion of the practice or acquisition phase, participants completed an immediate post-test, which was identical to the pre-test. At the end of Day 1, participants signed a payment receipt for participation and agreed not to practise on their own.

2.2.3.2 Day 2

On Day 2, participants returned to the laboratory for 4 further tests, each consisting of 6 trials at the criterion distance of 275 cm, in the following order; 1) retention test, 2) secondary task test, 3) outcome prediction (visual-occlusion) test, and 4) weighted-transfer test. All but the first 10 participants filled out the CSAI-2 and modified SMS before beginning the tests on Day 2.

The retention test was identical to the pre-test and post-test. Before starting the secondary task test, participants listened to the tones to discern between the high and low tones and

practised mentally counting the high tones in a short warm-up sequence. During the secondary task condition, participants counted high tones while throwing a set of 3 darts at the criterion distance. They did not begin their first throw until the first tone of the sequence was played. When participants completed each set, the audio playback was stopped and they were asked to report the number of high tones (average playback duration was 11 s). Two sets of secondary task trials (t = 6) and two tone-counting responses were made in this test. In the outcome-prediction task, vision was occluded before dart release (between the time when participants had their elbow cocked and wrist/flexed to just before the moment of dart release). After each outcome-prediction trial, the experimenter would retrieve and record the landing of each dart before asking the participant to give their outcome prediction score (0-8). No feedback was given during this test. In the weighted-transfer task, with the exception of the weight strapped to a participant's wrist, this test was identical to the retention test.

At the end of Day 2, participants were interviewed and asked to describe any rules, techniques or methods pertaining to dart-throwing that they had generated or tested during the experiment, and filled out two customized items related to motivation (all participants) and perceived future ability (only first 10 participants).

2.2.4 Data collection and analysis

2.2.4.1 Outcome measures

The key dependent variables were accuracy scores and radial error, which were respectively determined by the concentric zones where the darts landed on the target board, and dart landing position in relation to the origin (analyzed post-experiment). Acquisition accuracy (both scores and RE) was analyzed in 2 Group (easy-to-difficult, difficult-to-easy) x 7 Distance or Practice block order (200 – 350 cm) repeated measures (RM) ANOVA. Separate Group x Time/Condition RM ANOVAs were also conducted to compare accuracy in the pre-test, post-test and retention tests, and to compare accuracy in retention to the secondary task condition. Separate independent t-tests were used to determine group differences for the outcome prediction and weighted-transfer tests. Where RM ANOVA were conducted, partial eta squared (η^2_p) values were reported as measures of effect size and post hoc analyses were conducted using

Tukey's HSD ($p <. 05$). Greenhouse-Geisser corrections were applied for violations to sphericity. Cohen's *d* values were reported for t-test analyses.

For participants that were recruited later (not first 10), *x* and *y* coordinates of dart landings were derived from video recordings, using Dartfish © Prosuite software. From these coordinate positions (i.e., constant error), radial error (RE), and bivariate variable error (BVE; Hancock, Butler & Fischman, 1995) were calculated. BVE was based on the following equation:

$$BVE = \sqrt{\frac{1}{k}\sum_{i=1}^{k}(X_i - X_c)^2 + (Y_i - Y_c)^2}$$

where: k = number of trials

X_c = average constant error on the *X* axis within a test or block

Y_c = average constant error on the *Y* axis within a test or block

Accuracy of participants' responses on each set of secondary task trials was first verified according to the reported count and the corresponding correct count for when the audio sequence was stopped. Each response was coded as either correct or incorrect. Accuracy of tone-counting responses was then assessed with a Mann-Whitney U analysis for between group differences in the number of response errors made by each participant (maximum of two as there were two audio sequences during the secondary task condition). For the outcome prediction task, we analyzed the number of trials with a prediction error as well as the average magnitude of prediction error (estimated – actual), using a Mann-Whitney U group comparison.

2.2.4.2 Measures of self-efficacy, motivation, anxiety and explicit knowledge

Mean self-efficacy ratings were calculated for each acquisition block/target distance. A 2 Group x 7 Distance repeated measures ANOVA, similar to accuracy scores, was applied. Self-efficacy ratings provided during pre-test, post-test and delayed retention were analyzed in 2 separate Group x Test RM ANOVAs. Between-group differences in number of explicit rules generated and customized motivation-related items were analyzed in Mann-Whitney U analyses. Overall

changes in ratings (Day 2 – Day 1) of subscales of the SMS and CSAI were analyzed with Wilcoxon signed-rank tests for matched samples.

2.3 Results

2.3.1 Outcome error was not reduced for the easy-to-difficult group in retention and transfer

Accuracy scores and radial error (RE; for participants recruited later, 7-8/gp) were compared based on distance, not order of which practice was conducted. These data are illustrated in Figure 2.3. On a 2 Group x 7 Distance RM ANOVA, accuracy scores yielded only a main effect of distance, $F(3.8, 86.3) = 112.67$, $p < .001$, $\eta^2_p = .83$, with scores increasing as distance to target decreased. Group-related effects were absent in acquisition. However, there was a Group x Distance interaction for RE, $F(3.0, 39.4) = 3.87$, $p < .05$, $\eta^2_p = 23$. Post hoc analyses indicated that the difficult-to-easy group was not as accurate as the easy-to-difficult group only at the two furthest distances; 325 cm (20.45 cm vs. 15.61 cm respectively) and 350 cm (23.14 vs. 16.69 cm respectively). For accuracy scores only, a Group x Time (pre-test, post-test) RM ANOVA revealed a significant main effect of time, $F(1, 23) = 11.71$, $p < .01$, $\eta^2_p = .34$, that also indicated an overall improvement in practice accuracy, though there were no group-related effects.

When comparing accuracy scores and RE across pre-test and retention, there were no significant effects. Analysis of the transfer tests also did not yield any group-related effects for either accuracy scores or RE. Tone-counting errors did not differ between the 2 groups (overall $M = .36$, $SD = .57$). There were also no group differences with respect to errors in prediction (all ps > .13).

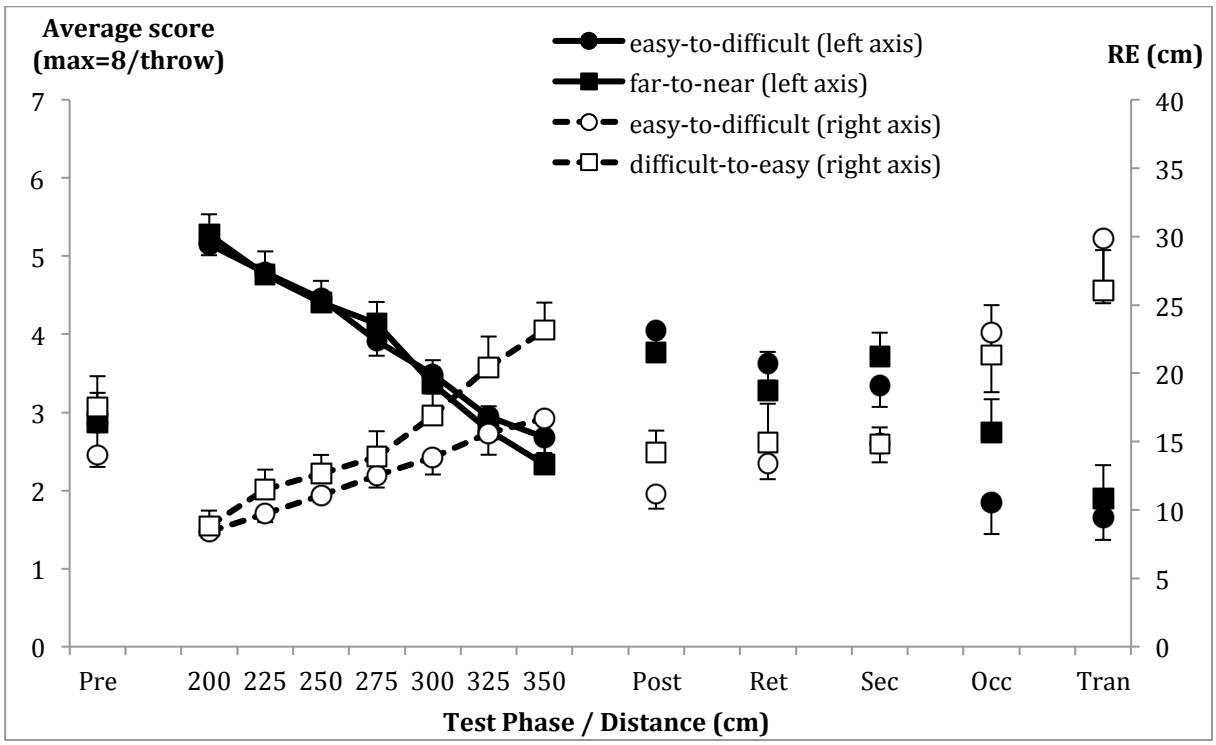

Figure 2.3. Mean outcome score (black data points corresponding to y-axis on left) and radial error (RE; white data points associated with y-axis on right) as a function of test phase/distance; pretest (Pre), acquisition blocks 200 – 350 cm, post-test (Post), retention (Ret), secondary task test (Sec), vision-occlusion test (Occ) and transfer test (Tran). Acquisition blocks were either increasing in 25-cm distances (200 – 350 cm) for the easy-to-difficult group or decreasing (350 – 200 cm) for the difficult-to-easy group. All tests were at the criterion distance of 275 cm. Error bars represent *SE*.

2.3.2 Outcome variability was lower for the easy-to-difficult group in some test conditions

Based off a 2 Group x 7 Distance RM ANOVA for BVE (n = 7-8/gp), the distance main effect, $F(3.6, 46.7) = 36.17$, $p < .001$, $\eta^2_p = 74$, was due to the expected decrease in consistency with increasing target distance. Although the group effect of BVE was not significant ($p = .07$) in acquisition, there was a Group x Distance interaction, $F(3.6, 46.7) = 2.69$, $p < .05$, $\eta^2_p = 17$. The difficult-to-easy group was more variable than the easy-to-difficult group in the three furthest distances (300, 325 and 350 cm). A Group x Time (pre-test, post-test) RM ANOVA of BVE showed only a main effect of time, $F(1, 13) = 11.39$, $p < .01$, $\eta^2_p = .47$, indicating that BVE decreased from pre- to post-test as anticipated.

When comparing BVE between pre-test to retention, no effects were significant. Analysis of retention and secondary test conditions, as well as the other transfer tests also revealed no significant effects.

2.3.3 Self-efficacy was not sensitive to practice-progression group

Overall self-efficacy did not differ across the two groups in acquisition, $p > .18$. There was a main effect of distance, $F(3.0, 68.7) = 45.70$, $p < .001$, $\eta^2_p = .67$, because self-efficacy ratings decreased as distance increased (see Figure 2.4). There was also a Group x Distance interaction, $F(3.0, 68.7) = 4.41$, $p < .01$, $\eta^2_p = .16$. Post hoc analyses showed that the groups were only different for the 200 cm distance block, where the easy-to-difficult group ($M = 56.25$ %, $SD = 25.51$), which completed the 200 cm block first, reported lower ratings than the difficult-to-easy group ($M = 87.69$ %, $SD = 21.18$), which completed this distance last. A 2 Group x Time (pre-test and post-test) analysis showed a main effect of time, $F(1, 21) = 53.51$, $p < .001$, $\eta^2_p = .72$, confirming the practice-associated improvement in self-efficacy. There was also a significant interaction, $F(1, 21) = 8.36$, $p < .01$, $\eta^2_p = .29$, with post hoc tests revealing that the difficult-to-easy group showed more improvement in self-efficacy than the easy-to-difficult group, from pre- to post-test (Figure 2.4).

A comparison of self-efficacy ratings across the pre- and retention tests showed no group-related differences in self-efficacy, *p*s > .27. Overall, participants showed an increase in self-efficacy, $F(1, 21) = 11.68$, $p < .01$, $\eta^2_p = .36$, from pre-test ($M = 29.13$, $SD = 21.51$) to retention ($M = 50.87$, $SD = 22.55$; see Figure 2.4).

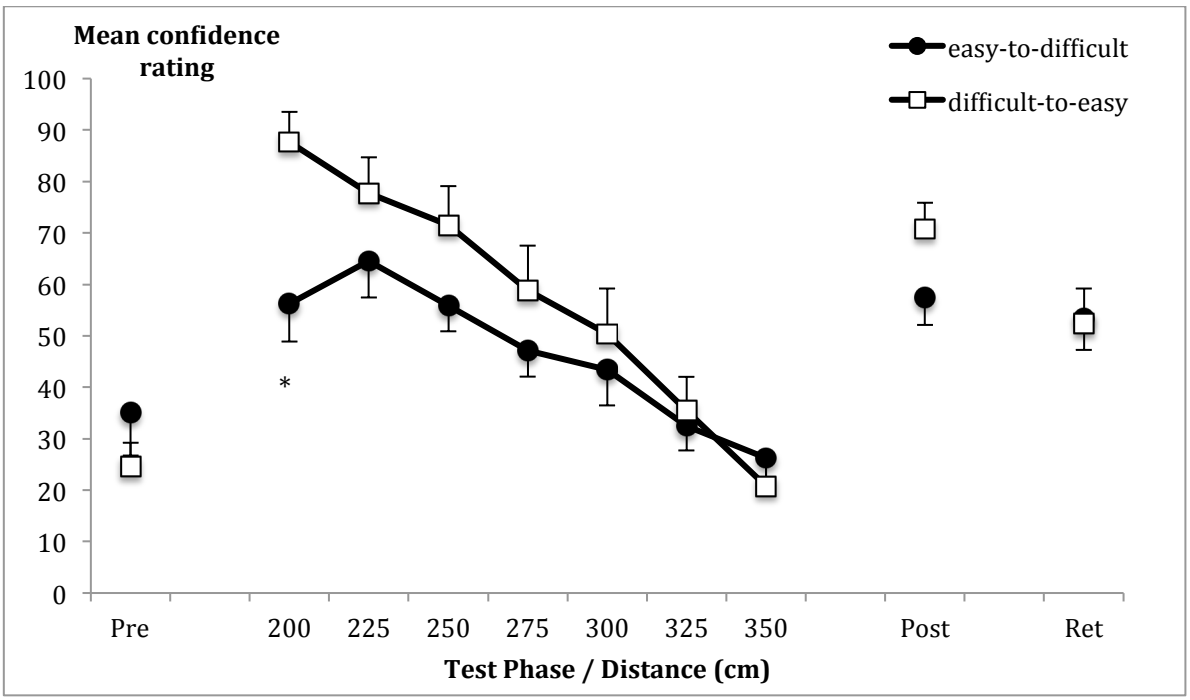

Figure 2.4. Mean self-efficacy rating as a function of pretest (Pre), acquisition blocks 200 – 350 cm, post-test (Post) and retention (Ret). Error bars represent *SE*. Asterisk indicates significant difference at $p < .05$.

2.3.4 Explicit knowledge and motivation were not affected by practice progression

The median number of rules (including strategies and hypotheses) reported was 3 ($M = 2.6$, $SD = .9$), and there were no group differences, U = 57.50, $p = .27$. Changes in motivation from Day 1 to Day 2 were compared for the subscales of SMS (intrinsic motivation, identified regulation, external regulation and amotivation) for all but the first 10 participants. There was an increase in ratings for intrinsic motivation (Day 1: $Mdn = 4.75$; Day 2: $Mdn = 5.25$), and a decline in ratings for amotivation (Day 1: $Mdn = 3.50$; Day 2: $Mdn = 2.75$), ps < .05. However, there were no group differences, ps > .09. These participants were also not different in ratings on customized items assessing their motivation to improve during practice and play darts again (ps > .39). For the first 10 participants that did not complete the SMS, they responded to questions on whether they would play darts again (easy-to-difficult: $M = 90\%$ sure, $SD = 17.3$; difficult-to-easy: $M = 76\%$ sure, $SD = 20.7$) and their future ability in darts and whether, with practice, they would become a decent dart player (easy-to-difficult: $M = 68\%$ sure, $SD = 23.9$; difficult-to-easy: $M = 56\%$ sure, $SD = 15.2$). For both questions the easy-to-difficult group was more certain of their desire to play again and to do well with practice (statistical analyses were not conducted due to the low n for these items).

There were no group differences (n = 7-8/gp) in ratings for cognitive state anxiety, somatic state anxiety and self-confidence subscales of the CSAI-2, ps > .23, although there was a general decrease in somatic anxiety (Day 1: *Mdn* = 10; Day 2: *Mdn* = 9), and an increase in self-confidence (Day 1: *Mdn* = 23; Day 2: *Mdn* =27), based on Wilcoxon tests (ps < .05).

2.4 Discussion

There were two objectives to this study. First, we wanted to determine if an easy-to-difficult practice progression would elicit similar errorless learning advantages over a difficult-to-easy progression, as reported in previous studies (e.g. Maxwell et al., 2001). The second aim was to probe potential perceptual/motivational reasons for these effects in lieu or in addition to the implicit learning account, specifically testing whether perceptions of self-efficacy and motivation may have moderated or caused group differences. In the thesis proposal, I had planned to test additional, easy-to-difficult and difficult-to-easy practice groups that would also receive positive social comparative feedback in early practice. However, due to the lack of group differences, these additional groups were not tested.

Contrary to previous work, we did not show performance and learning advantages for the easy-to-difficult versus difficult-to-easy practice group (cf. Capio et al., 2013a, 2013b; Maxwell et al., 2001; Miller, 2014; Savelsbergh et al., 2012). The groups in the present study were not different in outcome accuracy scores during acquisition or retention. Group differences were apparent for RE and BVE, but only for the two furthest practice targets. The difficult-to-easy (far-to-near) group that started with more difficult or further targets was initially more errorful (or inaccurate) than the easy-to-difficult (near-to-far) group that ended with these further distances. However, these differences did not translate into higher error overall, and, importantly, group differences in accuracy and variability on the further practice targets were not reflected in retention or transfer test performance. Though the groups became more self-efficacious over practice, and reported an overall increase in motivation and self-confidence, and a decline in somatic anxiety, behavioural learning outcomes were not differentially affected by the task progression manipulation, nor did they show any differences in measures of explicit knowledge, secondary task tone-counting or outcome prediction accuracy, that would be indicative of a more explicit control/error-processing versus implicit type of learning process.

Individuals that practise an easy-to-difficult task progression are likely to experience early success or low error that stimulate a more implicit type of learning than early conditions promoting high error. Yet, as the task variation gradually becomes more difficult in an easy-to-difficult practice, error tends to increase and subsequent performance may stagnate or regress relative to initial performance, potentially depressing self-efficacy and motivation by the end of practice. The opposite could be true for difficult-to-easy task variations, with lower success/greater error in initial practice, followed by large improvements in performance that possibly enhances self-efficacy and motivation towards the latter half of practice. It is not known how changes in relative performance or success within a practice session might impact perceptions and/or learning. This potentially moderating role of success perceptions as a function of practice improvement is considered in more detail in Study 4 (see Chapter 5).

We were not the first research group to report a lack of benefits for a practice schedule that progressed from easy to difficult with respect to performance in practice and motor learning in general. In a disc-propulsion training task, fewer overall target misses were made by participants that engaged in a difficult-to-easy (far-to-near) progression during practice and in transfer to a new distance, compared to participants practising the reverse progression (Sanli & Lee, 2014). However, no group effects were noted between the groups during retention and testing under dual-task conditions. Again, it is important to note that in the difficult-to-easy progression, participants were likely to experience large improvements across trials as the practice task became easier, although they started out with larger errors. Therefore, neither relatively more success at the end of practice (seen in Sanli & Lee, 2014), nor higher levels of initial success, as noted in our study, had an impact on behavioural measures in retention.

Avoiding errors during practice so as to prevent error processing and explicit motor control goes against other principles of motor learning that advocate making practice more difficult, leading to more error in practice, but less error in retention. As detailed in the introduction, conditions of greater CI, such as a randomized order of practice, degrades performance but benefits retention due to the cognitive processing demands imposed on the learner. Further evidence against the benefits of errorless learning protocols was shown by Lee and colleagues in a series of keypress experiments (2015; cf. Levac et al., 2017). The amount of choice or guidance (1-choice to 4-choice) that was provided for the next keypress of a sequence

was manipulated to affect error rates during acquisition. Most guidance was given in the 1-choice condition resulting in the least practice error, and vice versa for the 4-choice condition. Contrary to expectations, it was the most errorful group that performed best in retention. The authors argued that it was not necessarily the quantity of error that mattered for learning; rather it was the type of error that was either desirable or undesirable. Desirable errors emanating from task-relevant challenges were considered beneficial for learning because committal of such errors would enhance overall cognitive effort including error-detection and correction processes, decision-making and discovery of strategies to aid task performance. Undesirable errors, in contrast, were committed due to task-irrelevant difficulties, such as distractions or inconsistencies in the performance environment. In the present study, the quality of errors experienced by both groups of participants was likely to be equally desirable for learning, as the underlying structure of dart-throwing, such as rules/constraints, objective difficulty and sensory-motor feedback, was consistent across groups. The absence of performance or learning differences between the groups was possibly due to the absence of differentiation in quality or quantity of errors experienced by the participants.

It is worth considering whether the lack of behavioural effects might have been in part moderated by the difficulty of the present task. In previous research where advantages of an easy-to-difficult practice progression over the reverse has been shown, a considerable quantity of practice trials were performed (t = 400, golf-putting, Maxwell et a., 2001; ~3 days, beanbag throwing, Capio et al., 2013a, 2013b). Dart-throwing is likely subject to greater variability than a simple putting or throwing task. While our participants showed a general increase in accuracy across day 1 (i.e., pre- to post- tests), differences between the pre-test and retention were not seen (although neither were significant decrements noted across the 24 hr retention interval). To attain performance stability, the participants may have required more than the 210 trials of practice or would have benefitted from practice spread over more days/sessions. However, a large number of trials were provided in the disc-propulsion task, which was relatively simple, and an absence of retention and secondary task effects was still reported (Sanli & Lee, 2014).

Individual participants may react differently to performance outcome, diverging from the reactions or interpretations that we have hypothesized. Participants that opted into the study with more robust self-confidence may maintain a stable confidence in their ability in the face of

challenges, high error or negative performance feedback (Beattie, Hardy, Savage, Woodman & Callow, 2011). Other individual traits, such as achievement goal orientation, can also affect personal interpretations of error or negative feedback (e.g., Dweck, 1986; Nicholls, 1984). For someone who is highly task-oriented, large persistent errors in early practice, as seen in a difficult-to-easy progression, may not significantly impact self-efficacy or motivation as the individual is focused on achieving skill mastery and unlikely to be deterred by low success. High task-orientation is likely to encourage problem-solving and rule generation, as long as the goal of the task, i.e. hitting the bullseye, was not consistently achieved. High success rates in early practice also do not necessarily augment perceptions of success or competency, particularly if individuals attribute the cause of success to external factors, such as task simplicity, instead of ability (Weiner, 1979).

In the present study, we had expected error or success to be differentiated by the task progression manipulation, in that an easy-to-difficult progression would generate greater perceptions of success in early practice, vice versa for the difficult-to-easy group. However, unlike other studies where success was indicated by the sinking of a golf ball (Maxwell et al., 2001), or a target hit (Capio et al., 2013a, 2013b; Savelsbergh et al., 2012), it could be argued that none of the dart-throwing trials were considered successful by the participants in our groups, unless the bullseye was hit. Considering that the bullseye was hit on ~ 2 % of practice trials, participants' perception of success may have been equally low in both groups. In lieu of a graduated scoring system, a binary (hit or miss) scoring system would have better distinguished the groups in terms of success in early or overall practice (see Study 2).

While it makes logical sense to organize practice in an easy-to-difficult progression for a learner, so as to promote early adoption of optimal movement techniques and avoid injury, it would appear that errorless learning protocols, such as task-difficulty progressions, do not necessarily differentiate learners' experiences of success or error in a consistent way. The efficacy of such protocols may be moderated by overall task difficulty, saliency of success in performance, and pre-existing individual differences. Errors themselves may not be undesirable for learning, as implicit learning proponents have suggested. Challenging or difficult practice conditions that result in high error have been shown to be beneficial for learning, prompting greater error detection and correction processes that aid retention and generalizability of skill.

2.5 Bridging Section to Study 2

In Study 1, the aim was to test how task progression manipulations impact both behavioural measures of performance, as well as psychological factors related to competence and motivation. Although I did not find evidence that these perceptions influenced overall success, one of the reasons for this lack of difference may have been due to the lack of difference in overall error experienced in practice. In Study 2, my plan was to more directly probe if and how perceptions of success and error in practice impact motor learning through manipulations to target size. Two distinct targets were used in a dart-throwing task that would have associated high (large target) and low (small target) success rates.

3 Manipulating Target Size Influences Perceptions of Success When Learning a Dart-Throwing Skill But Does Not Impact Retention[1] (Study 2)

3.1 Introduction

Becoming skilled at a task or sport is often the ultimate goal of a participant or athlete when self-initiating participation and practice. Although "skilled" performance may be defined in many different ways, what it requires is the ability to produce a movement (form) or outcome with precision and consistency to a preset level or standard of attainment (e.g., Adams, 1987; Crossman, 1959; Fitts & Posner, 1967). As a learner progresses through practice, a reduction in performance errors is typically experienced and this reduction serves to inform both the learner and their coach about the efficacy of a training method and level of skill and success attained (e.g., Lohse & Hodges, 2015).

Error information is available through intrinsic and extrinsic (or augmented) sources of feedback. Intrinsic sources of feedback are those that are naturally occurring consequences of interaction with the task or skill, such as vision and proprioception. Augmented feedback is an external, supplementary source of information about the task or skill (Magill & Anderson, 2012; Schmidt & Lee, 2011). Much of the research in motor learning, involving manipulations to augmented feedback, has been conducted and interpreted within an information processing (cognitive) framework, based predominantly on theoretical ideas of Adams (1971) and later Schmidt (1975, 2003). According to this framework, augmented feedback is argued to provide error information about performance, which impacts the learner's subsequent attempts in an error negating manner. Feedback could play a positive role or a negative role, depending on how and when it was provided and the learners' degree of dependency on this information (e.g., Winstein & Schmidt, 1990). For instance, the frequency of augmented feedback has a direct impact on learning, with augmented feedback after every trial in practice resulting in less effective learning (as evidenced in a no-feedback retention test), than a practice with a reduced frequency of feedback (e.g.,Weeks & Kordus, 1998). Recently, there has been a shift in thinking about how feedback regarding error works to influence learning. In addition to its information

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[1] *This chapter was published as an independent manuscript in Frontiers in Psychology in 2015, volume 6: 1378.*

processing/cognitive role, it has been argued that the affective role of error feedback for learning is important and that this has mostly been ignored in studies of motor learning over the past 40 years (e.g., Lewthwaite & Wulf, 2012). There is now evidence that manipulations to the perception of error information impact motor learning and how well performance is retained over a retention interval.

Manipulating the goal-criterion is an intervention, which researchers have used to influence perceptions of error feedback and interpretations of success during skill acquisition. In a visuomotor adaptation task, where learners experience a mismatch (angular discrepancy) between their actual hand movements and a virtual cursor trajectory representing their hand movement and learn to adapt to this discrepancy, Trempe et al. (2012) assessed the 5-min and 24-hour retention of aiming to hit virtual targets. Of the two groups that completed the 24-hour retention, the group that practised with an easy-goal, (i.e., a successful trial if the cursor touched the target) outperformed the difficult-goal group (i.e., successful trial only if the cursor completely covered the target) during retention. This advantage for the easy-goal group was despite the fact that both groups were tested under the difficult-goal criterion in retention. Importantly, the two groups did not differ from each other with respect to objective error during practice. The authors suggested that perceived success was an important contributor to memory consolidation processes, possibly through modulation of arousal-related hormones, such as epinephrine, or the reward-related dopaminergic system (e.g., Brashers-Krug et al., 1996; Robertson et al., 2005; Shadmehr & Holcomb, 1997).

In the study by Trempe and colleagues (2012), the participants were asked once, at the end of practice, how they perceived their performance (i.e., efficacy ratings) using a 5-point Likert scale. The easy goal groups evaluated their performance as being significantly better than participants in the difficult criterion groups. This supports the authors' claim that it was perception of success that mediated retention improvements. However, because the participants were not asked again in retention, it is possible that the enhanced feelings of efficacy carried through to retention and potentially impacted performance at the moment of testing in retention in addition to or instead of during the consolidation interval.

Adaptation learning has sometimes been noted as a special case of learning, due to the requirement to adapt motor commands in an altered, often artificial or virtual environment (Krakauer, 2009). In these tasks, the error signal is one that alerts to a mismatch between sensory sources of information (e.g., vision and proprioception) that have been abnormally perturbed. As such, adaptation effects are thought to have limited applicability to other motor learning tasks that require adaptations to errors that are naturally occurring consequences of a normally calibrated sensory system (e.g., throwing a dart too high or too low). Moreover, in adaptation tasks, improvements in responding to the mismatch are often implicitly driven (unconscious) and not necessarily aided by explicit strategies in response to errors (e.g., Mazzoni & Krakauer, 2006). Therefore, it would be important to test the generalizability of these results for tasks where the feedback is veridical, error processing and correction is encouraged and that in general, better typify learning episodes more frequently encountered outside the laboratory.

In the only other study to date where goal-criterion manipulations have been used to influence success perceptions, there was again evidence that these perceptions influenced how well a motor 'skill' was retained. Using a coincident-anticipation timing task, participants controlled when they received feedback about objective timing error (the degree and direction of error in ms), with the constraint that it was limited to a third of all practice trials (Chiviacowsky et al., 2012). Participants practised under one of three conditions; 1) a difficult goal-criterion (an error of 4 ms or less was considered a "good" trial), 2) a less difficult or more viable goal criterion (an error of 30 ms or less was considered a "good" trial), or 3) they were not told what constituted a good trial (control group). In a 24-hour retention test and an opposite limb transfer test, participants given the difficult goal were less accurate and more variable than the other groups. Although the groups were not statistically different in practice, the difficult group showed a tendency for greater error and variability, suggestive of immediate effects of success perceptions on performance (that arguably carried through to retention). However, because the statistical differences were located after a retention interval, the authors argued that perceptions of success impacted memory processes occurring in the retention interval (i.e., consolidation). After practice ended, on a confidence scale of 1 (not at all) to 10 (very) that participants could perform the task with errors of less than 50 ms and 30 ms on the following day, both the less difficult goal and control groups indicated higher self-efficacy (i.e. task-specific confidence)

ratings than the difficult goal group. As with Trempe et al. (2012), self-efficacy was probed once only, post-practice.

Though the coincident-anticipation timing task used by Chiviacowsky and colleagues (2012) was arguably more representative of real-world motor skills than a visuomotor adaptation task, the occlusion of visual stimuli during the response phase and lack of naturally-occurring, intrinsic feedback (in addition to the small percentage of trials when feedback was provided), was likely to have resulted in a heavy dependence on the augmented feedback for error detection and judgments of success. It is highly unlikely that participants were able to rely on internal timing mechanisms (i.e. intrinsic feedback) to accurately judge timing errors to the precision of 50 ms (1/20th of a second) or smaller. Hence, from the literature on goal-related manipulations to success, it is difficult to know how well these findings apply to other tasks where objective error is more salient and the success manipulations are interpreted co-jointly with objective error feedback. Stated in practical terms, is it sufficient to loosen the constraints on "success" to enhance learning, such that the same performance in practice (as a comparison group) is made to look more successful than another? Importantly, participants are not aware that there is a comparison group and whether they are performing worse or better than that group (as positive "self-other" comparisons, or what has been termed "social-comparative feedback", have been shown to enhance learning, e.g., Ávila et al., 2012; Lewthwaite & Wulf, 2010a).

In summary, there is some evidence that techniques which promote perceived success are beneficial to motor consolidation and learning, although the strength of these effects and potential mechanisms are still unclear. In both studies by Trempe et al. (2012) and Chiviacowsky et al. (2012), because objective performance was not different between groups in practice, differences in perceptions of success (and potentially efficacy) were purported as explanations for the learning effects. It is also possible that a perception of higher error leads to a more explicit, strategic mode of control, whereby individuals are consciously trying to control/correct performance from trial to trial (e.g., Masters & Poolton, 2012; Maxwell et al., 2001; Poolton et al., 2005). This may be maladaptive for stabilizing performance (Schmidt, 1991; Sherwood, 1988) or for performance under conditions that promote self-awareness and anxiety (such as retention tests or tests performed under dual-task loads). Indeed, participants with the difficult goal-criterion in the study by Chiviacowsky et al. (and similarly in the Trempe et al., study) may

have been trying to correct errors that could not have been corrected or controlled (e.g., improving on timing errors less than a 20th of a second), which might also have negatively impacted their overall retention if the memory representation was less stable over time.

The aim of the current study was to investigate how perceptions of error (and hence success) during practice of a 'real-world' motor task, where feedback is a naturally-occurring consequence of performance, would moderate motor learning and retention. Perceptions of error were manipulated by changing the size of the target area in a dart-throwing task. This is a relatively simple method that could be used in other tasks to enhance perceptions of success, without changing the constraints on performance and keeping the objective error alerting role of feedback integral and essentially constant. Participants practiced dart throwing at either a small or a large target from the same distance. Because the throwing distance is identical for both groups and that aiming to the centre of the target (i.e., the bullseye on a dartboard) would be the best strategy for success, we expected that objective practice performance (i.e., radial error from the centre) would be matched across the groups. However, the groups would differ with respect to their subjective interpretation of this information and hence perceptions of success, with more successful target "hits" and increased perceptions of efficacy in the large (easy) target group compared to the small (difficult) target group. Based on past research, we expected that participants throwing to the larger target and hence that experienced more success in practice, would show enhanced performance on a delayed (one-week) retention test than participants throwing to a smaller target (i.e., show improved learning). However, objective error during the practice phase was not expected to be different between the groups.

Self-efficacy perceptions were continually monitored throughout practice and before delayed retention. We also assessed how the manipulation to target size affected explicit knowledge and rules generated by participants about how to perform the skill (i.e., strategic control). If potential benefits associated with greater experience of success in practice is related to a less explicit mode of control (i.e., a more automatic and stable type of control) as suggested by Maxwell and colleagues (2001; Poolton et al., 2005), then the large target group was expected to report fewer rules/hypotheses about dart-throwing than the small target group. As an additional measure of the type of control adopted when performing the dart-throwing task, we also tested participants under secondary task conditions, where they simultaneously performed

the throwing task and a tone-counting task. Again, we expected that the large target group would not experience a performance decrement in this condition, while the small target group was expected to show a decrement, indicative of a more explicit mode of control.

3.2 Methods

3.2.1 Participants and groups

Adult, female, right hand-dominant, novice dart players were recruited via posters and advertisements. All participants were volunteers and gave informed consent before participation (in accordance with ethical procedures of the University). Remuneration of $10 per hour was paid. To ensure that only novice players were included, we verified that participants had not played darts on more than three occasions. We pseudo-randomly assigned to group with the constraint that participants were approximately matched for performance based on a pre-test (i.e., throwing 9 darts at a dartboard, from the regulation distance of 237 cm). Participants were assigned to either a Large target group (Large-T; n = 28) or Small target group (Small-T; n = 27)[2].

3.2.2 Task and apparatus

We modified a regulation size bristle dartboard by removing all metal wire and rings (see Figure 3.1). The board was then mounted with the centre of the bullseye at a height of 1.73 m from the floor. In a pre and post-test, the task was to throw darts at the "bullseye" of the dartboard (defined in this study to comprise of both the inner and outer bull of a standard dartboard). During practice, participants in the Large target group and Small target group aimed at yellow, circular practice targets of 16 cm and 7 cm radii, respectively, that were paper targets stuck over the top of a regulation dartboard, with the centre of the targets overlaying the origin of the dartboard. The large target was approximately five times larger than the small target in area and covered the whole of the dartboard.

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[2] *Two participants were excluded from analyses as their mean pre-test radial error scores were more than 3SDs greater than the mean pre-test radial error of the other participants.*

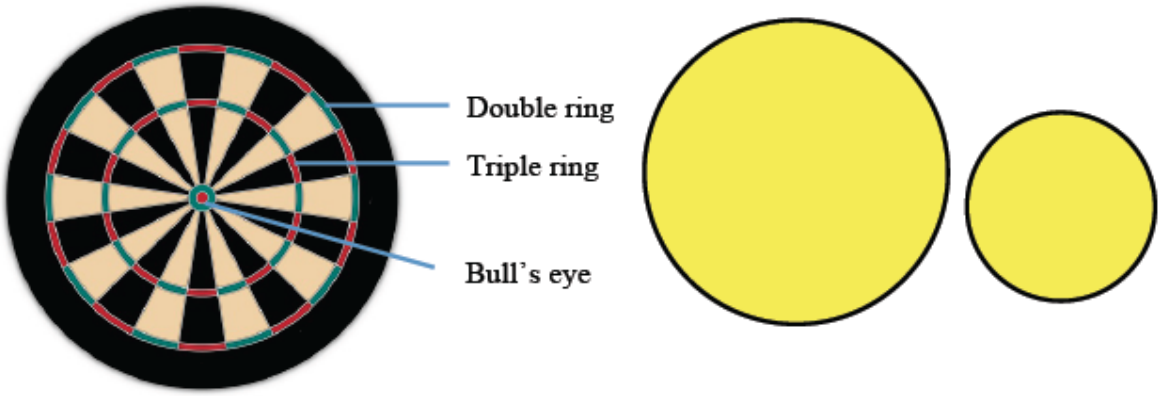

Figure 3.1. Schematic of dartboard (at left) and yellow practice targets (large and small). Bullseye comprised of both the red and green circular zones (the inner and outer bull respectively) in the centre of the dartboard.

Darts landing outside the yellow targets were recorded as "misses", scoring no points. "Hits" were hence recorded as darts landing in the yellow target area (see Figure 3.1). Both hits (checks) and misses (zeros) were recorded by participants on a tally table located to the right of the dartboard in order to increase the salience of success (after every 3 darts thrown). During the experiment, darts that did not fix on the board were recorded based on later verification by video. Three darts (26 g each) were given to participants to perform the task in sets of 3 trials. A video camera was set up behind and above the participant so that dart landings of all trials were recorded for subsequent analysis of *x* and *y* coordinate positions in relation to the centre of the dartboard (i.e. origin), using Dartfish © Prosuite video analysis software (Dartfish, USA)[3]. These values obtained from the video were used for computation of radial error (RE; accuracy) and bivariate variable error (BVE; variability) of throwing performance. A standard ruler was used to measure radial error during the pre-test, post-test and retention tests as a back-up measure of radial error (recorded by the experimenter in the interval between each set of 3 darts). No ruler was used in acquisition as we did not wish to alert participants to errors in relation to the centre of the dart-board (rather than merely aiming to hit the yellow target zone).

[3] *For the first 5 participants assigned to each group, videos were only recorded of dart landings during the acquisition phase. Hence, x and y coordinates, and bivariate variable error were not computed for the test phases of these 10 participants (only radial error was recorded from measurements made with a ruler at the time of testing).*

3.2.3 Procedure

The experiment took place across two sessions, separated by one week (range of 6-8 days). There was a pre-test, followed by a practice (acquisition) phase, then an immediate post-test during the first session and a delayed retention and transfer test approximately 1 week later. Participants were told not to step over the throw line and not to throw with a sidearm, that is, to keep their arm in the sagittal plane of motion as much as possible (this action was demonstrated). We also told participants that to maximize success at hitting the target a good strategy would be to aim for the centre, even though success would be determined based on hitting the target.

Three warm-up throws (which were not recorded) then followed, before participants were introduced to the self-efficacy rating scale which was posted approximately 50 cm to the left of the dartboard (from origin). The scale ranged from 0-100% (in increments of 10) and corresponding descriptors were; “0” = “not at all”, “10” = “not sure”, “40” = “somewhat sure”, “70” = “pretty sure” and “100” = “very sure” (Zimmerman & Kitsantas, 1997). Using the rating scale, participants were prompted for their self-efficacy of landing at least one out of three subsequent throws within each of three pre-determined areas, giving a total of three self-efficacy ratings. The largest of the three pre-determined areas was the area subtended by the ‘double’ ring on the outside rim of a standard dartboard, as shown in Figure 3.1. This was a size roughly corresponding to the large or easy practice target. The “small” area corresponded to the area subtended by the ‘triple’ ring around the middle of a standard dartboard (roughly corresponding to the small or difficult practice target in size). The smallest pre-determined area (not a practiced target) was the bullseye, which for the experiment consisted of both the inner and outer bull as illustrated in Figure 3.1.

3.2.3.1 Pre-test

Before pre-test trial 1, participants indicated a self-efficacy rating for each of the three pre-determined (large, small and bullseye) areas of the dartboard. Following the ratings, 9 pre-test trials ensued.

3.2.3.2 Acquisition

During acquisition, which immediately followed pre-testing, participants were asked to aim at their practice target and were told to make as many "hits" as they could (i.e., land the dart in the yellow target zone). Before Acquisition trials 1, 31 and 61, participants indicated their self-efficacy for making a hit on at least one of the subsequent three trials. A total of 90 darts (across 10 blocks) were thrown during acquisition. One point was awarded for each hit made. In between sets of trials, participants walked over to the tally table to record the hits and misses made in the set while the experimenter removed the darts. The intention for the self-tallying of hits/misses was to enhance perceptions of success (or failure) and to keep them engaged in their practice.

3.2.3.3 Immediate post-test

Procedures in the post-test were identical to the pre-test, consisting of nine trials and three self-efficacy probes before the first trial. When trials were finished, participants were interviewed by the experimenter to describe any rule, technique or method pertaining to dart throwing that they had generated or become aware of during practice. These qualitative responses were subsequently categorized and analyzed by the experimenter. The first session ended when participants signed a form confirming receipt of remuneration for participation and agreed that they would not practise or learn more about darts before returning to the laboratory in a week.

After a week, participants returned to the laboratory for Session 2. They first performed three warm-up trials (data not recorded), then administration of the delayed retention and secondary task tests were counterbalanced for order so that half the participants in each group completed one test before the other.

3.2.3.4 Delayed retention

The delayed retention test was identical to the post-test, with participants performing nine dart throws and indicating their self-efficacy on the three, pre-determined self-efficacy areas, before their first trial.

3.2.3.5 Secondary task

In addition to the primary task of throwing sets of three darts, participants had to simultaneously monitor and count high pitch tones in an audio sequence. It was verified that participants understood the secondary task in a warm-up tone-counting sequence that was similar to the audio sequences played during the test. High and low frequency tones (duration of 300 ms/tone) were interspersed at inter-stimulus intervals between 500-1000 ms, to create 3 random and unique audio sequences. Participants were instructed not to begin their set of three throws until the first tone of the sequence had been played. When participants completed a set of trials, audio playback was stopped, after which participants were prompted to indicate the number of high tones they had mentally counted in the set. In total, 3 sets of 3 throws were made in the secondary task condition.

3.2.4 Data Collection and Analysis

3.2.4.1 Outcome variables

In addition to recording the number of target hits made during practice as a function of group, a more sensitive measure of outcome accuracy was determined based on radial error (RE), which was defined as the absolute distance between dart landing and the origin of the dartboard. Mean RE was calculated for each block of 9 trials. Constant error in x (horizontal) and y (vertical) coordinates of dart landing in relation to the origin were calculated based on post-experiment analysis of the video using Dartfish © Prosuite software. With x and y coordinates extracted for each trial, RE for acquisition trials was calculated as $RE^2 = (x^2 + y^2)$. Based on the constant error data, we also calculated bivariate variable error (BVE; Hancock, Butler & Fischman, 1995), based on the following equation:

$$BVE = \sqrt{\frac{1}{k}\sum_{i=1}^{k}(X_i - X_c)^2 + (Y_i - Y_c)^2}$$

where: k = number of trials

X_c = average constant error on the X axis within a test or block

Y_c = average constant error on the Y axis within a test or block

Data collected on the first session were analyzed in separate independent t-tests on pre-test and post-test group mean RE and BVE. Two other Group (Large-T, Small-T) x Block (Blocks 1 to 10) repeated measures ANOVAs were applied to analyze acquisition mean RE and percentage of target hits, with block as the within-subjects factor. Mean RE and BVE from the second session were analyzed in a Group (Large-T, Small-T) x Test (retention, secondary task) repeated measures ANOVA, with group as the between-subjects variable and test as the within-subjects variable.

In the secondary task, we also assessed accuracy of the tone-counting response. The responses were either correct or incorrect. We tabulated the number of response errors made by each participant (maximum of 3 for each individual as there were 3 tone-counting sequences for 3 sets of dart throws during the secondary test condition). These data were compared across groups using a Mann-Whitney U test.

3.2.4.2 Measure of self-efficacy

Our primary measure of self-efficacy was assessed using ratings of self-efficacy. The three self-efficacy ratings provided by the groups during each test phase (i.e. pre-test, post-test, retention test) were analyzed in a 2 Group (Large-T, Small-T) x 3 Test (pre-test, post-test, retention test) x 3 Target area (large, small, bullseye) repeated measures ANOVA. The self-efficacy ratings based on the practiced target only, given three times during acquisition, were analyzed in a 2 Group (Large-T, Small-T) x 3 Acquisition probe (AQ1, AQ2, AQ3) repeated measures ANOVA.

3.2.4.3 Explicit knowledge

A comparison of the number of rules or strategies generated following the immediate post-test were analyzed as a function of group using a Mann-Whitney U test.

Partial eta squared (η^2_p) values were reported as measures of effect size and post hoc analyses were conducted using Tukey's HSD ($p <. 05$) for all significant effects. Greenhouse-Geisser corrections were applied for violations to sphericity.

3.3 Results

3.3.1 Manipulation checks

3.3.1.1 Target hits

Confirming the success of the manipulation, the Large-target group made significantly more target hits (M = 7.4/block, SD = 1.4) than the Small target group (M = 2.9/block, SD = 1.6), F(1, 53) = 384.17, $p < .001$, $\eta^2_p = .88$. Although there was also a block main effect, F(9, 477) = 2.445, $p = .01$, $\eta^2_p = .04$, indicating a general increase in frequency of hits over the course of acquisition, there was no significant Group x Block interaction, $F < 1$.

3.3.1.2 Self-efficacy

As shown in the middle of Figure 3.2, self-efficacy during acquisition increased, F(1.7, 90.0) = 16.96, $p < .001$, $\eta^2_p = .24$, with post hoc analysis showing a significant increase from AQ1 to AQ3. As would be expected, but serving as a manipulation check, the groups were also different in their self-efficacy in hitting their respective targets, F(1, 53) = 734.66, $p < .001$, $\eta^2_p = .93$. The Large-target group (M = 90.1%, SD = 14.1) was more self-efficacious about hitting their assigned target than the Small-target group was about hitting their assigned target (M = 55.3%, SD = 27.7). There was no interaction.

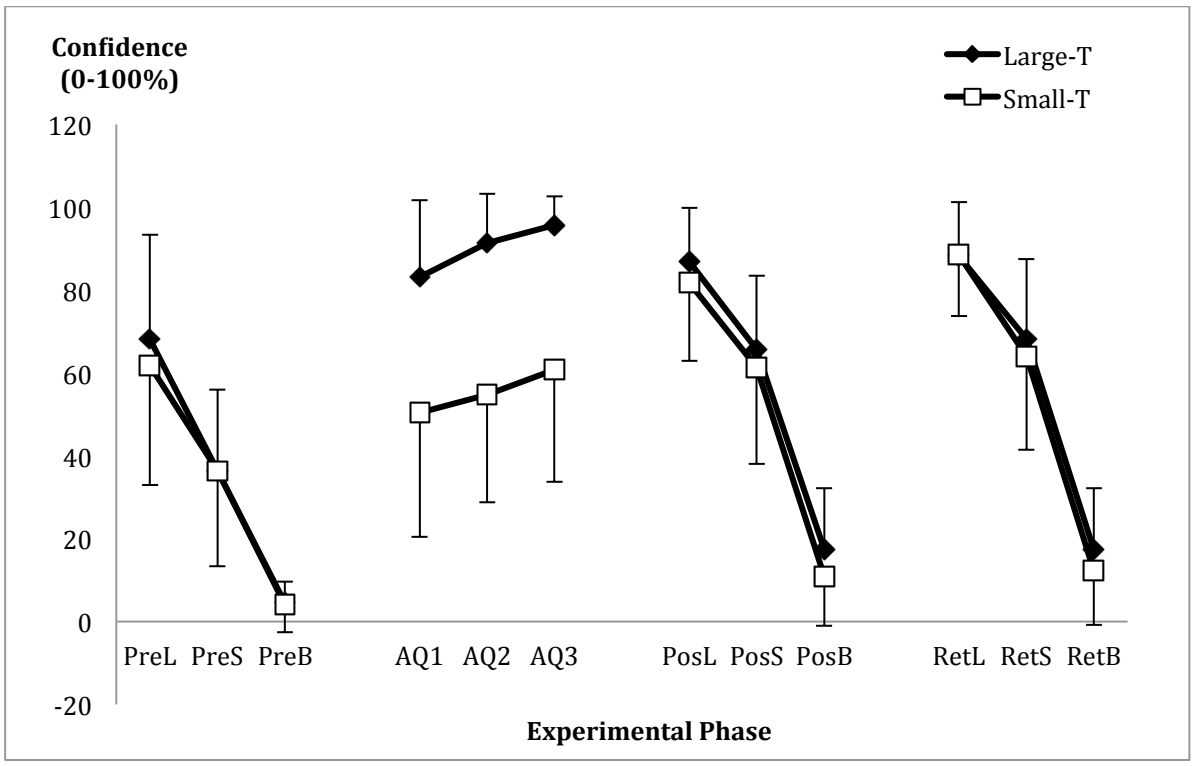

Figure 3.2. Mean self-efficacy ratings of hitting at least one out of subsequent three trials for the large (L), small (S) and bullseye (B) pre-determined areas, as indicated before pre-test (PreL, PreS, PreB), post-test (PosL, PosS, PosB), and retention (RetL, RetS, RetB). Acquisition probes 1-3 were the mean self-efficacy ratings of making a 'hit' at least once out of three subsequent trials before the 1st (AQ1), 31st (AQ2) and 61st (AQ3) acquisition trial. Error bars represent standard deviation of the mean.

3.3.2 Outcome measures

3.3.2.1 Mean radial error (RE)

Outcome accuracy is shown in Figure 3.3. As expected, the groups did not differ on pre-test accuracy, $t(53) = .28$, $p = .78$. Despite our predictions, the groups were not significantly different in the post-test, $t(53) = .42$, $p = .68$, nor was there a significant group main effect, $F(1, 53) = 1.66$, $p = .20$ or interaction ($F < 1$), when the groups were compared during retention and secondary task tests.

A separate analysis was conducted on the acquisition data. Again, there were no effects involving group (all Fs <1), only a main effect of block. This was best described by a linear trend, $F(1, 53) = 11.71$, $p = .001$, $\eta^2_p = .18$, indicating a decrease in RE over the course of acquisition (see Figure 3.3).

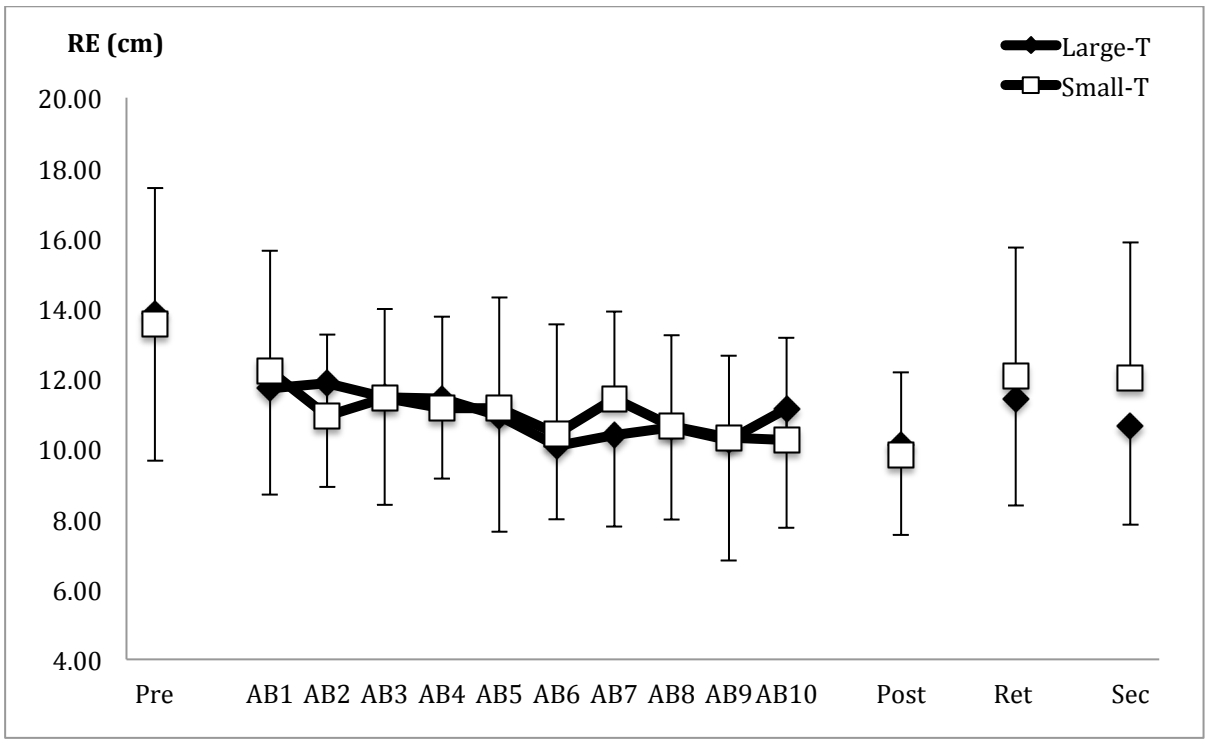

Figure 3.3. RE as a function of pre-test (pre), acquisition blocks (AB1-10), post-test (post), retention (ret), secondary task test (sec), and group (Large Target (T) versus Small Target). Data points and error bars represent the mean of 9 trials and between-subjects *SD*.

3.3.2.2 Bivariate variable error (BVE)

BVE is displayed in Figure 3.4. As with RE, there were no group differences in any of the testing phases (all t and F values equal to or <1).

For acquisition, only the main effect of block was significant, $F(9, 387) = 1.96$, $p < .05$. The groups showed a linear trend of improving consistency (i.e. decreasing BVE) in their throws over the blocks of practice, $p < .01$. For all group-related effects, Fs < 1.2.

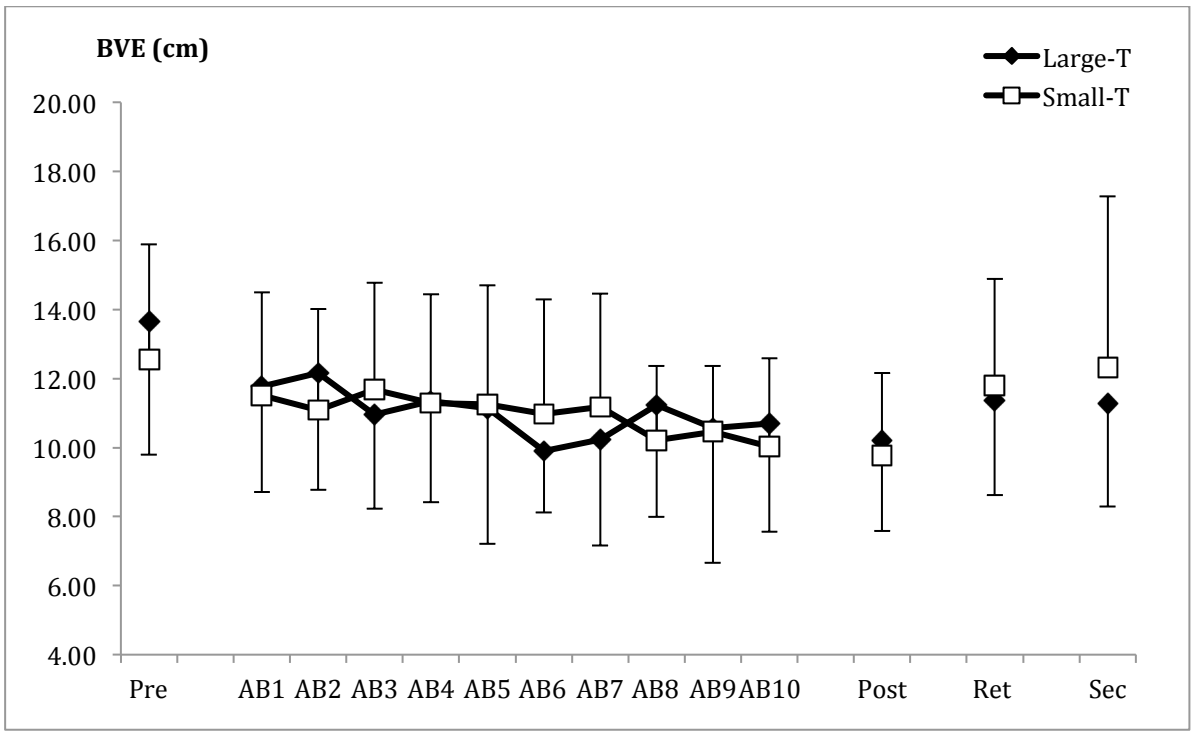

Figure 3.4. BVE as a function of pre-test (pre), acquisition blocks (AB1-10), post-test (post), retention (ret) and secondary task test (sec). Data points and error bars represent the mean of 9 trials and between-subjects *SD*.

3.3.2.3 Accuracy of secondary task tone-counting

The average number of tone-counting response errors made by the Large-target group was 0.7 (*SD* = 0.9) and 1.0 (*SD* = 0.8) for the Small-target group. The groups were not significantly different based on the Mann-Whitney U test, U = 294, $Z = 1.51$, $p = .13$.

3.3.3 Process measures

3.3.3.1 Self-efficacy ratings in the post-test and retention

Self-efficacy ratings were assessed before the pre-, post- and retention-tests, for the three dart-board areas (Large, Small and bullseye), as displayed in Figure 2. Although there was the expected increase in self-efficacy as target area increased, $F(1.6, 69.2) = 465.35$, $p < .001$, $\eta^2_p = .92$, there were no significant effects involving group (all Fs < 1.2). There was a test-phase effect, $F(1.7, 72.6) = 51.43$, $p < .001$, $\eta^2_p = .55$, with self-efficacy increasing from pre-test to post-test and into retention, especially for the two practised targets, as shown by a Test x Target area interaction, $F(3.2, 136.4) = 13.07$, $p < .001$, $\eta^2_p = .24$.

3.3.3.2 Post-experiment explicit knowledge

Neither group reported many rules, strategies or hypotheses for performing the dart-throwing task. The average number reported by the Large-target group was 2.4 (*SD* = 1.3); for the Small-target group this was 2.5 (*SD* = 0.9). These means were not significantly different, U = 357, Z = .37, *p* = .71.

3.4 Discussion

Manipulation of practice target size resulted in greater rates of success for the Large target group than the Small target group during practice. Self-efficacy, as probed by the confidence ratings, also indicated higher self-efficacy for the Large target group than the Small target group. These results were expected outcomes of the manipulation, confirming the fact that changes to target size influenced perceptions of success.

Despite the fact that success rates changed across the two groups, this manipulation to target size did not impact learning (cf. Chiviacowsky et al., 2012; Trempe et al., 2012). Either manipulations to target size did not affect the interpretation of error feedback or enhanced perceptions of success in practice do not always translate to improved learning, as assessed by performance in a delayed retention test. There was evidence of improvement during practice for both groups, in that all participants showed a general increase in frequency of target hits, increase in accuracy (RE) and decrease in variability (BVE) over the course of practice. Moreover, the groups did not differ in objective performance error during acquisition even though they differed on subjective rates of success (number of target hits made).

On the impact of perceived success on motor skill learning, the differences in rates of success (due to target hits) did not translate to more permanent differences in self-efficacy as assessed at delayed retention. Although this was not measured in prior work, the absence of group differences in retention for both practiced and non-practised targets raises issues about the potential of relatively easy target goals to transfer to positive perceptions of efficacy for more difficult goals (i.e., from large to small). Success on a large target does not inform as to success on a smaller target and as evidenced by the self-efficacy scores, the Large (easy) target group did not evaluate their chances of success any more favourably than the Small (difficult) target group.

Perhaps this should not be too surprising, given that going from a difficult to an easier target should result in enhanced perceptions of success, whereas the reverse would result in a decrease. This shows the need to evaluate "success" perceptions with respect to both practiced and non-practised targets to get a true understanding of whether a manipulation to success is likely to affect learning. In this case, the post-test measures of efficacy were not different between the groups when assessed on the same targets.

Unlike the experimental tasks in Trempe et al. (2012) and Chiviacowsky et al. (2012), the current task presented salient outcome error during skill practice, a source of veridical feedback that may have moderated the success experience intended by the current target goal manipulation. Besides success-related outcome feedback based on target hits and misses, objective performance error (i.e., error in relation to the bullseye/centre of target) was available and evident to participants for every dart throw. Hence, this objective source of feedback may have dominated over the subjective success that was assumed to be experienced with target hits. In previous work (i.e., in Chiviacowsky et al., 2012; Trempe et al. 2012), because of the lack of objective error information and the greater dependency on augmented feedback during task performance, perceptions of success were likely less ambiguous.

From the goal setting literature, it appears that moderately difficult goals are most motivating for learners (see Atkinson, 1964; Bar-Eli, Tenenbaum, Pie, Btesh & Almog, 1997; Locke, 1968) and will also avoid a ceiling that leads to learners setting other (more difficult) personal goals. Participants in the Large target group were successful at hitting their target approximately 82 % (mean of 7.4 out of max. 9) of the time during practice. Since they were performing close to the ceiling, it is likely that they had spontaneously set themselves a more difficult personal goal (see Bandura & Simon, 1977) or attributed success to an overly easy task (Bandura, 1998). The saliency of error in relation to the centre of the target may have thus muted perceptions of success that potentially contribute to overnight consolidation processes for both groups. With these considerations, manipulation checks for potential personal goals should be in place for future studies using tasks that provide extra sources (or ambiguous sources) of outcome error, to ensure that the participants had accepted the prescribed goal criterion for evaluations of success. What seems to be a conclusion from this emerging research about the affective role of feedback for learning is that moderations to learning via success perceptions only occur when

these perceptions are unambiguous. If naturally-occurring objective error is available, even if participants may feel more or less successful on another criterion, this source of information appears to dominate how well a task is learned and hence the influence of success perceptions.

It is also important to point out that the groups did not differ on the secondary task, which was expected to give some indication of explicit control. There was no evidence that during practice the Small target group acquired more explicit knowledge (rules and hypotheses) about how to throw the dart (i.e., determining error correction strategies) which are arguably more susceptible to performance breakdowns when working memory demands are increased through the addition of a secondary task load (cf. Masters & Poolton, 2012; Maxwell et al., 2001; Poolton et al., 2005).

The role of error feedback on cognitive-affective processes in motor learning has garnered and generated much research interest of late (e.g. Ávila et al., 2012; Chiviacowsky et al., 2012; Lewthwaite & Wulf, 2010a; Trempe et al., 2012). In this study, we have highlighted limitations to the effectiveness of positive or success-related feedback for learning. Manipulating performance perceptions through different goal-criteria, we showed that whilst target size moderates perceptions of efficacy during practice, the differences in perceptions of success (at least with respect to measures of self-efficacy and successful target hits), did not lead to differences in retention. It appears that when veridical objective error is available, the saliency of this feedback moderates or overwrites subjective success manipulations intended to benefit learning. It is also possible that goals that are too easy are not evaluated positively or judged as motivating or rewarding (e.g., Caplin & Dean, 2008). In comparison to Trempe et al. (2012), success was achieved on 62 % of trials for the easy-target group in their study, whereas this was 82 % in the current study. Similarly, in Chiviacowsky et al. (2012), the less difficult goal group was “successful” on 53 % of their feedback trials. Given these differences in success, it is possible that there are limits to which “success”, associated with achieving goal-criteria, would actually translate to positive perceptions of performance for the learner. In comparison to the relative success of social comparative feedback (i.e., superior performance relative to peers) in influencing perceptions of success (e.g., Ávila et al., 2012), manipulations to the target goal rely on a subjective perception of what the feedback means. Therefore, feedback is likely to be less effective at changing perceptions of success and subsequently learning, when the goal-criterion

is easily attained, when other sources of performance feedback are available and when comparisons are not made to other people.

Regardless of the reason for the lack of positive effects on learning associated with easier target goals, we would argue that caution is needed when using goal criteria to manipulate success perceptions and learning. In order to tap into potential affective gains associated with positive or success-related feedback, instead learners might benefit more from receiving positive social comparative feedback or evaluating their performance on unambiguous standards/goals when objective error feedback is present.

3.5 Bridging Section to Study 3

The purpose of Study 2 was to examine if and how success perceptions impact motor learning through manipulations to target size (large vs. small) during practice. While groups were differentiated according to success rates attained in practice, we noted some limitations related to methodology. In Study 3, we re-examined the same research question with minor modifications to procedures that were aimed at simplifying the task and eliciting practice success rates that better matched other work that reported learning benefits with similar goal/target size manipulations.

4 Target Size Manipulations affect Error-Processing Duration and Success Perceptions but do not Impact Behavioural Indices of Performance and Learning (Study 3)

4.1 Introduction

The field of motor learning has seen a recent shift of focus from a traditional, informational-processing perspective towards motivational (i.e., affective and social-cognitive) perspectives of study. Empirical evidence indicating the efficacy of practice manipulations which enhance competency/success, on motor skill learning, has contributed to the conception of the OPTIMAL (Optimizing Performance Through Intrinsic Motivation and Attention for Learning) theory (Wulf & Lewthwaite, 2016; Lewthwaite & Wulf, 2017). According to this theory, enhanced expectancies, such as self-efficacy, outcome expectations and predictions of rewards, help satisfy the intrinsic, human psychological need for competency (Deci & Ryan, 2000), which benefits motor learning. However, there is evidence that such enhanced expectancies, which we term success perceptions, do not always benefit learning and the evidence from research groups external to the main proponents of OPTIMAL theory seem ambiguous at best (e.g., Carter et al., 2016; Ong et al., 2015; Ong & Hodges, 2017; Patterson & Azizieh, 2012). The purpose of this study was to further explore the impact of success-enhancing manipulations (i.e., different target sizes) on performance, learning and motivational outcomes, whilst controlling for factors which might have explained the lack of learning effects in previous studies. A secondary purpose was to determine how psychophysiological, neuromuscular and explicit-control processes, related to knowledge acquisition, are affected by such manipulations in the absence of, or in tandem with, behavioural effects.

A number of studies have been published (mostly by the same group of researchers) showing how manipulations that target "success perceptions", impact motor learning. In one such study, the manipulation was employed before any physical practice, by simply revealing to participants that the experimental, balance-task was "acquirable" (Wulf & Lewthwaite, 2009). Motor learning for the "acquirable" group, as assessed in a retention test, tended to be superior to a control group which did not receive this information, and a group that was informed that the task reflected an inherent ability (also Drews, Chiviacowsky & Wulf, 2013). Other success-

related manipulations have been implemented during skill practice, usually through augmented feedback. By providing false, positive social comparative feedback (e.g., Ávila et al., 2012; Chiviacowsky & Drews, 2016; Gonçalves et al., 2018; Lewthwaite & Wulf, 2010a; Wulf et al., 2010, 2012), or selective feedback on practice trials with better outcomes (e.g., Abbas & North, 2018; Badami et al., 2012; Chiviacowsky & Wulf, 2007; Saemi et al., 2012) benefits to learning have been shown.

Besides manipulations to feedback, researchers have set easy task criterion goals for success (e.g., Chiviacowsky et al., 2012; Trempe et al. 2012), or manipulated task difficulty, such as increasing the physical size of aiming targets (e.g., Palmer et al., 2016), to impact overall success. For example, in a golf-putting study, participants practising to a large circular target were more accurate in practice and retention compared to a small target group, even when both groups were subsequently tested on a small target (Palmer et al., 2016). In other manipulations to target size, learning benefits for large-target groups have often been in conjunction with evidence of enhanced perceptions of self-efficacy, compared to control or small target groups (e.g., Chiviacowsky et al. 2012; Trempe et al., 2012).

Researchers have attributed the learning advantages associated with error/success manipulations to various factors including: (i) increased motivation, due to increased feelings of competency and efficacy (potentially mediated through effort/concentration as detailed in OPTIMAL theory, Wulf & Lewthwaite, 2016), greater automaticity in movements associated with less explicit cognitive control and processing, perhaps as a result of (ii) an external focus of attention (Wulf, 2013) or (iii) more implicit learning (reinvestment hypothesis, Masters & Maxwell, 2008), and (iv) enhanced memory consolidation associated with biochemical processes related to release of dopamine associated with high reward states (Trempe et al., 2012; Wise, 2004; Wulf & Lewthwaite, 2016), In the following paragraphs we discuss evidence related to these various mechanisms.

Learning related benefits that seem to be mediated by enhanced self-efficacy and increased motivation has been provided by a number of researchers (e.g., Chiviacowsky et al., 2009; Lewthwaite & Wulf, 2010a; Palmer et al., 2016). The relation between self-efficacy and motivation has been detailed in social cognitive theory, whereby high competency perceptions

are thought to have an energizing effect on performance (Bandura, 1991, 1997; Zimmerman, 2000). In two studies whereby participants were selectively given feedback either on trials with better or worse outcomes, the group receiving better feedback reported greater intrinsic motivation (Badami et al., 2011) and self-efficacy (Saemi et al., 2012) than the worse feedback group. Self-efficacy was also higher in participants that performed an easy version of a dowel-balancing task compared to a difficult-version group (Stevens, Anderson, O'Dwyer & Williams, 2012). Although researchers have argued that motivation plays a mediating role in the contribution of success-manipulations towards enhanced motor learning, it is unclear how motivation affects practice within a practice session, other than affecting participants' effort in the task. To date, no one has examined changes in effort with such success-manipulations.

Success-manipulations can also affect performance and/or learning through cognitive processes, which can impact motor control. When a task is relatively easy and errors are minimized in performance, learners accrue less explicit knowledge and are thought to achieve greater automaticity in movement control (e.g., Masters, 1992, Maxwell et al., 2001). In contrast, skills or tasks that are difficult or demanding promote explicit hypothesis testing and build-up of task-relevant knowledge and potentially a more conscious or explicit mode of control, characterized by more rigid (less automatic) movements (e.g., Lewthwaite & Wulf, 2010a; Poolton et al., 2005). More controlled cognitive processing has been shown to be detrimental to retention and/or in more challenging conditions involving dual-tasks or added stress (e.g., Beilock & Carr, 2001; Ford, Hodges & Williams, 2005; Masters & Maxwell, 2008).

A third process proposed to explain delayed learning benefits associated with success-manipulations is memory consolidation. Memory consolidation processes are subject to dopaminergic modulations that facilitate stable memory formation and are responsive to rewarding consequences (see Wise, 2004). They are thought to stabilize and enhance the encoding of information into memory during the retention period when practice has ceased (Brashers-Krug, Shadmehr & Bizzi, 1996; McGaugh, 2000; Robertson, Press & Pascual-Leone, 2005; Shadmehr & Holcomb, 1997). Such delayed differences between groups, which differ based on success experienced, have been shown in a couple of motor learning studies (e.g., Chiviacowsky et al., 2012; Trempe et al., 2012). In these studies, task difficulty was manipulated such that easy-goal groups were assessed under more lax success criterion for a 'good' trial

during practice and experienced greater success than difficult-goal groups (Chiviacowsky et al., 2012; Trempe et al., 2012). Though the groups showed no objective difference in performance during practice, in both studies, the easy-goal groups were more accurate in delayed retention, an indication that enhanced success perceptions benefited learning through post-practice, memory consolidation processes.

Contrary to evidence in support of the OPTIMAL theory and benefits associated with enhancing success perceptions in practice as a means to aid learning, some researchers have not had success replicating these effects. In studies where selective feedback was provided for trials with better versus worse outcomes, on tasks involving object-throwing or accuracy in positioning a slider, performance and learning differences were absent between groups (Carter, Smith & Ste-Marie, 2016; Patterson & Azizieh, 2012). The lack of effects was in spite of more positive judgments of learning reported by the better-outcomes feedback group (Carter et al., 2016). Similarly, in Study 2 of this thesis (Ong, Lohse & Hodges, 2015), we showed enhanced perceptions of self-efficacy and significantly more target hits recorded by a large, compared to a small, target group during practice, but no accuracy differences between groups were recorded in practice and retention.

The methods employed in my Study 2 were similar to the golf-putting study discussed earlier (Palmer et al., 2016), yet no group differences were observed. However, the groups in the golf study were significantly different in performance throughout practice, with the large target group outperforming the small target group. This group difference was apparent from the very first, 10-trial practice block. While pretest performance was not significantly different between the groups, the trend in the performance was in the direction of the differences later seen in practice. This raises concerns about these earlier individual differences explaining any later effects. Moreover, from a motor control perspective, there is reason to suspect that movements to small rather than large targets will differ in their control strategies, due to subjective difficulty demands and well established relations between variability of movement, force, movement amplitude and movement time, termed the impulse variability theory (Schmidt, Zelaznik, Hawkins, Frank & Quinn, 1979). With a smaller target, greater precision demands would likely lead to more time in movement planning and processing the task, and greater variability in movement kinematics, such as joint amplitude, angular velocity or movement time, than practice

with a larger target. As such, it is important to measure how the movement is performed to get a better index of how strategy differences in movement execution and planning might explain potential target size effects (or lack thereof).

Success-related manipulations to targets/goals have been reported in two other studies as noted above (Chiviacowsky et al., 2012; Trempe et al., 2012). In both these studies, group differences were only seen after a retention period (in favour of the easier goal groups), suggesting that memory consolidation processes were enhanced by elevated subjective perceptions of success. However, in both these studies, somewhat artificial laboratory tasks were used which would force individuals to become heavily reliant on augmented feedback to succeed and/or adopt certain control strategies that would not be suited to "easier" conditions. For example, in performing a coincident anticipation timing task with stringent goal feedback within milliseconds (Chiviacowsky et al., 2012), performers would come to rely on the extrinsic feedback at the expense of their own intrinsic feedback about errors. Therefore, there are issues with the generalizability of results from these tasks as a result of asymmetries between strategies adopted in practice and tested in retention, which may be independent of success-perceptions.

Based on the mixed evidence with regard to the efficacy of success manipulations on motor learning and issues concerning how it works, the aim of this study was to further evaluate how perceptions of success, through manipulations to target size, impact motor learning. We did this by: a) addressing potential limitations with the design and methods of our earlier Study 2, and b) studying the control processes and potential mechanisms that might explain any success-related effects. This included measurement of: (i) time between throws to index processing and planning activities, (ii) movement kinematics to alert as to changes to movement velocity and amplitude to do with target size, as well as (iii) indices of effort. These latter indices related to arousal, as assessed through electro-dermal activity (EDA), and physical effort, as related to muscle co-contraction and EMG (electromyography). Again we used a dart-throwing task, which was simplified such that the throwing distance was decreased (from 237 to 200 cm) and requirements to achieve outcome accuracy/scores were only in the vertical direction (what we refer to as a target-band criterion). These measures were designed to reduce both between and within-subject variability, particularly with reduced force and force variability on a shorter throwing distance (Schmidt & Lee, 2011). By reducing variability, we hoped to increase the

power to detect effects should they exist and improve the likelihood that participants are practising at performance saturation (or asymptote), which has been shown to enhance memory consolidation in other cognitive and visual-motor tasks (Hauptmann et al., 2005; Krakauer et al., 2005). With respect to the differences between groups concerning our target size manipulations, targets were actually smaller than those used in our previous study. This was done to more closely match success rates experienced in other studies as discussed below.

Both groups in Study 2 had experienced higher rates of hits/success than participants in other studies, where the success rates experienced by the easy and difficult target or goal groups were between 50-60 % and less than 10 % respectively (Chiviacowsky et al., 2012; Trempe et al., 2012). In fact, in a recent golf putting study, the success rate for the large target group was only 22%, compared to 7.9% for the small target group (Palmer et al., 2016). In comparison, the success rates in our Study 2 were 82 % for the large target group and 32 % for the small target group. These increased success rates might have affected efficacy perceptions in an unexpected way. For the easy target group, a performance ceiling might have occurred, given that the task was likely too easy and was lacking in challenge (although unpublished findings of Study 2 did not indicate low motivational scores for this large target group; see summary of study in Appendix 2). The difficult target, being of moderate difficulty, might not have sufficiently depressed success rates. Indeed, we had evidence that the small target group was as equally motivated as the large target group. Therefore, in the current study, we piloted and modified target sizes to better match success rates from these past studies.

If enhanced success perceptions are beneficial to motor learning, we would expect a large, target-band (Large-band) group to perform with greater accuracy than a small, target-band (Small-band) group during acquisition and/or for this group difference to be shown in retention. We might also expect more between-trial variability in the Small-band group during practice, due to the higher number of target misses that would require correction. If enhanced success perceptions work by increasing motivation in practice, potentially leading to greater effort in practice, we would expect the Large-band group to be or become more accurate (and more consistent) than the Small-band group during practice and for this difference to continue to manifest in delayed tests of learning. Were memory consolidation processes responsible for the learning benefits of success perceptions, group differences would only be expected in delayed

retention. Without measures of modulations to dopaminergic activity (e.g., Molina-Luna et al., 2009), or genomic tests for levels of enzymes facilitating dopaminergic activity (e.g., Krause, Beck, Agethen & Blischke, 2014), it is difficult to confirm or refute the memory consolidation explanation for success-related motor learning benefits. However, to better understand what is happening in practice, we collected a number of process measures to help indicate how target size impacts performance and included transfer tasks to assess what had been acquired.

Manipulations to target size might affect how the action is executed in practice leading to a stiffer, less efficient pattern of activation in the muscles of the throwing arm for the Small- rather than Large-band group. This pattern would reflect what is typically seen in early, rather than later stages of learning, when learners are more actively engaged in cognitive processing, as compared to later stages when movements are more fluid and automatic (e.g., Moore & Marteniuk, 1986). Inefficiency would manifest as greater co-contraction between the agonist (triceps) and antagonist (biceps) muscles in the throwing arm, as measured through electromyography (EMG), for the Small- rather than Large-band group (Lohse & Sherwood, 2012). Hence, the ratio of triceps to biceps EMG activity should be smaller in the Small-band group, due to an increase in redundant muscular activity in the antagonist muscle. Kinematic measures of shoulder and elbow angles, angular velocity and temporal markers of preparation and end of throw were also assessed to indicate differences in control strategies as a result of the manipulation. For a proxy measure of effort and arousal during practice, we collected psychophysiological measures of electrodermal activity (EDA; Brehm & Self, 1989; Kahneman, 1973). If participants were feeling more motivated during practice as a result of the greater success, then the Large-band group should show higher levels of arousal in general than the Small-band group.

As with Study 2, participants performed a secondary tone-counting task in conjunction with the primary task of dart-throwing. This allowed us to test how knowledge or conscious control processes (associated with target size) impacted learning. The added demands of a secondary cognitive task was expected to interfere more with performance of dart-throwing for the Small-band than the Large-band group, if practice with a smaller target promoted greater conscious control and cognitive processing, leading to a reduced capacity for additional cognitive tasks. Related, the Small-band group should report more explicit knowledge than the

Large-band group, due to the greater propensity for the learners to engage in error correction processes and test relevant hypotheses to improve their task performance (see Masters & Maxwell, 2008, reinvestment hypothesis).

We also included a prediction test and a manipulation to throwing pace to better probe differences in control strategies during the retention phase. For the prediction test, participants were asked to predict the landing zones of each throw (in the absence of vision) to determine whether either target practice had resulted in an improved awareness of outcome error (i.e., an index of intrinsic feedback processing). The Small-band group was expected to be more accurate in their predictions than the Large-band group as a result of more frequent feedback and error processing. Participants were also asked to regulate the pace of their throws to a metronome in both a fast- and slow-paced condition. In the fast-paced condition, the time between a set of throws was shortened so that there was scant time for feedback processing or movement planning. In the slow-condition, participants had to delay their throws, which afforded more time for processing and planning than usual. We considered that practice on a smaller target might promote slower-paced movements, due to additional evaluation and planning-related demands. In the paced conditions, if there were any costs to such processing and planning for the Small-band group, then speeding up throws might aid performance relative to going slowly. The Large-band group should also show costs as a result of slowing down, if this is one of the reasons why differences between different target sizes are seen.

4.2 Methods

4.2.1 Participants and groups

Right-hand dominant, female adults (*M* age: 21.4 yr; range: 18 – 31 yr) with normal or corrected vision and who were free from upper-limb injuries or neurological disorder were recruited via online advertisements and posters. To ensure that participants were novices, two additional exclusion conditions were verified by self-report; 1) they had not played darts more than five times ever or more than once in the past 12 months, 2) they were not current competitive athletes in a sport involving throwing (such as softball and basketball). All participants gave informed consent before the study, in accordance with ethical procedures of the University and then were

randomly assigned to either a Large-band (n = 14) or a Small-band group (n = 15). Remuneration of $11/hr was paid to participants.

Three participants were initially excluded from analyses due to large errors on either the pre-test or the first block of Acquisition (≥ 2*SD*s above group mean), and because these were identified early, participants were replaced until there were n = 15/group. However, later analysis of individual acquisition and retention data showed that one participant neither improved in outcome accuracy (i.e., AE) during practice (comparing Block 1 to 10), nor exhibited learning as determined from a comparison of the initial block of acquisition to retention[4]. Subsequently, this participant was excluded from analyses resulting in n = 14 in the Large-band group.

4.2.2 Task and apparatus

In pre-test (Day 1) and retention phase testing (Day 2), participants aimed to a horizontal line that depicted the target (see Figure 4.1 for schematics of targets). During acquisition, participants aimed to either a large (10 cm) or small (2 cm height) horizontal band[5]. The targets were drawn on rectangular (56 x 71cm) poster-boards that were affixed over a bristle dartboard that was surrounded by thick Styrofoam, on a wall of approximately 1.5 m x 2.5 m. The midline of the horizontal target bands was aligned on both sides to markings on the wall to ensure that the centre of the targets was parallel to the floor, and at a height of 173 cm.

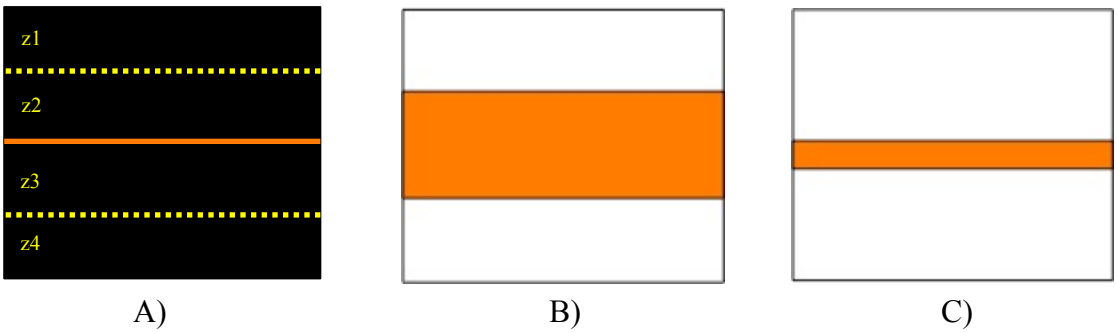

Figure 4.1. Schematic of the dartboard with target(s): A) horizontal line target (solid orange) during pre-test and Day 2's tests of learning; zones z1-z4 are denoted in reference to the prediction tasks on Day 2, B) large horizontal band target presented to the Large-band group, and C) small horizontal band target presented to the Small-band group during acquisition.

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[4] *See Appendix 6 for data from select individuals and further rationale for exclusion.*
[5] *A pilot study (n = 4) was conducted to determine the target sizes that would lead to ~ 50% success/hits for the Large-band group and ≤ 10% for the Small-band group.*

Three darts (26 g each) were used to perform the throwing task. On some throws, participants wore a pair of liquid crystal, visual occlusion goggles (Translucent Technologies Inc., Canada) that were activated via a custom hand-held switch. A video camera was set up behind and above the participant so that dart landings were recorded and later analyzed for positional, vertical error. A second video camera recorded the participants' throwing motion from the right side (sagittal plane) at 30 frames/sec, providing information about movement kinematics, and pre- and post-throw durations.

To obtain a psychophysiological measure of arousal, two disposable pre-gelled Ag/AgCl electrodes (0.5% chloride salt; Biopac systems Inc.) were affixed to the thenar and hypothenar prominence on the participants' non-dominant palm for recording of EDA. Specifically, exosomatic EDA was measured with 0.5 V constant current. Two EMG electrodes were attached to each belly of the triceps and biceps muscles of the throwing arm, and a grounding electrode on the acromion process to measure muscular activity. Both EMG and EDA signals were wirelessly amplified and transmitted to a data acquisition module unit (BioNomadix MP150, Biopac systems Inc.) and recorded at a sampling rate of 1 KHz, for post-experiment analyses (AcqKnowledge 4.2; Biopac systems Inc.).

Participants completed the perceived competency and task interest/enjoyment subscales of the Intrinsic Motivation Inventory (IMI; McAuley, Duncan & Tammen, 1989), the intrinsic motivation and amotivation subscales of the Situational Motivation Scale (Guay et al., 2000), and three customized items concerning whether they; 1) looked forward to practising a similar throwing/aiming activity in future, 2) were motivated to do well during practice, and 3) felt successful during practice. All questionnaires were scored on a 7-point Likert scale (1 = "strongly disagree, 7 = "strongly agree"). During practice, participants were also asked to report self-efficacy in making at least one "hit" out of the next three throws. This was assessed using a self-efficacy scale which ranged from 0-100 % in increments of 10, with descriptors, "0" = "not at all sure", "10" = "not sure", "40" = "somewhat sure", "70" = "pretty sure" and "100" = "very sure" (Zimmerman & Kitsantas, 1997).

4.2.3 Procedure

The study was conducted over two sessions, separated by ~24 hours. On Day 1, there was a pre-test, followed by an acquisition (practice) phase. Before the pre-test, participants completed only the perceived competency subscale of the IMI and were fitted with EDA and EMG electrodes and transmitters. Reflective stickers were attached to the acromion process of the scapula (shoulder), lateral epicondyle of the humerus (elbow), styloid process of the ulna (wrist) and first knuckle of the index finger of the throwing arm for post-experiment video analysis of throwing kinematics. Participants then stood still for one minute while the EDA and EMG signals were validated. Instructions were also given on the task – including a demonstration on how their throwing motion was to be maintained in the sagittal plane (not "side-throwing", i.e. not swinging the arm across the frontal plane anterior to the body) and where the dart should be gripped. In all cases, the distance from the board was 200 cm.

4.2.3.1 Pre-test

Participants performed a warm-up throw (outcome was not recorded), followed by 6 no-vision, pre-test trials. When participants pulled back their wrist and were about to throw, the goggles were manually activated to turn opaque, preventing vision of the throw's outcome (hence preventing feedback that would lead to performance improvements). In between pre-test trials, vision was restored.

4.2.3.2 Acquisition

Participants were instructed to make as many "hits" as they could. A "hit" was recorded when a dart landed within the horizontal band (regardless of position on x-axis). Three darts were placed on a stool to the right and slightly behind the participant and they were asked to retrieve and throw each dart one at a time. After each throw, participants were asked to turn and reach for a dart before looking back at the target again to make the next throw. This was a necessary step in measuring pre-throw duration, by marking the moment of "visual fixation", defined as the first moment when participants fixated on the target before they began a throw, to the moment when the dart was released. In between sets of 3 trials, participants tallied their hits and misses on a score sheet to help make successes (or failures) salient, and the experimenter returned the darts.

Ninety acquisition trials were performed. Before trials 4, 31 and 61 (Trial 4 was chosen as participants were less likely to be overwhelmed by initial instructions), self-efficacy was probed. The self-efficacy rating scale was posted to the right of the dart-board and participants were prompted for their self-efficacy on making at least one hit out of the next three throws (similar to Study 2). At the end of acquisition, participants filled out the IMI and SMS subscales as well as responded to the three customized questions probing motivation/success. They were then reminded to get sufficient rest and avoid playing darts before the next session.

4.2.3.3 Delayed tests of learning

On Day 2, participants completed only the perceived competency subscale of the IMI. One warm-up throw was performed before 6 no-vision retention trials (same procedures as pre-test). After completing the no-vision trials, other tests were conducted consisting of 9 trials/condition. First, a full-vision retention test was conducted, followed by an outcome prediction test (no-vision). In this latter condition, participants wore occlusion goggles and after each trial predicted the landing zone of the dart (no feedback was given, see Figure 4.1a). A dual-task, tone-counting condition was then performed. Participants completed 3 sets of 3 throws while mentally counting the number of high pitch tones that were played in a sequence of high and low tones (300 ms/tone), interspersed by intervals of 500-1000 ms. Three unique random sequences were generated for each set. Participants did not begin throwing until after the first tone of the sequence was played. Subsequent darts for the set were handed to participants 2-3 s after they had thrown the previous dart, so as to regulate throw pace, ensuring that the number of tones were approximately matched across participants. In the final tests, participants threw darts at both a fast and slow pace, counterbalanced for order. Pacing was achieved through auditory tones, which dictated when the next dart should be thrown. Pilot work showed that the fast pace was the minimum amount of time needed to grip and throw the dart with some accuracy (1 tone/s), whereas the slow pace was long enough that participants could evaluate the outcome and make any new plans or adjustments between throws (1 tone/5s).

At the end of the study, participants were asked to report any task-relevant rules, techniques or method that they had generated or become aware of during acquisition on Day 1. Participants were paid and debriefed.

4.2.4 Data collection and analysis

4.2.4.1 Outcome variables

Outcome accuracy was derived post-testing from videos recorded of the dartboard and was completed with Dartfish © Prosuite video analysis software (Dartfish, USA). Positional error of the dart landings, as measured in the *y*-dimension from the target line (pre-tests and retention/transfer tests) or midline of the horizontal target bands (acquisition), was determined. For acquisition, positional error was extracted only from the first and last nine trials of practice (even though measures of successful target hits were noted for all trials). From these positional errors, constant error (CE), absolute error (AE) and variable error (VE) were derived for each block of nine trials. Mean CE, AE and VE across blocks or time were compared between groups in Group (Large-band, Small-band) x Time repeated measures (RM) ANOVAs. Separate analyses were conducted on pre-tests, acquisition and retention, although we did compare the no-vision pre-test to the no-vision retention test in a 2 Group X 2 Time RM ANOVA. For retention, accuracy on both vision and no-vision retention tests were compared in a 2 Group X 2 Vision RM ANOVA. Independent t-tests were used to compare across groups in the pre-test and other transfer tests on Day 2.

Target hits during acquisition were analyzed in blocks of 30 trials (i.e., mega-block) and analyzed in a 2 Group x 3 Mega-block RM ANOVA. On non-parametric data, such as accuracy of tone-counting responses in the secondary task and prediction errors, group differences were analyzed with the Mann-Whitney U test.

4.2.4.2 Measures of success, competence and motivation

Self-efficacy ratings were analyzed in a 2 Group x 3 Mega-block (self-efficacy obtained at the beginning of each 30 trial-Mega-block) RM ANOVA. Ratings of perceived competency, interest/enjoyment, motivation and success, were analyzed with the Mann-Whitney U test.

4.2.4.3 Process and motor-control measures

EDA, EMG, kinematic and temporal data were analyzed for all participants during practice for Blocks 2 (t10-18), 5 (t37-45), and 8 (t64-67). Three participants (2 = Large-band, 1 = Small-band group) were excluded from analyses due to equipment errors during data collection.

The EDA (in μS) waveform was re-sampled at 62.5 Hz, median-smoothed on 62 samples and low-pass filtered at 1 Hz to provide skin conductance level (SCL; Dimov, 2016) for each trial. Pre-throw EDA was collected in the duration between visual fixation and dart release. Post-throw EDA was tabulated from dart release to the visual fixation for the next trial. For the last trial of each set of 3 throws, EDA duration was estimated using the post-throw duration of the previous trial. Each pre- and post-throw was subtracted from the baseline (quiet standing) mean EDA for each participant to obtain a difference score. These difference scores were converted into *z* scores based on each individual's overall mean difference EDA and *SD*. The *z* transformed EDA data (in *SD* units) were analyzed in a 2 Group x 3 Block (2, 5 and 8) x 2 Throw Period (pre and post) RM ANOVA.

For EMG we took a measure of co-contraction to index stiffness/inefficiency of the throw. The waveform was first band pass filtered (5 and 500 Hz) and transformed to root-mean-square (RMS) EMG, using 10 ms windows (De Luca, 1997). The mean, and max RMS EMG were derived for the triceps and biceps muscles for all trials in acquisition blocks 2, 5 and 8. Muscular activity (mV) was analyzed between the onset of the muscle to the moment of dart release. Onset was defined as the point of earliest continuously rising RMS EMG deviating above baseline. Normalized mean RMS EMG (Norm-Mean) percentages were obtained by dividing the mean RMS EMG by the max triceps RMS EMG for each trial. The ratio of Norm-Mean triceps to biceps activity (indicative of co-contraction) for a trial was calculated and analyzed in a 2 Group x 3 Block RM ANOVAs on the same three blocks of acquisition trials as the EDA data.

Shoulder and elbow joint angles were determined from video using Dartfish © Prosuite software. As illustrated in Figure 4.2, shoulder angle is the angle subtended by a straight, 90° line (ground, G) from the acromion process of the shoulder (S) and a straight line joining the lateral epicondyle of the humerus (E) to the acromion process. The elbow angle is subtended by the straight line joining the acromion process of the shoulder (S) to the lateral epicondyle of the humerus (E), and a straight line joining the lateral epicondyle of the humerus to the styloid process of the ulna (W) (see Lohse, Sherwood & Healy, 2010). Each of these angles was tabulated at two moments for each trial, first at the moment of maximum retraction (maximum elbow flexion immediately before dart release; refer to Figure 4.2A) followed by the moment of

dart release (see Figure 4.2B). Amplitude of joint movement (degrees) and movement time (*ms*) were tabulated respectively by subtracting joint angle or time at the moment of dart release from the values at maximum retraction (flexion) for each dart throw. Angular velocity was calculated by dividing the amplitude of elbow movement by movement time. Standard deviation of joint amplitude, movement time and angular velocity were also tabulated to provide a measure of movement variability for each block, and the respective block means and *SD*s were independently analyzed in 2 Group x 3 Block (2, 5 and 8) RM ANOVAs.

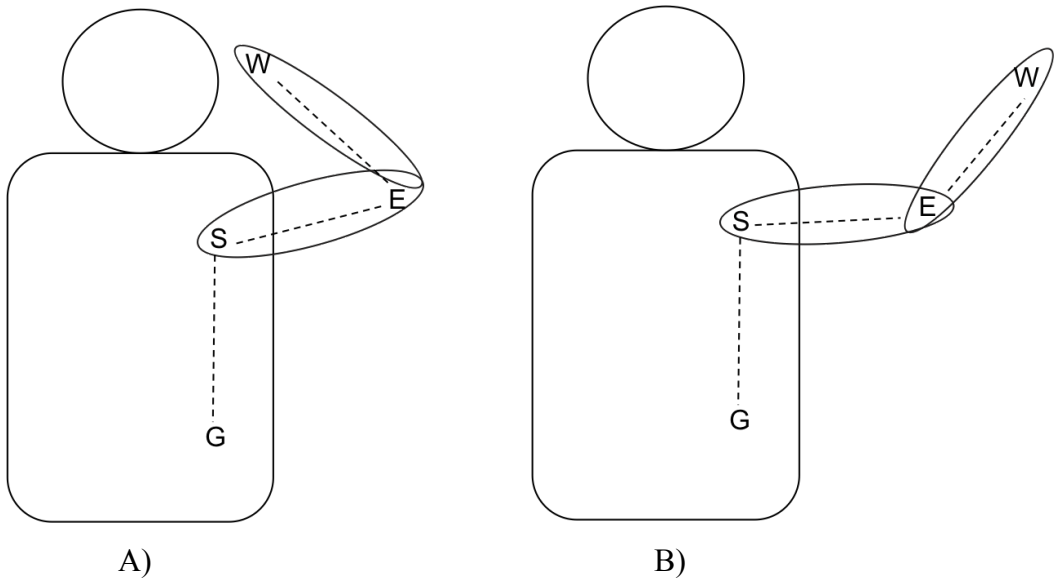

Figure 4.2. Schematics of the shoulder and elbow angles at the moment of A) maximum retraction, and B) dart release. Shoulder and elbow angles are the acute angles subtended by the points G-S-E, and S-E-W respectively.

Pre-throw duration was the time between visual fixation and dart release. Post-throw duration was the time between dart release and visual fixation for the following throw. When participants did not take their eyes off the target or were still moving towards the throw line while their eyes were on the target, visual fixation time was marked as the first frame where participants stopped moving. For the last trial of each set, post-throw duration was not analyzed. These temporal measures were analyzed in a 2 Group x 3 Block x 2 Time Period (pre- and post-throw) RM ANOVA on the same three blocks of acquisition as EDA and EMG.

Finally, a comparison of the number of rules or strategies generated was analyzed as a function of group, using the non-parametric Mann-Whitney U test. The correlation coefficient, *r*, was reported as effect size for Mann-Whitney U tests. Overall, for parametric data, partial eta

squared (η^2_p) values are reported as measures of effect size and post hoc analyses were conducted using Tukey's HSD (p <. 05) for all significant effects. Greenhouse-Geisser corrections were applied for violations to sphericity. Where t-tests were performed, Cohen's d was reported for effect size.

4.3 Results

To help with navigation of the results' section and major analyses, a summary table detailing significant effects and test statistics has been included (see Table 4.1).

Table 4.1. Summary table of statistically-significant effects in Study 3.

Measures and effects		Test statistic	p-value	Effect size
Target hits				
Acq:	Group	F(1, 27) = 218.02	***	η^2_p = .89
Self-efficacy probes:				
Acq:	Group	F(1, 26) = 27.98	***	η^2_p = .52
	Mega-block	F(2, 52) = 30.90	***	η^2_p = .54
	Group x Mega-block	F(2, 52) = 3.32	*	η^2_p = .11
Perceived competency:				
End Acq:	Group	U = 22.50	***	r = .67
Ret:	Group	U = 52.00	*	r = .43
Perceived success:				
	Group	U = 43.50	**	r = .53
Outcome error (AE)				
Acq:	Block	F(1, 27) = 47.26	***	η^2_p = .64
Ret:	Vision	F(1, 27) = 58.19	***	η^2_p = .68
Outcome error (CE)				
Acq:	Block	F(1, 27) = 44.79	***	η^2_p = .62
Ret:	Vision	F(1, 27) = 57.10	***	η^2_p = .68
Outcome error (VE)				
Acq:	Block	F(1, 27) = 38.07	***	η^2_p = .59
Ret:	Vision	F(1, 27) = 5.19	*	η^2_p = .16
Processing duration:				
Acq:	Throw Period	F(1, 24) = 126.09	***	η^2_p = .84
	Group	F(1, 24) = 4.83	*	η^2_p = .17
Joint amplitudes:				
Shoulder:	Block	F(2, 48) = 4.29	*	η^2_p = .15
	Group x Block	F(2, 48) = 6.14	**	η^2_p = .20
Elbow:	Group x Block	F(2, 48) = 6.94	**	η^2_p = .22
Variability (*SD*) of joint amplitudes:				
Shoulder:	Group x Block	F(2, 48) = 4.43	*	η^2_p = .16
Electrodermal activity (EDA):				
Acq:	Throw Period	F(1, 24) = 15.24	**	η^2_p = .39

Key: Acq = Acquisition phase; Ret = Retention test; * p < .05; ** p < .01; *** p < .001.

4.3.1 Success rates and success perceptions were affected by target size manipulations

As expected, the Large-band group experienced more hits (success = 44.05 %, *SD* = 7.78) than the Small-band group (success = 11.26 %, *SD* = 3.56), see Table 4.1. There was no overall improvement in target hits over 3 mega-blocks of practice, $F(2, 54) = 1.61$, $p = .21$, nor a Group x Mega-block interaction, $F(2, 54) = 2.33$, $p = .11$.

The Large-band group reported greater self-efficacy (*M* = 63.33 %, *SD* = 13.22) than the Small-band group (*M* = 29.78 %, *SD* = 19.59) and self-efficacy for both groups increased across practice[6]. There was a Group x Mega-block interaction due primarily to a larger change between the first and second self-efficacy probes for the Large-band group (*M* change = 25.0) compared to the Small band group group (*M* change = 10.0). Both groups were significantly more confident on the final self-efficacy probe compared to the first.

Ratings of perceived competency were compared pre- and post-acquisition on Day 1 and at the start of testing on Day 2. As illustrated in Figure 4.3, the groups were not different before acquisition, but they were different after acquisition and before retention tests on Day 2. This was confirmed by Mann Whitney U, paired comparisons for each period. The Large-band group (*Mdn* = 5) also rated themselves as overall more successful at the end of acquisition than the Small-band group (*Mdn* = 3; see Table 4.1).

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[6] *One participant did not have self-efficacy ratings for all trials and they were not included in the RM analysis.*

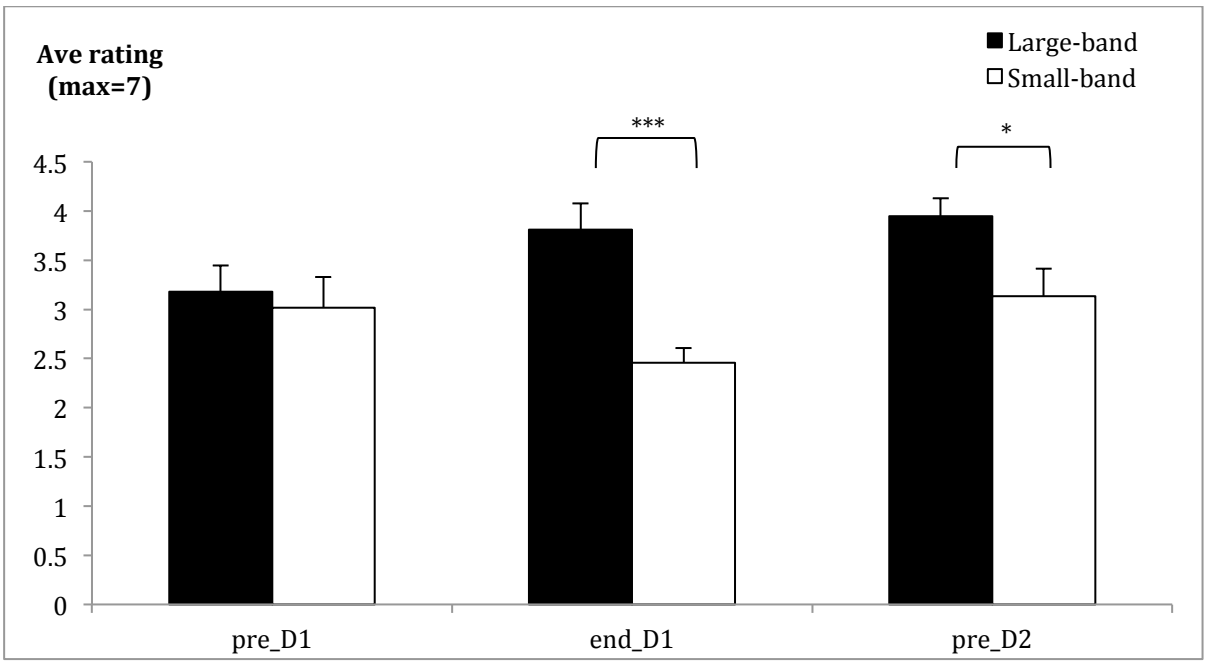

Figure 4.3. Mean group ratings (*SE* bars) for perceived competency before Acquisition Day 1 (pre_D1), after Acquisition Day 1 (end_D1) and before retention tests on Day 2 (pre_D2). * $p < .05$; *** $p < .001$

4.3.2 Success did not impact outcome measures

4.3.2.1 No vision pre-test

Absolute error (AE) data are illustrated for all phases of the experiment in Figure 4.4. Unless otherwise indicated, CE displayed the same trends as AE throughout the study. There were no group-related differences in either AE or variable error (VE; not indicated).

4.3.2.2 Acquisition

Performance improved from early (Block 1) to late acquisition (Block 10) for all measures of outcome accuracy and consistency, Fs > 38.06, *p*s < .001, but there were no group-related effects. For AE, all Fs < 1 (see Figure 4.4). For CE, for group F < 1 and the Group x Block $F(1, 27) = 2.60$, $p = .12$. For VE, for group F < 1 and the Group x Block $F(1, 27) = 3.96$, $p = .06$.

4.3.2.3 Retention tests

The groups did not differ in any measure of accuracy in retention when comparing them across the no-vision and full-vision retention tests (all Fs < 1; see Figure 4.4). Not surprisingly, there was an effect of vision, with lower AE when throwing with vision than without (similar vision effects were also seen in CE and VE).

4.3.2.4 Other delayed tests of learning

In other tests of learning, there were generally no group differences in either accuracy or consistency (see Figure 4.4) (all ts ranged from .01 to 2.03). In addition to a general lack of group differences in outcomes during the prediction test, there was no significant group difference in prediction response accuracy. On average, the groups made approximately 5.7 response errors (max = 9), when predicting landing zones, indicating accuracy of ~37 % (chance = 25 %). No differences were noted in outcome error under secondary task conditions (ts ranged from .30 to 1.61), nor were there differences in the accuracy of responses in this condition. Changes to the pacing of throws did not impact accuracy or result in predicted group differences in retention.

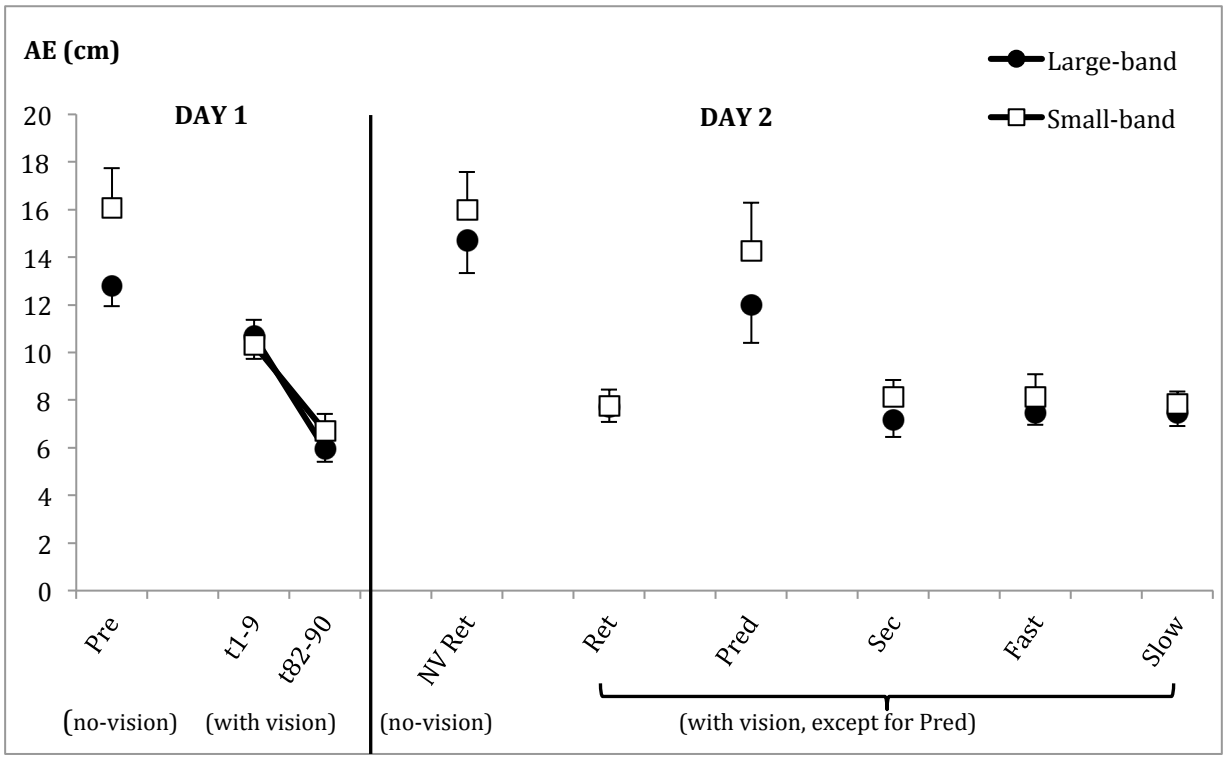

Figure 4.4. Mean AE (and *SE* bars) as a function of testing phase and condition. Pre = no vision-pre-test; t1-9 = first 9 Acquisition trials; t82-90 = final 9 Acquisition trials; NV Ret = no vision-retention; Ret = retention; Pred = outcome prediction test (no vision), Sec = secondary task test; Fast = fast-paced test, and Slow = slow-paced test.

4.3.3 Success did not impact motivation

The groups were not significantly different on measures of intrinsic motivation, amotivation, other customized motivational items, and interest/task enjoyment subscales (Us ranged from 66.50 to 101.00, *p*s > .09; see Figure 4.5).

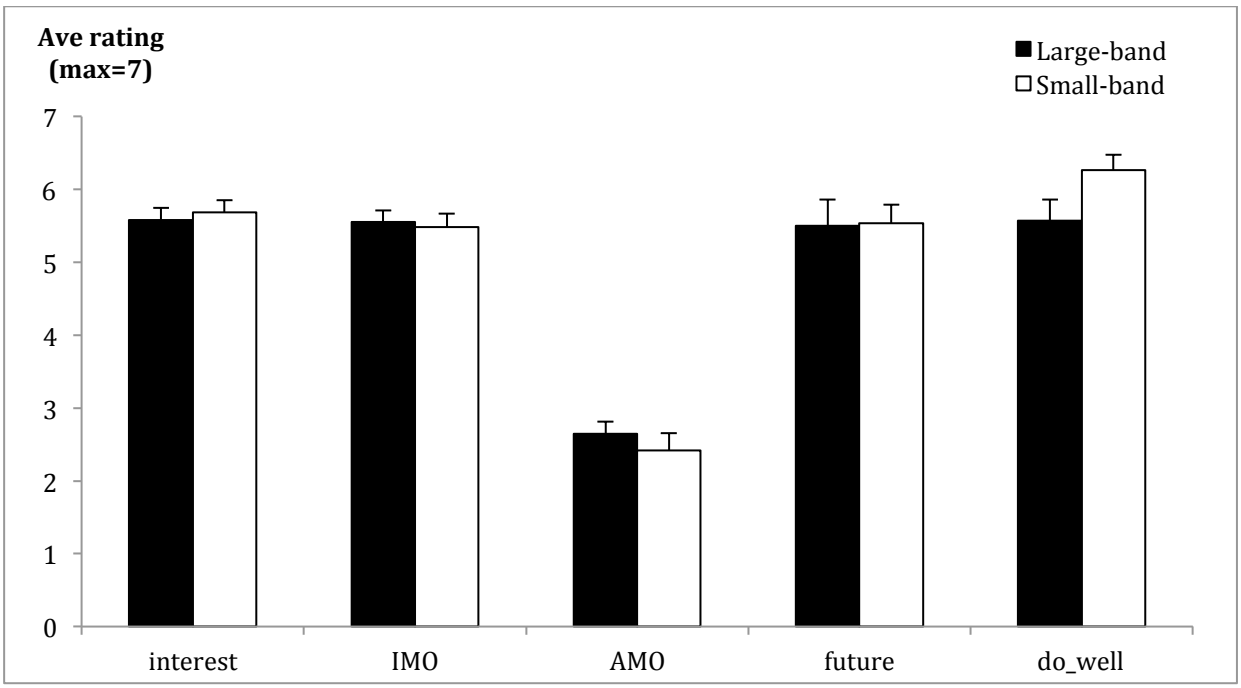

Figure 4.5. Mean group ratings (and *SE* bars) obtained after practice on Day 1, on interest/task enjoyment (interest), intrinsic motivation (IMO), amotivation (AMO), motivation to practise in future (future), and motivation to do well during practice (do_well).

4.3.4 Processing durations and movement kinematics were affected by target size manipulation

4.3.4.1 Pre-throw and post-throw duration

Post-throw duration (*M* = 4.51 s, *SD* = 1.16) was significantly longer than pre-throw duration (*M* = 1.87, *SD* = 0.86), but more importantly, the groups differed on these variables (see Table 4.1). As predicted, the Small-band group (*M* = 3.48 s, *SD* = 1.82) was significantly slower overall than the Large-band group (*M* = 2.85 s, *SD* = 1.43). There were no other effects involving group, block and throw period (see Figure 4.6), all Fs < 1.5, with the exception of Group x Block, $F(2, 48) = 2.15$, $p = .13$, and Group x Block x Time, $F(2, 48) = 2.02$, $p = .14$.

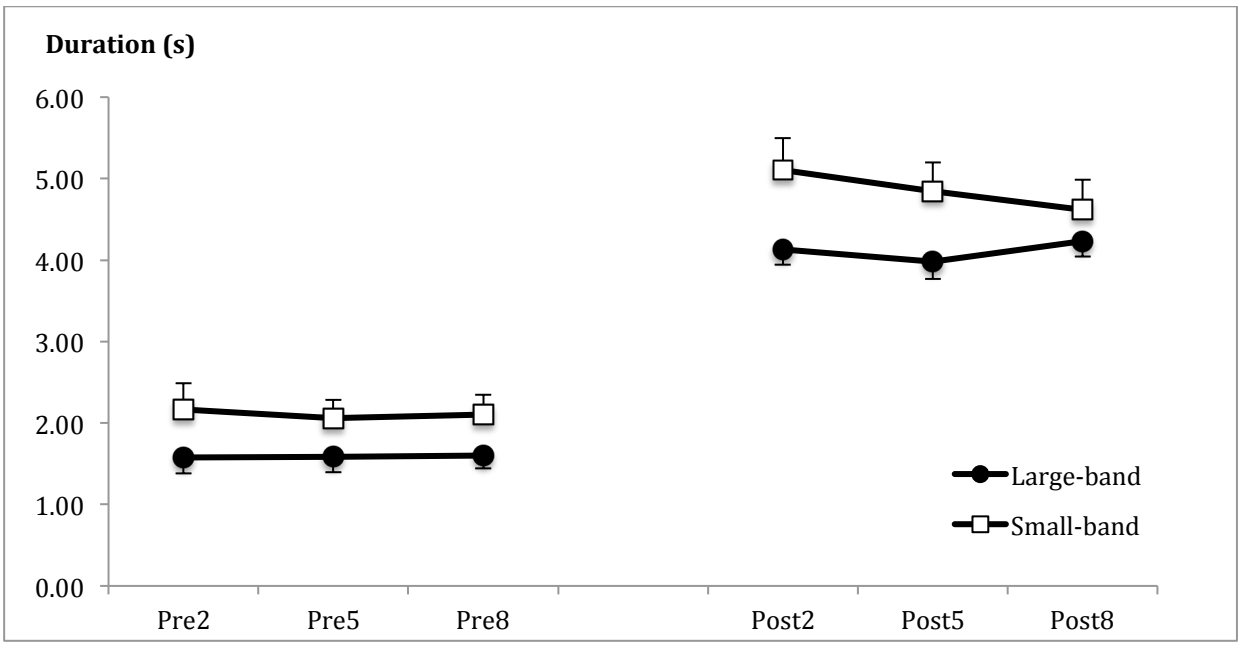

Figure 4.6. Mean duration (and *SE* bars) as a function of pre-throw (Pre) and post-throw (Post) periods for Blocks 2, 5, 8.

4.3.4.2 Explicit knowledge

There were no group differences.

4.3.4.3 EDA, EMG and kinematics

Analysis of the *z*-transformed means for EDA difference scores in relation to baseline, showed only a significant main effect of throw period. There was a larger increase in EDA from baseline in the post-throw period (*z*-score = .15) compared to the pre-throw period (*z*-score = -.15). No other effects were significant (all Fs < 1, except Group x Time, $F(1, 24) = 3.46$, $p = .08$).

There was no indication that there was more co-contraction in the EMG activity of the Small- vs. Large-band group during practice, Fs < 1.29.

With respect to kinematics, no significant group differences were shown in mean angular velocity and movement time and their *SD*s (Fs < 1.05). For joint amplitude, these data are illustrated in Figure 4.7. The groups were not different overall for either shoulder amplitude (F < 1; *M*: Large-band = 6.1°; Small-band = 8.1°) or elbow amplitude (F < 1; *M*: Large-band = 66.8°; Small-band = 69.0°) and only the shoulder amplitude differed across blocks indicating an increase in amplitude over practice. There were significant Group x Block interactions for both

shoulder (Figure 4.7A) and elbow (Figure 4.7B; see Table 4.1 for statistical details). Post-hoc analyses indicated group differences only in the early practice block (Block 2), where this was larger for the Small-band in comparison to the Large-band group for shoulder and elbow amplitude. The Large-band group demonstrated an increase in shoulder and elbow amplitude from early (Block 2) to end of practice (Block 8), with a mean change of 5.3° for shoulder and 4.19° for elbow. There was no change in shoulder or elbow amplitude for the Small-band group (although there was a significant decrease in elbow amplitude from Block 2 to 5; see Figure 4.7B).

Analyses of between trial *SD* of amplitudes revealed a significant Group x Block effect for shoulder amplitude only. Post-hoc tests showed group differences only in Block 2, when the Small-band group (M = 5.0°) was more variable in shoulder amplitude than the Large-band group (M = 3.4°). Only the Small-band group decreased variability across practice.

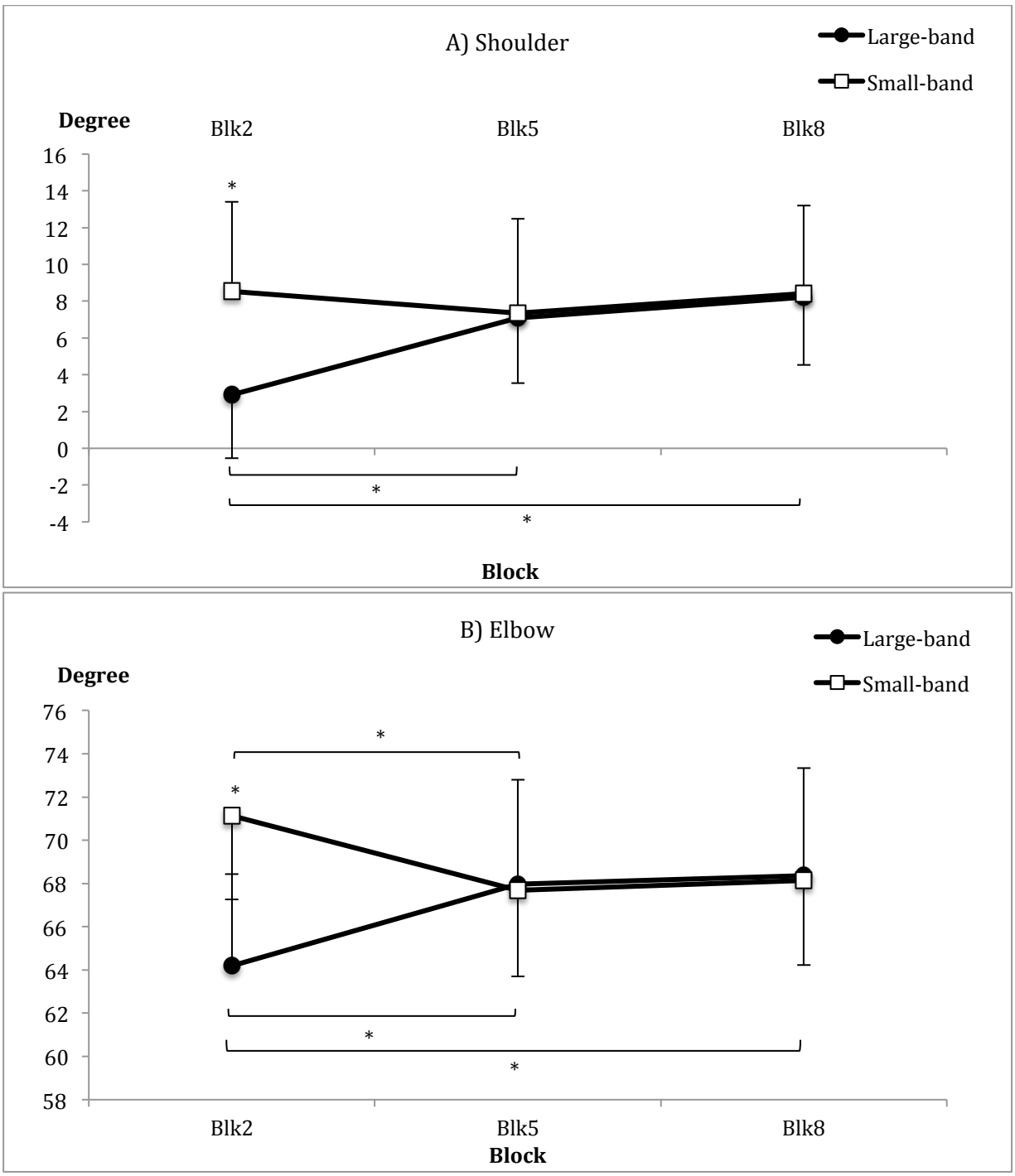

Figure 4.7. Mean A) shoulder and B) elbow joint amplitudes (and *SE* bars) as a function of group and block (Blocks 2, 5 and 8). * $p < .05$

4.4 Discussion

The aim of Study 3 was to test for success-related influences on motor learning through manipulations to target size, with significant design modifications to address potential concerns highlighted in Study 2. Measurement of variables that would serve to highlight how target size impacts performance and learning included psychophysiological and neuromuscular measures (EDA and EMG), movement kinematic and temporal measures (i.e., joint angles, angular velocity, and pre- and post-throw durations) and self-report measures (related to competency, success perceptions, self-efficacy and motivation).

As a result of the manipulation, the groups were significantly different in terms of success rates, self-efficacy, perceived competency (both post-acquisition and before retention) and perceptions of success. The Large-band group was more successful and rated themselves as more successful than the Small-band group. Although there were improvements across trials and into retention for both groups (i.e., in AE, CE and VE), there were no group-related differences. These findings add to a growing number of published studies failing to show learning benefits associated with success manipulations (cf. Carter et al., 2016, Ong et al., 2015; Ong & Hodges, 2017; Patterson & Azizieh, 2012).

Other researchers have reported motor learning benefits associated with enhanced perceptions of success or expectancies, such as self-efficacy (e.g., Chiviacowsky et al., 2012; Saemi et al., 2012), leading them to propose a motivational basis for these benefits in accordance with predictions of social cognitive theory (Bandura, 1991). It is thought that when individuals are highly self-efficacious, they tend to become more motivated and hence exert more time and effort towards performance (as claimed by Lewthwaite & Wulf, 2010b, Palmer et al., 2016; Saemi et al., 2012; Wulf et al., 2013). This would be evidenced in enhanced performance during motor practice. However, our data do not show support for this process or the resulting effects. The more efficacious participants in the Large-band group did not show improved accuracy in practice compared to the less efficacious, Small-band group. Though an increase in success perceptions is typically associated in a causative manner with improved motor learning in the literature, there is reason to question this relationship. Pre-existing group differences in task ability might be one explanation for early performance differences between groups seen in other

studies, especially as there has been evidence of differences as early as the first practice block (Chiviacowsky et al., 2009; Saemi et al., 2012; Palmer et al., 2016). Although it is unlikely that individual differences in random allocation can explain all group differences seen early in practice in the literature, particularly as these are in favour of the more successful group, it is possible that these might explain some of the positive results.

In at least two motor learning studies, motivation was shown to be unrelated to retention (Grand, Daou, Lohse & Miller, 2017; Levac et al., 2017). This also questions the purported role of motivation in being responsible for enhanced motor learning. Grand and colleagues studied the effects of incidental (i.e., task-irrelevant) choice on motor learning. Motivation was unaffected by incidental choice and did not correlate with retention. In the study by Levac et al., autonomy-supportive instructions were shown to be more effective in learning full-body step sequences than regular, non-autonomy instructions, but self-reported motivation was not a predictor of overall task performance (acquisition and retention).

Even when success manipulations impact self-efficacy and related measures of competency, efficacy perceptions may not influence motivation in a consistent way. One reason why this relationship between efficacy and motivation might be different to that proposed by social cognitive theory (Bandura, 1986, 1997), is that here (and in other motor learning studies) we are dealing with short-term effects on relatively simple, laboratory-based tasks. We are not tapping into whether individuals are prepared to engage in more practice to improve, or engage in more quality practice, as opportunities are not provided to do this within the confines of the study. In the present study, participants in the Small-band group reported lower success perceptions than the Large-band group, but this did not extend to motivation ratings (both groups scored high on all measures of motivation and they did not differ in these measures). Even if the groups had been different on measures of motivation, it is not clear how motivation, beyond exertion of greater effort during practice, would translate into enhanced learning without the option for more motivated participants to practice more. Being more motivated to be accurate at dart-throwing might make one more variable in movement kinematics, or result in increased time to plan movements, which has been taken as a proxy of effort in other studies (e.g., Daou, Lohse & Miller, 2016; Wilson, Smith & Holmes, 2007). However, none of these methods defined the Large-band group. Rather, it was the Small-band group that made larger, more variable joint

movements and took longer to plan and process their throws. In summary, not only did we fail to show a relationship between self-efficacy and motivation, if pre-throw duration is interpreted as a marker of effort, our results are opposite to what would be predicted based on an effort-related motivation explanation (cf. OPTIMAL theory).

With respect to movement kinematics, larger shoulder and elbow amplitudes and more variable shoulder movements were made by the Small- compared to the Large-band group early in acquisition. This might be indicative of differences in motor control strategies as a function of the task demands. Aiming to more difficult targets requires greater precision, effort and error correction, which might result in increased movement variability to achieve success early in practice. In the absence of group-related differences in other kinematic measures of movement time and angular velocity, we would have expected that greater movement amplitude and variability should have resulted in more variable outcomes (Schmidt et al., 1979). However, there was no evidence of group differences in measures of outcome accuracy (AE or CE) or consistency (VE). In short, although there were some effects of target size on measures of motor control, these were small and isolated to joint amplitudes (not MT and velocity as we might have expected for movements to different target sizes; Fitts & Peterson, 1964). Moreover, differences in kinematics were not related to overall outcomes.

Taking into consideration other applied psychological perspectives, a non-positive relationship between success perceptions and motivation might appear less surprising. In control theories of self-regulation, a negative relationship is thought to exist between self-efficacy and performance (Powers, 1991). When standards of performance are not met, individuals are expected to be motivated to reduce the discrepancy between performance outcome and criterion standards. As such, increased motivation would be expected in the Small-band/less successful group. Other situational and individual factors could also influence the impact of low success (high error) on effort and performance (Ilgen & Davis, 2000). Individual personality traits such as high task/mastery orientation or conscientiousness (Yeo & Neal, 2008) could lead to maintained or greater effort despite lack of success or positive feedback, especially when individuals perceive a task to be of high difficulty. Although we did not collect data on participants' initial state of motivation (only post-practice motivation, interest, etc. on the IMI), it is probable that participants in our study were generally highly-motivated individuals. All had

been paid to participate and had taken the time to respond to adverts and come to the laboratory for the study.

The assertion that motivation and effort underlie phenomena predicted by the OPTIMAL theory can be assessed through psychophysiological means. Indicators of arousal, such as heart rate and EDA, are used as indirect measures of the attentional or mental effort expended by individuals (Kahneman, 1973). However, we did not find group-related EDA distinctions as a result of the differential success experienced by participants. The only significant effect involved throw period, indicating greater EDA in the period after the dart was thrown rather than before. Although this may indicate greater effort in post-throw feedback processing, it is difficult to delineate and relate EDA changes to specific events in these relatively short pre- (~ 2 s) and post-throw (~ 5 s) periods. There is a known latency in phasic EDA responses by ~1 to 3 s, and a lag in decay as only 50 % of response recovery is achieved in 2-10 s (Dawson, Schell & Filion, 2000). There were also no group differences in EMG measures related to muscle co-contraction, which might also indicate increased effort. In summary, although there was some indication of increased post-throw feedback processing for the Small band group, there was no evidence that this disadvantaged learning as purported by implicit learning advocates (cf. Masters & Maxwell, 2004, Masters & Poolton, 2012). Even when individuals were tested under secondary task conditions, any effects associated with the longer processing time failed to evidence in poorer performance of the Small-band group (secondary task tests are meant to be sensitive to strategies of learning that are high in working memory demands, Eversheim & Bock, 2001).

Through two independent studies involving manipulations to target size in a discrete, dart-throwing task, we have failed to show supportive evidence for OPTIMAL theory, specifically for success-related manipulations that purportedly benefit motor learning. Though in both studies the target size manipulation had shown the predicted impact on success perceptions (i.e. self-efficacy, perceived competency and success), movement planning and feedback processing (pre- and post-throw durations) and motor control measures (movement kinematics), motivation and behavioural indices of performance and learning (including transfer tests) were for the most part not impacted. Besides feedback about success with respect to target hits and misses, participants were also privy to the actual dart landing position relative to the target centre. It is possible that this additional information was used to make strategic modifications to

the next trial regardless of target size. Indeed, the Large-band group was just as variable in their performance as the Small-band group. Contrary to predictions of OPTIMAL theory, that participants in a less successful group would be less motivated than those experiencing more success, the Small-band group did not report lower motivation. Although this may be moderated by the saliency of exact outcome error, indicating overall improvement despite "misses", or potential ceilings in motivation due to participant payment or mastery-orientation in learning goals, these studies serve to raise doubts about simple relations between success perceptions, motivation and motor learning.

4.5 Bridging Section to Studies 4 and 5

The purpose of Study 3 was to evaluate if success perceptions would benefit learning in a dart-throwing task that was a simplified version of Study 2, with success rates that more closely mirrored rates reported in other work. Despite these changes, there were no beneficial performance or learning effects. A recurring cause of concern in Studies 2 and 3 was the saliency of outcome error in the dart-throwing task and how this information might have afforded alternative interpretations of performance. Hence for Studies 4 and 5, we selected a task with less salient (visual) feedback comprising a dynamic, continuous balancing task and one that has been used in past studies to show benefits associated with success perceptions. Importantly, manipulations were made to feedback to control for absolute success, that is actual error feedback in terms of time-on target and error with either stringent or lax goals, as well as relative success, with respect to improvement across trials and also in comparison to others.

5 Balancing our Perceptions of the Efficacy of Success-Based Feedback Manipulations on Motor Learning[7] (Studies 4 & 5)

5.1 Introduction

In the behavioural study of motor learning, much of the established research has been focused on cognitive processes that impact the effectiveness of practice. Recently, this focus has shifted toward a social-cognitive and affective perspective. Spearheading the study of social-cognitive influences on motor skill acquisition, Wulf and colleagues have conducted a number of studies which seem to point towards an important role of competency and success perceptions on motor learning[8] (e.g. Chiviacowsky & Wulf, 2007; Lewthwaite & Wulf, 2010a, 2012). This has culminated in the proposal of the OPTIMAL theory of motor learning (Wulf & Lewthwaite, 2016). In addition to short-term (immediate) effects of success perceptions on performance, potentially associated with increased effort during practice, the authors have shown retention effects over longer time periods, with or without performance effects, suggestive of enhanced memory consolidation associated with feelings of success.

Several creative methods have been used to enhance perceptions of success in motor learning, through selective provision of feedback on trials with better (or worse) outcomes, through interventions involving manipulations to the target goal, or through the provision of false comparative (normative) feedback (e.g., Badami et al., 2012; Chiviacowsky & Wulf, 2007; Chiviacowsky et al., 2009; Saemi et al., 2012). One of the first motor learning studies to show benefits from false comparative feedback was conducted using a stabilometer, balance task (Lewthwaite & Wulf, 2010a). Here, feedback that participants were doing better than others positively impacted performance and learning (compared to 'negative' feedback and no comparative feedback groups). The authors concluded that both performance and learning were aided by enhanced perceptions of success and motivation. However, no measures of success perceptions were taken and there was no indication as to how this feedback immediately impacted balance performance, which may reflect existing between group differences.

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[7] *This chapter was published as an independent manuscript in the Journal of Motor Behavior in 2017. doi: 10.1080/00222895.2017.1383227.*

[8] *Hereafter we use the term "success perceptions" to encompass both competency and success-related perceptions.*

Motor learning has also been enhanced through target/goal-criteria settings that render greater success experiences for a group engaged in an easier, rather than more difficult version of a task (e.g., larger targets or more lax accuracy requirements). In one such study, novices practised golf-putting to either large or small targets, resulting in success on 22 % versus 8 % of trials respectively (Palmer et al., 2016). Not only did the easier target group make more successful 'hits' during practice, it was more accurate in delayed retention when putting to the small target. The authors concluded that performance and learning were positively influenced by expectancy to succeed in the task and that this might have led to a more 'automatic' mode of control that supported learning. However, there was no evidence that the learning effects were driven by enhanced feelings of success, rather than perhaps different control strategies associated with task accuracy demands. Without data on outcome or movement variability, it is also not possible to rule out the interpretation that learning was compromised due to decreased stability in performance, as a result of more trial-to-trial corrections associated with attainment of a more stringent goal.

Practice protocols or techniques that encourage fewer errors, or less knowledge of errors, are thought to be good for long-term learning, because they encourage a more "automatic" or proceduralized mode of control (e.g., Maxwell, Masters & Eves, 2000; Maxwell et al., 2001; Poolton et al., 2005). This type of learning, which has been studied in reference to implicit motor learning, is particularly robust under pressure or working memory demands (such as dual-tasks). Negative feedback or unsuccessful performances are believed to promote conscious control of movement and accumulation of verbalizable, explicit knowledge. This knowledge is then prone for "reinvestment" under test or pressure sensitive conditions and leads to diminished learning and stability over the long-term (e.g., Gray, 2011; Masters, 1992; Masters & Poolton, 2012; Maxwell & Masters, 2009). Therefore, any negative effects associated with error manipulations may be a function of knowledge build-up, rather than success perceptions. Without assessment of performance under dual-task or pressure conditions, or measurement of verbalizable knowledge, it has not been possible to rule out alternative explanations for these effects.

Interestingly, long-term effects associated with manipulations to success perceptions have emerged in the absence of short-term effects (Ávila et al., 2012; Badami et al., 2012; Chiviacowsky & Wulf, 2007; Trempe et al., 2012; Wulf et al., 2010). For motor skill learning,

the post-practice retention period has been shown to be a crucial time period, allowing motor skills to be encoded into stable memory forms, facilitating successful retrieval (Brashers-Krug et al., 1996; McGaugh, 2000; Robertson et al., 2005; Shadmehr & Holcomb, 1997). Both reward and positive affect have been associated with improved memory consolidation, through neural modulations of the dopaminergic (e.g., Holroyd & Coles, 2002; Hosp et al., 2011; Murayama & Kitagami, 2014; Wise, 2004) and hormonal systems (Cahill & Alkire, 2003; McGaugh & Roozendaal, 2002 for a review). Therefore, it has been argued that perceptions of success complement instances of reward and aid retention through processes of memory consolidation, when people believe they have been successful.

Data consistent with memory consolidation ideas was provided in a visuo-motor adaptation aiming task, via manipulations to target size (i.e., goal criteria). Here an easier goal group was more accurate in retention compared to a difficult goal group, even though it did not differ in practice and retention was tested under difficult goal conditions (Trempe et al., 2012). In such tasks, greater precision in aiming and large magnitude errors, have been associated with a more strategic type of learning (and different neural structures) that is less robust over time than aiming to targets with reduced constraints and smaller magnitude errors (e.g., Criscimagna-Hemminger, Bastian & Shadmehr, 2010). Hence, although goal-success and perceptions of competency may offer one reason for the goal-related effects, the nature of adaptation learning, raises the issue as to whether control mechanisms changed as a result of the aiming constraints.

Consolidation processes were also implicated in two further studies where success perceptions were believed to have changed learning, but not performance. However, rather than there being benefits associated with practise to easier goals, disadvantages were shown for practice with difficult goals (compared to control conditions; Chiviacowsky & Harter, 2015; Chiviacowsky et al., 2012). These findings were based on a coincident timing task, with success dependent on correct timing within 4 ms (difficult) versus 30 ms (easy). Although differences in retention may have been moderated by feelings of (lack of) success, supported by the fact that confidence was higher in the easier than difficult groups, it is also possible that a greater feedback dependence was created for the difficult group, in order to determine success within such a short time window, hindering intrinsic, error detection processes in the no-feedback, delayed tests of learning.

Despite the growing belief that enhanced perceptions of success change how people learn and what they remember, there has been reason to question the robustness of these effects, not only for reasons detailed above, but also based on difficulties in replication. It may be that these effects of success perceptions are very small or that they occur only under specific practice conditions and tasks. There have been published studies, which have not shown any effects associated with manipulations to success and there are likely to be unpublished studies too, given the overrepresentation of positive effects in journal publications. In one published study where the "standard" results were not replicated, only participants' awareness of the type of feedback they received, but not the content (three best or three worst trials), impacted learning (Patterson & Azizieh, 2012). These results contradicted those of Wulf and colleagues (Badami et al., 2012; Chiviacowsky et al., 2009; Chiviacowsky & Wulf, 2007; Saemi et al., 2012), where participants were also unaware of the content of their feedback. Carter and colleagues (Carter et al., 2016) also failed to show learning benefits associated with relatively better feedback. The absence of this effect was despite the fact that participants in the relatively better feedback group indicated higher judgments of learning than those in the relatively worse feedback group. Finally, in a study that involved manipulations to target size during dart-throwing, no differences in measures of accuracy were noted in performance or delayed tests of learning, despite a significant disparity in the success rates experienced by the large (82 %) and small (32 %) target groups during practice (Ong et al., 2015). Although the goal-criterion manipulation successfully changed the amount of success experienced and impacted self-efficacy during practice, these success perceptions did not impact learning.

One issue in this literature is the potential for participants to downplay the feedback or success manipulation due to competing error signals related to actual success and outcomes. For example, in a dart-throwing task, even if a target is large, the participant can still tell how close they are to the centre of the board which, regardless of target size, is still the best indicator of performance improvement. One of the few studies where outcome feedback is not readily available about success is in the stabilometer, balance task (e.g., Lewthwaite & Wulf, 2010a; Wulf et al., 2012; Wulf et al., 2013). Although this task signals general balance performance (through proprioceptive feedback), average error over a trial period or time-on-target is difficult to ascertain. This is because trials last ~ 60 sec and measures of balance vary depending on the sensitivity of the feedback/measures (i.e., completely balanced (0 deg), or stable within 1 - 5

deg). Therefore, it may be that success-related effects on motor learning are moderated by task and the saliency of actual error feedback.

A second issue with manipulations about success, especially with respect to early differences that have emerged between groups (e.g., Chiviacowsky et al., 2009; Lewthwaite & Wulf, 2010a; Palmer et al., 2016; Saemi et al., 2012), is that rather than error (or accuracy) on a trial being the driving signal of success, it may be that improvement over trials best relates to perceptions of success (and learning). In tasks where goal-criterion or target size have been manipulated (e.g., Chiviacowsky et al., 2012; Chiviacowsky & Harter, 2015; Ong et al., 2015; Palmer et al., 2016; Trempe et al., 2012), participants assigned a difficult goal may not only experience low absolute scores, but also a lack of improvement. However, for targets that are only of moderate difficulty (e.g., Ong et al., 2015), there is more room for improvement, which might lead to positive perceptions and potentially wash out any negative effects associated with overall success or accuracy. Indeed, improving on a difficult task is likely to be more rewarding than not improving very much on an easy task. Therefore, there is a need in these studies to control and/or independently manipulate improvement in accuracy across trials.

In two studies, our aim was to test for both short and long-term effects related to enhanced success perceptions on motor learning through manipulations to: 1) accuracy feedback and the degree of improvement experienced during practice; and 2) feedback that encompassed comparative/peer results. We adopted a stabilometer, balance task that had been used in one of the earliest studies because it showed both short and long-term benefits associated with perceptions of success (cf. Lewthwaite & Wulf, 2010a) and because participants are generally not privy to the actual outcome of their performance (such as overall time on target). In both studies, efforts were made to control for individual differences before practice manipulations through strict inclusion criteria. We restricted our recruitment to only females and non-competitive athletes with no prior training on balance tasks, in order to minimize between-subject variation as well as potential opposite-sex experimenter-participant interactions (e.g., Singer & Llewellyn, 1973; Stevenson & Allen, 1964).

5.2 Experiment 1

Our aim was to determine whether manipulations to accuracy feedback, based on the stringency of goal-criterion and degree of improvement across trials, would impact short- and/or longer-term learning and whether potential effects would correspond to changes in self-efficacy. In addition to Easy and Difficult goal-criterion groups, two groups practiced with the goal either increasing or decreasing in difficulty. In the former group, the degree of improvement would be low or absent, whereas for the decreasing group, marked improvements would be evidenced.

Measures of motivation and explicit knowledge were obtained to help distinguish any motivational versus reinvestment-related effects associated with the manipulations. Increased explicit knowledge in the Difficult group coupled with poorer performance, would point towards a motor-control related effect, consistent with reinvestment ideas, as would balance decrements under secondary task conditions for this group (associated with limited attentional capacity due to more conscious control of movement). A decrease in measures of motivation and self-efficacy (in the absence of increased explicit knowledge) would point towards a more social-cognitive effect (although these are not mutually exclusive). With the improvement-related manipulation, the decreasing difficulty group would experience a large improvement, such that greater perceptions of success towards the conclusion of practice should lead to enhanced skill consolidation and hence better balance performance in delayed retention. The reverse result is also possible if these groups were considered in terms of the reinvestment hypothesis. There is evidence that when practice schedules facilitate success or minimize error early versus later in practice, less explicit knowledge is gained and automaticity is encouraged (Maxwell et al., 2001; Poolton et al., 2005).

5.2.1 Methods

5.2.1.1 Participants and groups

Females (*M* age of final sample = 22.6 yr, *SD* = 4.2; range = 18-34 yr, *n* = 48) without previous training in gymnastics or on balance devices and who were not competitive athletes responded to adverts. Participants had normal or corrected-to-normal vision and were not affected by current injuries or disorders that could affect balance. They were randomly assigned to one of four groups: Easy (goal criterion), Difficult, Easy-to-Difficult and Difficult-to-Easy groups. Six

participants were removed from analyses; two were unable to participate on Day 2, one participant (Easy-to-Difficult), reported not believing the feedback (ascertained during debrief), and three participants were highly accurate on the first practice trial, showing error that was more than 2 *SD*s below the overall mean for the trial (n = 1 from Difficult, n = 2 from Difficult-to-Easy). These participants were replaced until there were 12/group (N = 48). Participants received $10/hour and informed consent was obtained in accordance with ethical procedures of the University's BREB.

5.2.1.2 Task and apparatus

Participants stood on a stabilometer (Lafayette Instrument, IN, USA) and tried to maintain it in horizontal during a 60 s trial. Feedback was provided in terms of % time-on-target (TOT). Unbeknownst to the groups, %TOT was based off either an easy goal (board within ±5° of horizontal), or a difficult criterion (within ±1° of horizontal)[9]. Two further groups received %TOT feedback according to sliding goal-criterion, either increasing in difficulty (from 5-1°; Easy-to-Difficult), or decreasing in difficulty (from 1-5°; Difficult-to-Easy) across 12 acquisition trials. Feedback was only given in practice.

5.2.1.3 Procedure

Acquisition. Participants started each trial with the platform in a horizontal position (sides off the ground), holding onto a safety bar located at waist level. Data collection started when participants released their hands from the safety bar and crossed them in front of their chest. Approximately two familiarization trials of 10 s were completed without feedback. Acquisition consisted of 12 trials of 60 s duration, interspersed with rest periods of ~60 s. After each trial, participants received verbal percentage time-on-target (%TOT) feedback, such as "you were balanced for 32% of the trial" and shown a monitor display of "TOT: 32 %". On a descriptor scale of "0" (for "not at all confident") to "100" ("very confident"; Zimmerman & Kitsantas, 1997), participants rated their confidence (i.e. self-efficacy) for achieving at least a certain %TOT score on the next trial, for a series of score iterations from 10 %TOT to the max of 100 %TOT, in increments of 10 (Bandura, 2006). These self-efficacy probes were

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[9] *To avoid a performance ceiling effect for the Easy group or too easy a criterion for the Difficult group, we piloted which criteria resulting in percentage TOT scores that mirrored the success rates of ~ 50% for successful groups and < 10 % for less successful groups reported in earlier studies (Chiviacowsky et al., 2012; Trempe et al., 2012).*

administered before trials 3, 6, 9 and 12. For a list of measures as a function of experimental phase, please see left of Table 5.1.

At the end of acquisition, participants filled out a 10-item, Likert scale (1 = “strongly disagree, 7 = “strongly agree”) questionnaire consisting of the 8-item intrinsic motivation and amotivation subscales of the Situational Motivation Scale (SMS, Guay et al., 2000) and two customized items; whether they looked forward to practising a similar balance activity in future and whether they were motivated to do well during practice.

Delayed tests of learning. One day later, participants first performed two warm-up trials (10 s, no feedback) before completing five, 60 s retention trials without feedback. Before trials 1 and 4, participants provided self-efficacy ratings of achieving %TOT scores in 10 % increments. Two secondary task trials followed, where participants performed an additional cognitive task of counting the number of high tones played in an audio sequence (consisting of random high or low tones per 1.5 s). They were instructed to perform both the primary task of balancing and the secondary counting task as well as they could, without trading off performance in one for the other. At the end of the experiment, participants were interviewed and asked to report any rules or techniques that they had generated/used during acquisition, and were questioned about the veracity of the feedback (see Table 5.1 for an overview of these measures).

Table 5.1. Overview of experimental groups, feedback and measures in Exp. 1 and 2 as a function of testing phase.

Variables		Exp. 1	Exp. 2
Groups (Feedback received):		1) Easy (%TOT)	1) Positive (RMSE + Pos comparative)
		2) Difficult (%TOT)	2) Pos-Control (RMSE)
		3) Easy-to-difficult (%TOT)	3) Negative (Neg comparative)
		4) Difficult-to-easy (%TOT)	4) Neg-Control (None)
Measures			
Day 1:	Pre-session	None	IMI (competency) for Neg groups
	Acq	%TOT, RMSE	RMSE, MPF
		Self-efficacy	Self-efficacy/Comparative expectations
			Heart rate
	Post-session	SMS (intrinsic & amotivation)	SMS (intrinsic & amotivation)
			IMI (competency, enjoyment)
Day 2:	Pre-session	None	IMI (competency)
	Ret, Sec	%TOT, RMSE	RMSE, MPF
		Self-efficacy	Self-efficacy/Comparative expectations
		Accuracy Tone-counting	Accuracy tone-counting
	Post-session	Explicit knowledge	Explicit knowledge
		Feedback credibility check	Credibility and success check

Key: Acq = Acquisition phase; Ret = Retention test; Sec = Secondary task test; TOT = Time on target; Pos = Positive; Neg = Negative; RMSE = Root Mean Square Error; MPF = Mean Power Frequency; SMS = Situational Motivation Scale; IMI = Intrinsic Motivation Inventory.

5.2.1.4 Data collection and analysis

Platform deviations from zero were sampled with a potentiometer and rendered through LabVIEW software (version 9.0; National Instruments, TX, USA) at 1 KHz. From these raw data, root mean square error (RMSE), indicative of typical deviation from horizontal, and %TOT scores, that represented the duration of time the platform was within specific criterion angles of horizontal, were derived. Percentage TOT scores for 1, 3 and 5° were tabulated for all trials.

Separate repeated measures ANOVAs were applied with group as the between and trial as the within variable to analyze balance (RMSE, %TOT) and self-efficacy measures in acquisition and retention. All participants (n = 12/group) were included in statistical analyses. Self-efficacy on a trial was calculated by taking the average of all confidence ratings for the 10 score iterations (e.g., if 10% TOT was rated as 100 for “very confident”, 20% TOT as 70 for “pretty confident” and 30% TOT as 0 for “not at all confident”, the average rating would be 170/10 = 17%). A between-groups ANOVA was used to analyze mean balance measures for the secondary task trials. To assess for performance changes under secondary-task conditions, a repeated-measures ANOVA with group as the between and test (last retention trial, first

secondary task trial) as the within variable was analyzed. Post hoc analyses were conducted using Tukey's HSD ($p <. 05$). Within variables were corrected with Greenhouse-Geisser for violations to sphericity. Partial eta squared (η^2_p) values are reported as measures of effect size.

To further assess whether the goal/feedback manipulation had impacted performance and learning, Pearson's correlational tests were conducted on the first and last acquisition trials and first acquisition and first retention trials. A high significant correlation would indicate a weak influence of the feedback manipulation and enduring influences of early individual differences. The correlation between first acquisition and first retention trial was calculated to give us a sense of the persisting effect of pre-existing balance capability on "learning". We assessed the first rather than the last retention trial, because participants improved across the retention trials (which may or may not have been related to the previous day's manipulation).

The accuracy of the tone-counting responses (number of secondary task trials with response errors) was assessed for between-group differences using the Kruskal Wallis test. This non-parametric test was also used to compare the four measures of motivation (intrinsic motivation, amotivation, motivation to do well, and motivation to engage in activity in future), as well as the number of rules. To assess for potential primary-secondary task trade-offs during the secondary task condition, point-biserial correlational tests were conducted on RMSE scores and corresponding tone-counting errors. A significant negative point-biserial correlation would reflect possible trade-offs between performance on the primary and secondary tasks. To aid readability of the results we have provided a table (Table 5.2) of all statistically significant effects.

Table 5.2. Summary table of statistically-significant effects across Exp. 1 and 2.

Measures and Effects:		Exp. 1 Test statistic	Effect size(η^2_p)	Exp. 2 (a and b) Test statistic	Effect size
Feedback scores:					
	Group	F(3, 44) = 53.85***	.79		
	Trial	F(3.8, 166.1) = 44.96***	.51		
	Group x Trial	F(11.3, 166.1) = 45.26***	.76		
Self-efficacy/confidence probes:					
Acq:	Group	F(3, 44) = 23.62***	.62		
	Trial	F(2.1, 92.7) = 54.22***	.55		
	Group x Trial	F(6.3, 92.7) = 23.96 ***	.62		
Ret:	Group	F(3, 44) = 15.86***	.52		
Acq&Ret:	Trial	F(1, 44) = 12.71***	.22	(Exp 2a) F(1.3, 23.3) = 80.73***	η^2_p = .82
	Group x Trial	F(3, 44) = 6.07**	.29		
	Day			Exp 2a) F(1, 18) = 19.63***	η^2_p =.52
RMSE:					
Acq:	Trial	F(6.0, 263.8) = 92.21***	.68	Fs > 40.00***	η^2_p > .68
Ret:	Trial	F(4, 176) = 6.56***	.13	Fs > 9.43***	η^2_p > .33
Sec:	Test	F(1, 44) = 17.19***	.28	(Exp.2a) F(1, 18) = 7.81*	η^2_p = .30
Competency (IMI):					
End Acq:	Group			(Exp.2a) Z = 3.46, U = 4.50***	r = .77
	Group			(Exp.2b) Z = 2.91, U = 11.50**	r = .65
Ret:	Group			(Exp.2b) Z = 3.07, U = 9.50 ***	r = .69
Success rating:					
	Group			(Exp.2b) Z = 2.60, U = 16.50**	r = .58
Heart rate:					
	Group			(Exp.2b) F(1, 15) = 5.23*	η^2_p = .26
Mean Power Frequency:					
Acq:	Trial			Fs > 2.35*	η^2_p > .11
Ret:	Trial			(Exp.2a) F(3.3, 59.3) = 3.19*	η^2_p = .15
Intrinsic motivation (SMS):					
	Group			(Exp.2b) Z = 2.25, U = 20.50*	r = .50
Motivation to do well in practice:					
	Group			(Exp.2b) Z = 3.12, U = 10.00**	r = .70

Key: Acq = Acquisition phase; Ret = Retention test; Sec = Secondary task test; RMSE = Root Mean Square Error; SMS = Situational Motivation Scale; IMI = Intrinsic Motivation Inventory. * p < .05; ** p < .01; *** p < .001.

5.2.2 Results

5.2.2.1 Success of the feedback manipulation

Feedback scores. Participants received different %TOT scores during acquisition that were congruent with our intended manipulation, as illustrated in Figure 5.1. Average %TOT feedback for the Easy group was higher (M = 54.6 %) than the Difficult group (M = 11.1 %) and the Difficult-to-Easy group showed a marked improvement in scores (from 6.8 to 63.2 %), whereas the Easy-to-Difficult group plateaued in scores around trials 4-5, after which scores declined. This was confirmed by main effects of group, trial, and a significant Group x Trial

interaction (see Table 5.2). As can be seen from Figure 5.1 and confirmed through post-hoc testing, %TOT feedback for the Easy-to-Difficult group was not different from the Easy group in early practice, neither was %TOT feedback for the Difficult-to-Easy and Difficult groups. However, the changing-criteria groups started to show statistically significant deviations from the fixed criteria (Easy and Difficult) groups from the fifth trial onwards (*p*s<.05).

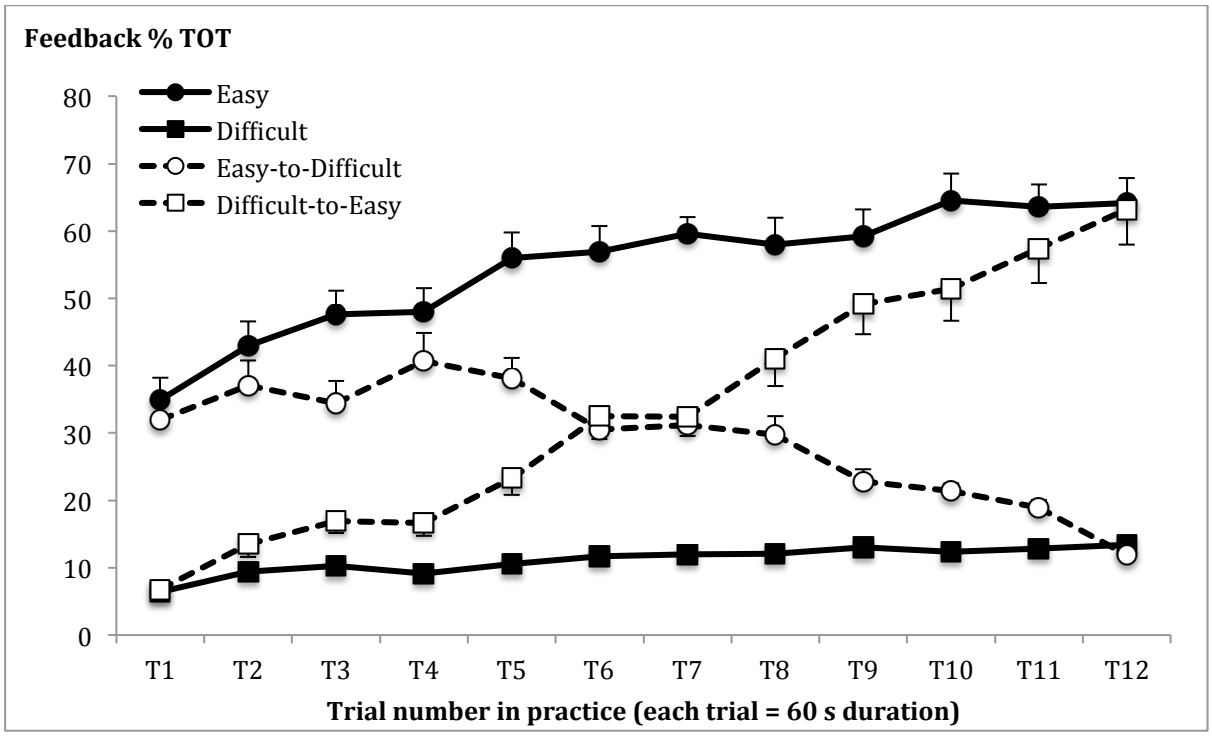

Figure 5.1 (Exp. 1). Average %TOT feedback (and *SE* bars) as a function of group and acquisition trials (T). SE bars for the Difficult group were too small to be visible on this scale.

Self-efficacy. Self-efficacy probes of self-efficacy closely mirrored %TOT feedback as illustrated in Figure 5.2. Again there were main effects of group, trial, and a Group x Trial interaction (see Table 5.2). Post-hoc analysis showed that the Easy and Difficult-to-Easy groups improved in self-efficacy from T3 to T12. The Difficult and Easy-to-Difficult groups did not change in self-efficacy from T3 to T12. The Easy and Difficult-to-Easy groups also showed a statistically significant increase in self-efficacy from T6 to T12, while the Easy-to-Difficult group decreased in self-efficacy. No significant change was noted for the Difficult group. Retention analysis yielded a similar pattern as observed at the end of acquisition (see right of Figure 5.2), again showing significant group differences.

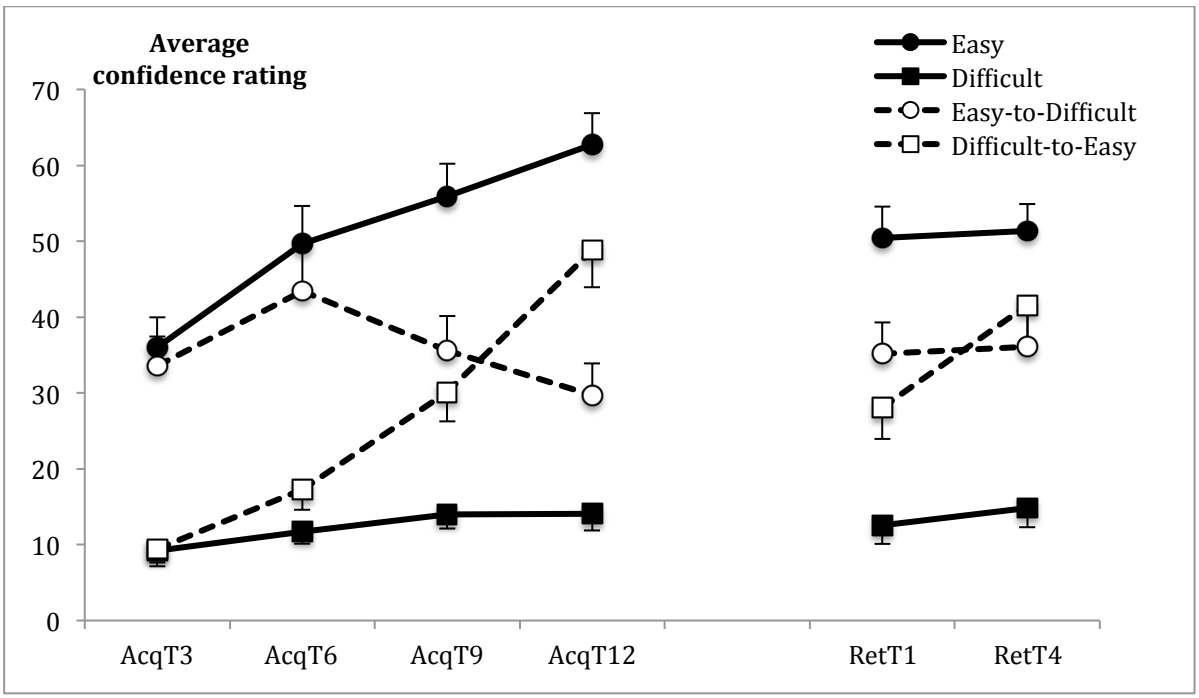

Figure 5.2 (Exp. 1). Average self-efficacy ratings (0-100%) across probe trials in acquisition (T) and retention (R). Error bars represent *SE*s.

5.2.2.2 No evidence that feedback impacted balance

All groups improved balance over acquisition and did not differ from one another (Figure 5.3). There was a significant trial effect but no significant effects involving group, Fs < 1. This was also true when we analyzed %TOT, based on various goal criteria (i.e., difficult = 1°, easy = within 5°, intermediate = 3°; see Table 5.2). The same was true for retention, where all group-related effects for both RMSE and other %TOT measures yielded Fs ≤ 1. Because there looked to be small, though non-significant, group differences for RMSE on T1 during acquisition, we ran additional ANCOVA analyses with T1 as a covariate. This did not change the group-related effects for RMSE or %TOT (all Fs < 1.1, ps > .39).

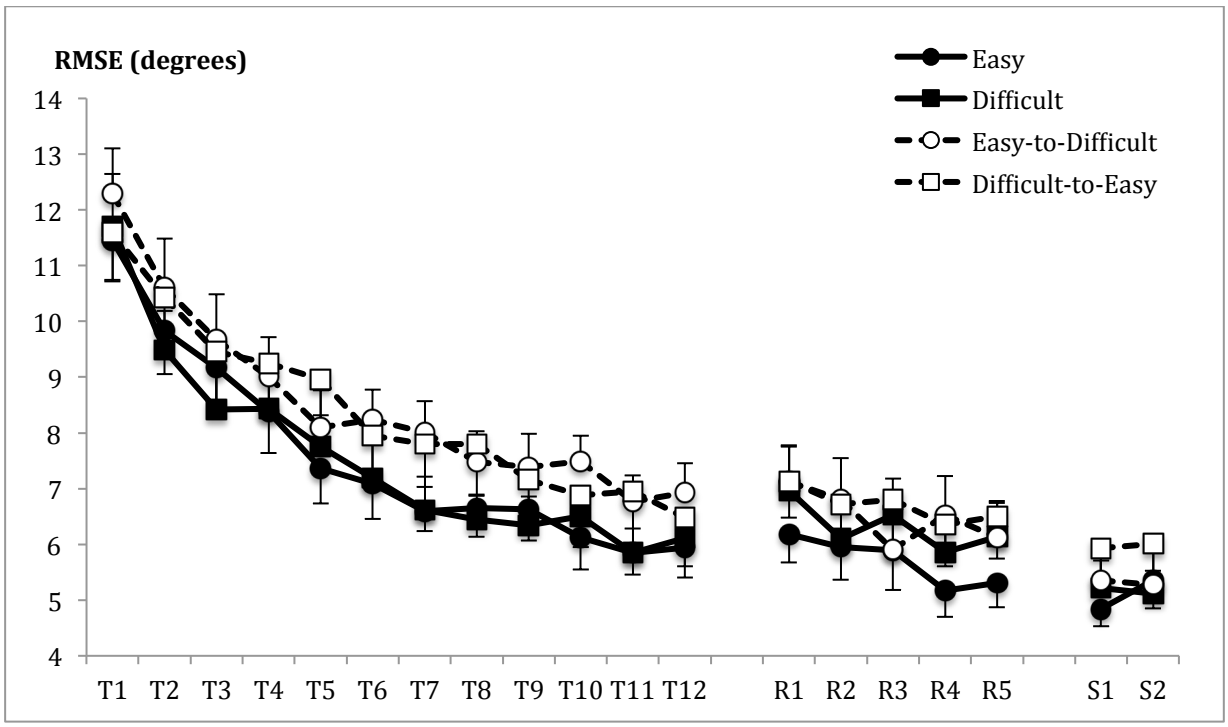

Figure 5.3 (Exp. 1). Average RMSE (and *SE* bars) over the course of 12 acquisition (T1-T12) trials, 5 retention (R1-R5) trials, and 2 secondary task (S1-S2) trials.

Performance on the secondary task also failed to differentiate the groups for RMSE and %TOT (Fs < 1). Participants unexpectedly improved in performance from the last retention trial (RMSE: $M = 6.02$, $SD = 2.15$) to the first secondary task trial ($M = 5.34$, $SD = 1.95$). Response accuracy for the secondary tone-counting task did distinguish the groups, $\chi^2(3, N = 48) = 8.50$, $p < .05$. It was the Easy group that made most errors ($M = .83$, $SD = .58$), although it was only significantly different to the Easy-to-Difficult group ($M = .17$, $SD = .39$). For comparison; Difficult ($M = .42$, $SD = .52$), Difficult-to-Easy ($M = .58$, $SD = .67$). There was a significant positive point-biserial correlation between RMSE on the first secondary task trial and accuracy of tone-counting response, $r_{pb} = .37$, $n = 48$, $p = .01$, but not on the second trial ($p = .58$). The direction of the relation indicates a tendency for high (or low) error on both tasks, rather than any trade-offs.

Participant's performance on the first practice trial before any feedback was received, continued to be correlated to final performance at the end of practice and in retention. Pearson's correlation analyses indicated large positive correlations between RMSE for the first and last

practice trial, $r = .70$, $p < .001$, and first retention trial, $r = .75$, $p < .001$, accounting for ~50% of the variance in outcome measures.

5.2.2.3 Feedback did not influence motivation or explicit knowledge

The intrinsic (overall $M = 5.55$, $SD = 1.00$) and amotivation (overall $M = 2.18$, $SD = .97$) subscales of the SMS did not differentiate the groups (see Table 5.3 for group descriptive statistics), nor did the two custom items assessing motivation to do well (overall $M = 6.06$, $SD = 1.06$) and to practice in the future (overall $M = 5.73$, $SD = 1.11$). All indices showed that participants were motivated to do well. Rules and strategies reported (overall $M = 2.3$, $SD = 1.0$) also did not yield group differences ($p = .53$). Participants generally reported rules and strategies related to maintaining a low centre of gravity (e.g., bending of knees, slight forward lean), a wide base of support (e.g., turning feet out, feet about shoulder width apart), concentration (e.g., focusing on the fixation cross, not thinking "too much" about the task), and breathing (e.g., regular calm breaths, deep breaths to relax).

Table 5.3. Descriptive statistics pertaining to the motivation and explicit knowledge measures for Exp. 1 and 2.

	Exp. 1 / Groups				**Exp. 2 / Groups**			
	Easy	Difficult	Easy-Diff	Diff-Easy	Positive	Pos-Ctrl	Negative	Neg-Ctrl
Measures:								
Intrinsic motivation:								
Mean	6.02	5.58	5.38	5.23	5.55	5.95	4.35	5.25
SD	.61	.79	.83	1.48	.93	.86	.80	.84
Amotivation:								
Mean	1.88	1.79	2.52	2.54	2.23	1.98	2.90	2.40
SD	.70	.56	1.01	1.27	.70	1.01	.58	.84
# Rules/strategies:								
Mean	2.3	2.4	2.0	2.5	2.1	2.0	1.8	1.6
SD	.9	1.0	.8	1.5	1.0	.7	.9	.7

Key: Diff = Difficult; Pos = Positive; Neg = Negative; Ctrl = Control.

5.2.3 Discussion

Our aim was to determine if and how manipulations to feedback pertaining to goal-attainment influence success perceptions and learning of a stabilometer balance task. Importantly, we assessed whether relative changes in feedback, reflecting more or lack of improvement over practice, would be more influential in determining success perceptions, and ultimately learning,

than feedback just signaling absolute high or low error. The goal-criterion manipulation successfully influenced %Time-on-Target (%TOT) feedback and self-efficacy. Participants in the Easy and Difficult groups received the highest and lowest %TOT feedback scores during practice. The Difficult-to-Easy group experienced the largest relative improvement and scores gradually declined for the Easy-to-Difficult group. Self-efficacy ratings mirrored these trends in practice and retention, even when feedback was not present.

There was no evidence that balance performance and learning were differentially impacted by these feedback manipulations and between group differences in self-efficacy. There were no group differences in outcome measures for either retention or secondary task performance, or evidence of a negative correlation indicative of a potential trade-off between primary task performance (RMSE) and secondary task accuracy (errors). These findings contrast with studies where similar practice manipulations have produced immediate and/or delayed impacts on learning (cf. Chiviacowsky et al., 2012; Chiviacowsky & Harter, 2015; Palmer et al., 2016; Trempe et al., 2012). Yet, these data are congruent with other studies which have failed to show learning benefits associated with relatively increased perceptions of success (Carter et al., 2016; Ong et al., 2015, Patterson & Azizieh, 2012). Participants also did not report being more motivated as a result of these success-related manipulations, even though they believed the feedback to be valid. Because of the lack of group differences, we were unable to determine relative influences on performance due to reinvestment of knowledge/conscious processing (e.g., Masters, 1992) or success perceptions and positive affect (i.e., OPTIMAL theory; Wulf & Lewthwaite, 2016). It appears that performance was primarily a function of initial individual differences and attempts to correct based on error-nullification, regardless of the magnitude of the error or improvement across trials.

For the secondary task trials, there was a small, yet significant improvement in RMSE when the last retention trial was compared to the first secondary task trial, which was independent of group. Although we expected the secondary task of counting tones to destabilize balance, improvements in balance have also been associated with such secondary tasks (e.g., Fearing, 1925; Swan, Otani, Loubert, Sheffert & Dunbar, 2004). The addition of counting may have led to an increase in concentration (mental effort), which in turn positively benefited balance. Alternatively, the secondary task may have directed attentional focus away from the

primary task, which facilitated balance due to the external focus (for a review see Park, Yi, Shin & Ryu, 2015). The Easy group also made the most tone-counting errors (although only significantly different to the Easy-to-Difficult group), which was not expected and goes against predictions related to reinvestment. Based on these data, we surmise that performance under secondary-task load conditions in this balance task might be ineffective in giving an indication of potential control strategies, related to reinvestment (cf. Masters, 1992; Maxwell & Masters, 2009). Because there were also no group differences in the amount of task-relevant rules and strategies generated to support performance, we do not have any evidence that the amount of error experienced or perceived in practice impacted knowledge accrual or attentional/movement control strategies.

One potential limitation of Experiment 1 was that performance was not evaluated against an explicit goal or standard. Though participants knew that higher %TOT meant better balance and that values close to 0% were poor and closer to 100% were good, and they could clearly see whether they were improving (at least in the Easy and Difficult-to-Easy groups), there was no specific criterion for interpreting "success". Although measures of self-efficacy suggested that performance perceptions were impacted by the feedback, if we had asked participants how they thought they were doing (in comparison to peers) we may have been better able to determine how feedback (and hence performance) was interpreted. Therefore, in Experiment 2, false feedback of others' performance was provided as a standard of comparison and as a means to manipulate success perceptions.

5.3 Experiment 2

False social comparative feedback has been effective for bolstering success perceptions in other stabilometer studies (Lewthwaite & Wulf, 2010a; Wulf et al., 2012; Wulf et al., 2013). In these studies, participants in a "positive" group received comparative feedback indicating they were performing better than others. This group showed immediate performance gains and sustained these benefits in retention, compared to a control group that received only veridical error feedback. Given other contradicting reports of a lack of behavioural effects with such success perceptions (Carter et al., 2016; Ong et al., 2015, Patterson & Azizieh, 2012), we first attempted

to replicate the benefits of positive social comparative feedback in this task (see Lewthwaite & Wulf, 2010a).

In Experiment 2, we studied control processes related to platform adjustments (i.e., Mean Power Frequency, MPF) with higher frequency values thought to indicate greater automaticity (e.g., McNevin, Shea & Wulf, 2003). As with Exp. 1, balance was also assessed under secondary task conditions and participants were asked to verbalize any task-relevant knowledge at the end of practice. According to reinvestment-related explanations, compared to a no comparative feedback control group, we expected the Positive group to demonstrate higher MPF, less performance decrement under secondary task conditions, and less task-relevant knowledge.

After analyzing the data collected from the two groups, it was apparent that participants in the control group had perceived themselves to be as successful and motivated as those in the Positive group. Therefore we tested two further groups (Exp. 2b). We reasoned that by withholding all feedback, and providing only general negative comparative feedback, the two further groups (Negative feedback and a no-feedback control) would be differentiated on success perceptions and hence allow clearer conclusions about the effectiveness of this type of feedback manipulation. To better elucidate how success perceptions might be mediating any performance benefits we also collected heart rate data to give a psychophysiological measure of arousal. This measure allowed us to infer the effects of feedback on psychophysiology as well as relate any performance changes to increased arousal (in line with the OPTIMAL theory). Both positive and negative feedback were expected to be more arousing than their control conditions (as indexed by increased heart rate; Brehm & Self, 1989; Kahneman, 1973), with positive performance effects associated with increased motivation or effort expected in the positive group only.

5.3.1 Methods

5.3.1.1 Participants and groups

Recruitment procedures were the same as Exp. 1. Only female participants (*M* age = 21.1 yr, *SD* = 3.4, range 18 – 33 yr) were recruited.

Exp. 2a. Participants were randomly assigned to either the Positive (RMSE + positive comparative feedback), or Positive (Pos)-Control group (RMSE only). One participant from the

Positive group did not perceive the practice to be successful (neutral on Likert rating) and hence was removed from analysis and replaced. The final numbers were n=10/group.

Exp. 2b. After testing was completed for Exp. 2a, additional participants were randomly assigned to either a Negative (just negative comparative feedback) or Negative (Neg)-Control (no augmented feedback) group. Three participants from the Negative group perceived their practice to have been successful (above neutral Likert rating) and hence were not included in analysis and replaced. Two participants on the first acquisition trial were ~2 *SD*s above the group mean in the Negative group, and one participant was ~2 *SD*s below the group mean in the Neg-Control group. These individuals were also replaced such that the final numbers were n=10/group.

5.3.1.2 Task and apparatus

The task and apparatus were identical to those in Exp. 1. In Table 5.1, an overview of groups and measures for Experiment 2 is provided.

Exp. 2a. For each acquisition trial, the Pos-Control group received error feedback, which represented typical angular deviation from horizontal (RMSE). The Positive group also received false, social comparative feedback about the "group average" of participants in our study on each acquisition trial. This closely mirrored the comparative feedback procedures of Lewthwaite and Wulf (2010a), although we applied a flexible rather than fixed (1.2) multiplier. Piloting revealed some issues in credibility with the latter procedure as a result of the exact increase and decrease in group error that mirrored the participant's own performance, even when they got unexpectedly worse with practice. Hence, to ensure that the comparative feedback was credible and scaled to initial performance error, a flexible multiplier approach was applied to the first acquisition trial, followed by gradual decreases of ~ 1° (with variation) on subsequent acquisition trials. For initial errors between 9-16°, a multiplier of 1.5 was applied. Because the maximum angular deviation of the platform was 26.8°, using a smaller multiplier of 1.2 when initial error was high (RMSE = 16° or >) prevented the average error from exceeding the maximum. If participants performed exceptionally well on the first trial (RMSE = 9° or <), a larger multiplier of 1.8 was applied. This ensured that participants could perform better than the false average on every trial as they improved, and the participants understood that they had performed better than "others".

Exp. 2b. Neither group received RMSE feedback. The Negative group was only given false comparative feedback that the trial was "below average performance", with the exception of the first acquisition trial where they were told the trial was of "average performance". This was designed to aid credibility and to alert to a relative lack of improvement compared to others. No feedback was provided to the Neg-Control group.

A photoplethysmography (PPG) sensor was attached to the distal phalanx of the middle finger for heart rate measures. Signals were wirelessly amplified and transmitted to a data acquisition module unit (BioNomadix MP150, Biopac systems Inc., QC, Canada) and recorded at a sampling rate of 1 KHz for further analyses (AcqKnowledge 4.2; Biopac systems Inc.).

5.3.1.3 Procedure

Acquisition. Procedures were the same as Exp. 1, except at the start of Day 1, participants were fitted with a PPG sensor, followed by one-minute of quiet standing to validate recordings. After initial familiarization trials, the acquisition phase consisted of seven 60 s trials to match the practice design of Lewthwaite and Wulf (2010a). However, as groups in the study by these authors were already differentiated in performance after one day of practice, which was sustained through the second day of practice and retention on Day 3, we eliminated the extra day of practice in our experiment. On conclusion of each trial, the RMSE score was displayed and read out by the experimenter in Exp. 2a. A second display of "group average" (RMSE) was provided and read to the Positive group only. For the Negative group (Exp. 2b), a general statement alerting the participant to the fact that their performance was below average in comparison to others who had previously completed the experiment was verbally provided after trials 2-7.

Before trials 2, 4 and 7, the Positive and Pos-Control groups were probed for their self-efficacy in a similar fashion to Exp.1. They rated their self-efficacy in achieving an RMSE score that was less than 20° on the next trial, followed by 18°, 16° etc. (in decrements of 2°). The Negative and Neg-Control groups were asked for their expected comparative performance on the next trial in terms of whether it would be "at average", "above average" or "below average" compared to other people who had taken part in the study.

At the end of acquisition, participants filled out a 7-point Likert scale questionnaire (1 = "strongly disagree, 7 = "strongly agree") consisting of the perceived competency and task interest/enjoyment subscales of the Intrinsic Motivation Inventory (IMI; McAuley et al., 1989), the intrinsic motivation and amotivation subscales of the SMS (Guay et al., 2000), and the two customized items from Exp. 1. For a summary of measures, see Table 5.1.

Delayed tests of learning. After ~24 hours, participants completed the perceived competency subscale of the IMI before performing 7 retention trials without feedback. No warm up trial was provided on Day 2. Before retention trials 1, 4 and 7, the groups were asked the same self-efficacy or expectation probes asked on Day 1. Following retention, one secondary task trial (identical to Exp. 1) was performed.

At the end of the experiment, participants were interviewed for any task-relevant rules, rated their outcome feedback (and/or group scores) with respect to credibility and provided a judgment of success pertaining to the end of practice on Day 1 (using Likert ratings from 1-7).

5.3.1.4 Data collection and analysis

Platform deviation was sampled and rendered in the same way as in Exp. 1. The balance outcome measures of mean RMSE and mean power frequency (MPF) were tabulated from the raw data. A rectangular window was applied to the fast fourier transform of the platform deviations to derive MPF. In all analyses, the comparative feedback groups were separately analyzed with their respective control groups, even though we illustrate all four groups in the figures that follow.

Separate repeated measures ANOVAs were applied to RMSE[10], MPF and self-efficacy measures, in acquisition, retention and secondary task testing, with Group as the between variable, and Day and Trial, or Test as within variables. The non-parametric Mann-Whitney U test was used to analyze questionnaire data. Pearson's correlational tests were conducted on the first acquisition trial with both the last acquisition trial and first retention trial, to assess the

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[10] *Although not reported in the published manuscript, one participant (S13) did not improve in RMSE across the two days, or when comparing the first practice trial to retention (see Appendix 7). Excluding this participant from analyses did not change any of the directional effects, nor moderate effect sizes in a way contrary to published results.*

impact of the feedback manipulation. Point-biserial correlational tests were conducted on RMSE and corresponding tone-counting errors to assess for potential trade-offs.

The entire HR waveform was low-pass filtered at 5 Hz and peaks were manually flagged across a 60 s trial to provide HR for each trial (bpm). As we were interested in the effect of the feedback manipulation on acquisition HR, the first acquisition trial on Day 1 served as the baseline/covariate in analyses. Psychophysiological data was missing[11] on 4.8 % of trials, either due to human error (e.g., forgetting to start collection), or equipment failure (e.g., detached electrodes). To aid with readability of the results, we have summarized statistically significant effects on the right side of Table 5.2.

5.3.2 Results

5.3.2.1 Success of the feedback manipulations

Self-efficacy and expectation. For Exp. 2a, self-efficacy/confidence probes showed a significant difference across trials, and testing days, as illustrated in Figure 5.4 (in both cases showing significant increases). However, the Positive feedback and its control did not differ in self-efficacy ratings during acquisition or retention. There were no group-related effects, Fs<1.

[11] *Three participants (1 from Pos-Control and 2 from Negative group) were excluded from the general linear analysis (GLM) of repeated measures ANOVA due to missing heart rate data. A linear mixed model analysis, that retained the valid data from the excluded participants, showed the same effects as the GLM analysis.*

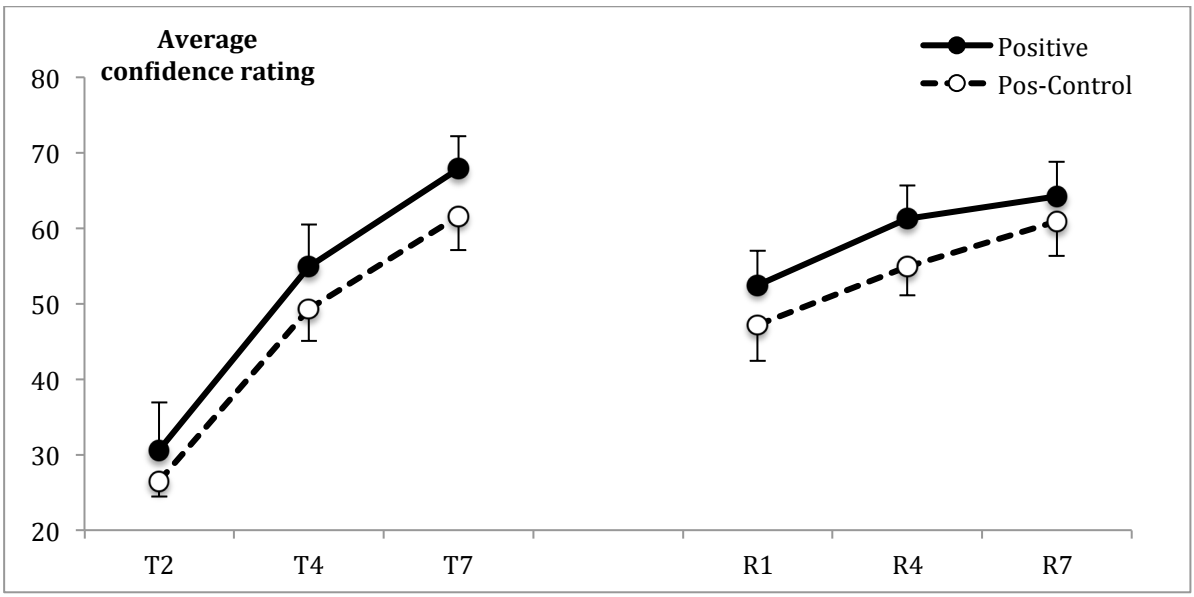

Figure 5.4 (Exp. 2a). Average self-efficacy ratings (0-100) across probe trials in acquisition (T) and retention (R). Error bars represent *SE*s.

In Exp. 2b, participants were asked whether they expected their next trial to be at, above or below average. We did not run statistical tests on these data, but present a descriptive analysis. Before T2, as illustrated in Figure 5.5A, all participants in the Negative group expected average performance on the following trial, but before T4, more than half expected below average performance and by T7, all participants expected below average performance. The trend for the Neg-Control group was somewhat opposite as expectations for average or above average performance increased from T2, to T4 and T7 (Figure 5.5B). These differences were maintained in retention without feedback, where ~70 % of people in the Negative group expected to be below average compared to less than 10 % in the Neg-Control.

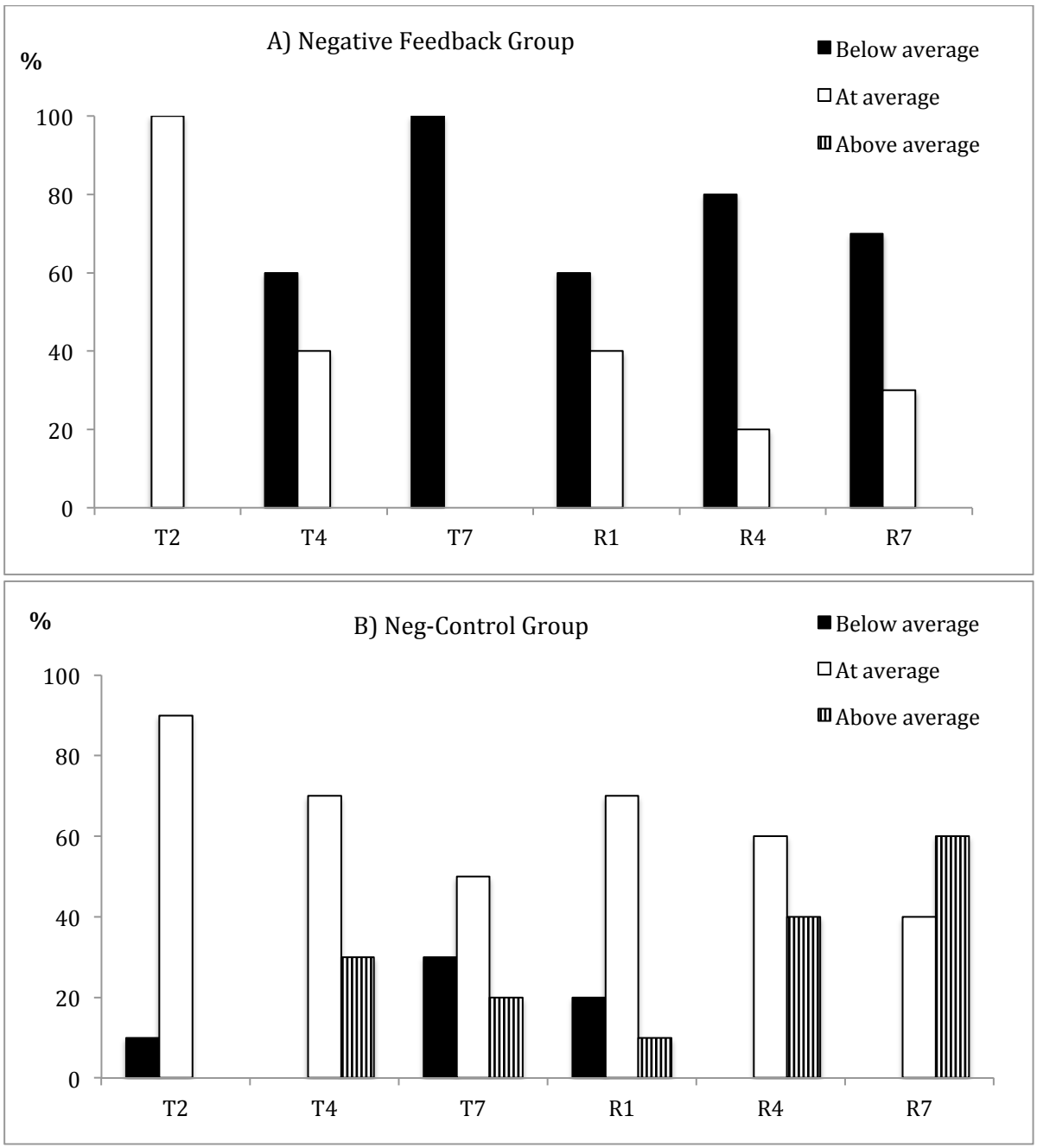

Figure 5.5 (Exp. 2b). Percentage of participants in A) Negative feedback group and B) Neg-Control groups who expected at, below or above average performance on the next trial in acquisition (T) and retention (R).

Perceived competency. The Positive group (M = 6.02, SD = 0.56) perceived itself to be more competent in the balance task at the end of acquisition than the control (M = 4.85, SD = 0.78; see Table 5.2), but there were no group differences before retention. For the Negative groups, competency ratings were also collected before practice, but significant group differences were only shown when assessed at the end of practice and before retention. In both cases, the

Negative group had lower ratings (Acq: *M* = 2.37, *SD* = .94; Ret: *M* = 2.80, *SD* = 0.90) than their control group (Acq: *M* = 4.32, *SD* = 1.20; Ret: *M* = 4.37, *SD* = 1.00).

Success rating and feedback credibility. There were no difference in mean perceptions of success measured at the end of testing between the Positive group (*M* = 6.50, *SD* = .53) and its control (*M* = 5.89, *SD* = .93). The Negative group did perceive lower success (*M* = 2.90, *SD* = .88) than their control (*M* = 4.50, *SD* = 1.35; see Table 5.2). Participants in all groups generally believed the feedback to be true (overall *M* = 5.39, *SD* = 1.21, max. = 7). There were no group differences in credibility ratings.

Heart rate (HR). There were no group-related differences during quiet standing (T1 – baseline). During acquisition, the Negative group had higher HR than the Neg-Control (see Table 5.2 and Figure 5.6 for T1, covariate-adjusted means). No other group-related effects were significant for either comparative feedback group when compared to their respective control for acquisition.

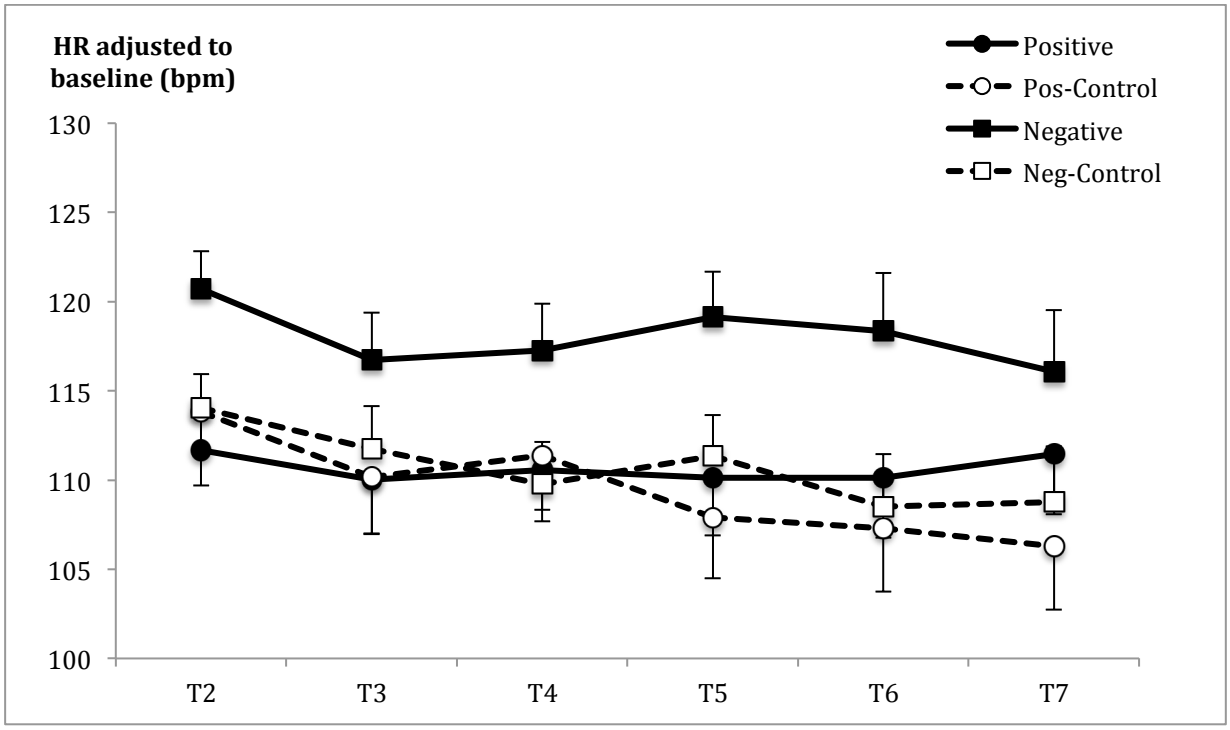

Figure 5.6 (Exp. 2a&b). Mean covariate-adjusted HR as a function of group and acquisition trials, T2-T7). Error bars represent *SE*s.

5.3.2.2 No evidence that feedback impacted balance

Acquisition. As illustrated in Figure 5.7, RMSE decreased across acquisition trials for both experimental and control groups. However, in neither experiment were group-related effects observed.

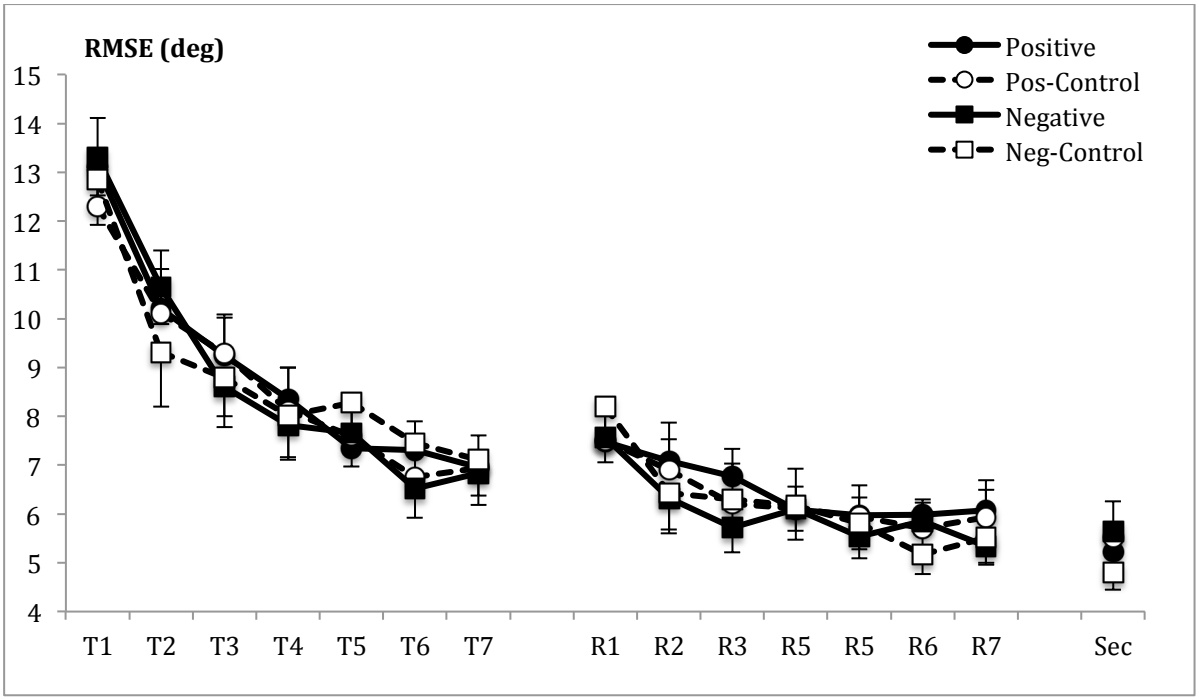

Figure 5.7 (Exp. 2a&b). Average RMSE as a function of group and experimental phase: acquisition (trials T1-T7), retention (trials R1-R7), secondary task (Sec). Error bars represent *SE*s.

There was also an increase in MPF (see Figure 5.8) for both experimental and control groups. Again, there were no group-related effects.

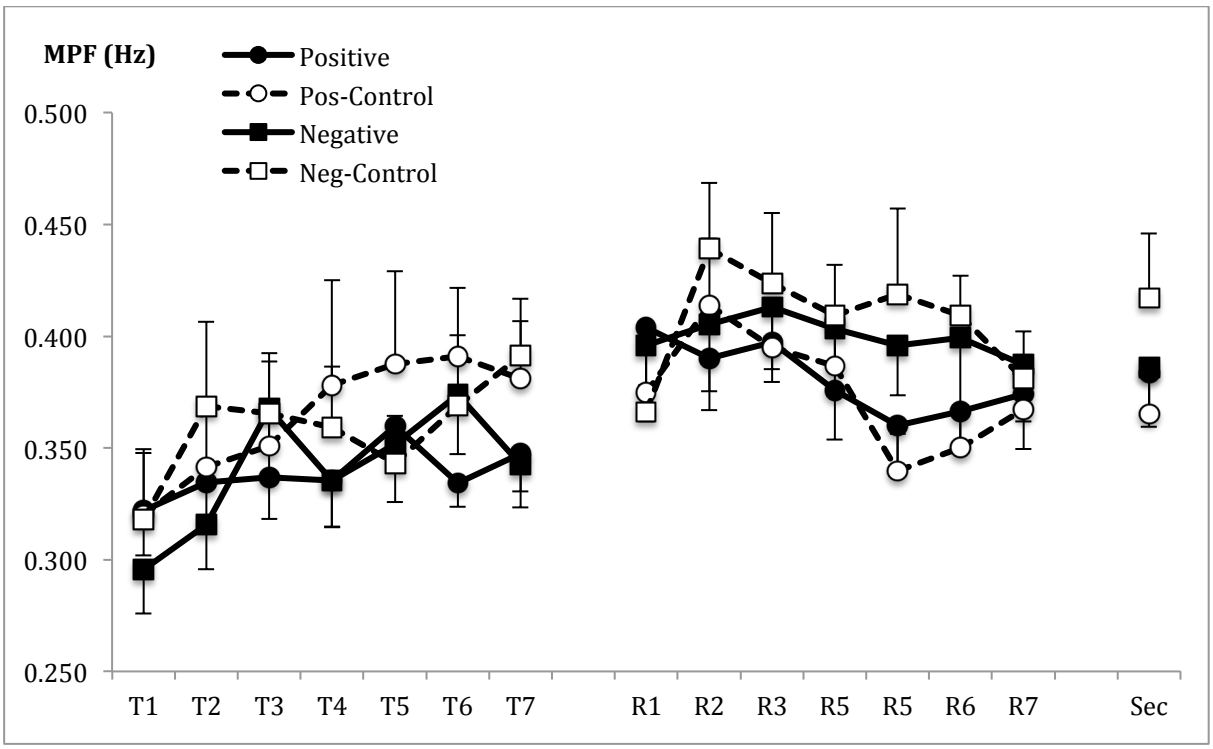

Figure 5.8 (Exp. 2a&b). Mean Power Frequency (MPF) of platform adjustments as a function of group and experimental phase: Acquisition (Trials T1-T7), Retention (Trials R1-R7), Secondary Task (Sec). Error bars represent *SE*s.

Delayed tests of learning. Participants continued to improve on RMSE over 7 retention trials on Day 2 as evidenced by a significant trial effect for the Positive and Pos-Control groups, and for the Negative and Neg-Control groups (see R1-R7, Figure 5.7), but again there were no group effects.

MPF showed a significant reduction over retention trials, for the Positive and Pos-Control groups, but not for the Negative groups, although there were no group-related effects.

The secondary task trial did not differentiate between either group and its control for RMSE and MPF, all *p*s > .28. There was a significant improvement in RMSE only for the Positive and Pos-Control groups for the secondary task trial ($M = 5.37$, $SD = 1.70$) compared to the last retention trial ($M = 6.00$, $SD = 1.90$). There were no differences in tone-counting accuracy (*p*s > .52) and no correlation between RMSE and tone-counting errors for either experiment, *p*s > .35.

5.3.2.3 Variance of outcome measures explained by early practice performance

Correlations between the first and last practice trials for all participants (Exp. 2a & b) were positive and relatively high for RMSE, $r = .52$, $p < .01$ and MPF, $r = .65$, $p < .001$ (accounting for ~27-42% of the variation in performance). Correlations between the first practice and first retention trials were similar; RMSE: $r = .42$, $p < .01$; MPF: $r = .54$, $p < .001$, underscoring the lack of influence of the feedback manipulations.

5.3.2.4 Negative (Not positive) feedback impacted motivation, but not explicit knowledge

The Positive and Pos-Control groups did not differ on any of the motivation-related measures as presented in Table 5.3. The Negative group did show significantly lower intrinsic motivation compared to the Neg-Control, and significantly lower motivation to do well during practice (Negative: $M = 4.40$; $SD = 1.35$; Neg-Control: $M = 6.40$; $SD = .84$). There were no differences in mean interest/task enjoyment ratings or explicit knowledge, ps > .10 (see Table 5.3 for descriptives). The type of rules and strategies that were verbalized in Exp. 2 were similar to those detailed for Exp. 1.

5.3.3 Discussion

We first tested two groups on the balance task, with the aim of replicating the work of Lewthwaite and Wulf (2010a) and testing mechanisms underlying any potential benefits associated with enhanced success perceptions (OPTIMAL theory, Wulf & Lewthwaite, 2016). To maximize the chances of eliciting these benefits, which were absent in Exp. 1, we used positive social comparative feedback (Lewthwaite & Wulf, 2010a; Wulf et al., 2012; Wulf et al., 2013). Surprisingly, this feedback did not impact balance measures (RMSE and MPF) in immediate performance or learning. Neither self-efficacy nor success perceptions were enhanced, although there were transitory effects of positive comparative feedback on perceived balance competency. The control group in this study was as self-efficacious and motivated as the Positive group, arguably because receiving veridical RMSE feedback that signaled progress in performance was perceived as success. There was also no evidence that positive comparative feedback impacted explicit control processes, as there was no group difference in secondary task performance or explicit knowledge reported.

As a result of the good performance and perceptions by both groups in Exp. 2a, we anticipated that there might be a ceiling effect and hence we recruited two more groups and depressed success perceptions. Negative comparative feedback was given to one group (and no veridical feedback that would be indicative of improvement/success) for the control. Nevertheless, even when negative comparative feedback was effective in depressing outcome expectations, perceived competency, success and motivation, the Negative group and its control were not different in balance-related outcomes. These results are in line with recent findings indicating that enhanced perceptions of competency did not mediate any learning advantages associated with self-controlled practice, as would be expected based on the OPTIMAL theory (Carter & Ste-Marie, 2017; Ste-Marie, Carter, Law, Vertes & Smith, 2016). In addition, motivation was not a significant predictor of motor learning in a study looking at the effects of (task irrelevant) choice in a throwing task (Grand, Daou, Lohse & Miller, 2017).

As with Exp. 1, there was a small, yet significant improvement in balance performance for both Positive and Pos-Control groups when a secondary task was added, again casting doubts on the efficacy of our chosen secondary task to indicate attention-related control processes through dual-task interference for such balance tasks. There was also no indication of greater explicit control in the Negative group, as assessed through reported explicit strategies and rules accrued. As such, we had no evidence supporting the idea that negative feedback, or perceptions of (more) error changed control processes for this group in line with predictions from the conscious processing/reinvestment hypothesis (Masters, 1992; Masters & Poolton, 2012; Maxwell & Masters, 2009). In accordance with the OPTIMAL theory (Wulf & Lewthwaite, 2016), one of the processes through which positive feedback and enhanced expectancies should benefit motor learning would be through increased motivation, as potentially indexed by increased arousal (Brehm & Self, 1989; Kahneman, 1973). However, the positive group was not different to its control in either arousal or motivation. Only the negative feedback group showed greater arousal compared to its control, but this did not impact performance measures.

Although this Experiment was based on procedures adopted by Lewthwaite and Wulf (2010a), we did modify the procedures, which may have impacted the results. For example, we shortened the trials from 90 to 60 s (following trial durations used in Exp. 1) and gave only one day of practice. However, performance effects as a result of positive comparative feedback were

present after just one day of practice in Lewthwaite and Wulf's study, which were maintained across the second practice session and retention. We also gave comparative feedback that was flexible rather than fixed to increase the validity of the feedback, which should have aided perceptions of success. We also limited our sample to only female participants, which should have minimized between-subject variability, facilitating statistical power. Individuals who deviated from the group average on initial performance and individuals who showed any skepticism in the credibility of the feedback were also removed to better control for individual differences. Thus, these relatively minor differences between the studies were unlikely to have been the reason for the disparities in the data.

In conclusion, these data from Experiment 2 raise serious doubts about the potential of feedback (positive, negative, general or comparative) to impact performance and learning in non-balance impaired populations in these tasks, even when success perceptions and motivation are moderated. Because of lasting impacts of initial performance differences (as indicated by correlation analysis), on later performance and learning, doubts are warranted about success-related feedback effects over and above any individual differences in initial performance.

5.4 General Discussion

Here we reported two sets of experiments where feedback manipulations had an impact on measures of self-efficacy (Exp. 1 & 2), success and intrinsic motivation (Exp. 2), but no impact on balance performance, learning, or motor control processes. In other stabilometer balance studies where practice manipulations have led to changes in success perceptions and impacted learning, performance differences were noted early in acquisition (Lewthwaite & Wulf, 2010a; Wulf et al., 2013) or were close to significant in acquisition (Wulf et al., 2012). These performance-related effects are suggestive of potential individual differences in performance across the groups or effort-related benefits associated with enhanced success perceptions, whereby short-term improvements continue to impact performance in retention. Because our "more successful" groups did not show these immediate performance effects, based on these previous results, delayed learning benefits (as a result of enhanced consolidation due to perceptions of success) were unlikely. Therefore, at least in these balance tasks, feedback

manipulations designed to impact success do not appear to impact motor learning through consolidation-related processes.

In two studies, where goal-criterion was manipulated, delayed learning benefits were elicited (Chiviacowsky et al., 2012; Trempe et al., 2012). In the study by Trempe and colleagues, participants adapted to a visuomotor rotation in the absence of visual feedback of their hand, completing consecutive aiming trials of short inter-trial durations (the next target appeared 1 s after participants moved their hand back to the start location). The task by Chiviacowsky and colleagues was a coincident-anticipation timing task, requiring participants to coincide the timing of a button press to the endpoint of a series of light stimuli without vision of their hand or the final trajectory of the light stimuli. Generally, participants who completed these laboratory tasks became dependent on the external feedback that they were provided. These tasks would not be ideal representations of real-world motor tasks that are inherently rich in intrinsic feedback.

Discrete aiming tasks have been used in other studies investigating success manipulations on learning. Even in these studies, the more competent or successful groups that were expected to benefit from the manipulation had demonstrated superior performance, or seemed to deviate in the direction predicted by the manipulation, as early as pre-test or after one block of practice (e.g., Chiviacowsky et al., 2009; Palmer et al., 2016; Saemi et al., 2012). This raises the question of whether these performance or learning benefits were a consequence of the experimental manipulation, or were merely manifestations of pre-existing group differences. For future research, or for examination of past data, we would argue that it is important to show that correlations between initial performance and later performance are low to moderate, as evidence that the manipulations are responsible for later emergent differences. In the current experiments, this correlational analysis yielded medium to high correlations, indicative of such persisting individual differences throughout practice, irrespective of feedback. Although this type of analysis is not without problems, where potentially more improvement is possible for people who start out with low accuracy (yielding low or negative correlations), high positive correlations, coupled with significant group effects, should of course be treated cautiously.

If success perceptions or expectancies moderated arousal and control processes related to the degree of “automaticity” in performance, we would have expected HR, MPF, secondary task

performance and amount of accumulated explicit knowledge to distinguish our groups. In general, this was not the case. We had hoped that these measures would allow us to make conclusions about whether success perceptions were being mediated by processes associated with a conscious focus on correction of error (cf. implicit learning ideas, Masters, 1992; Masters & Poolton, 2012; Maxwell & Masters, 2009). However, because there were no differences in any of our outcome measures we were not able to distinguish between different theories concerning how success feedback may potentially function.

Although we did not see differences between a no-augmented feedback group and negative feedback group with respect to outcomes, performing badly, or receiving negative feedback can function in a positive fashion. There is evidence that self-doubt can motivate individuals to exert more effort after initial failure (Ede, Sullivan & Feltz, 2017) and that negative feedback can enhance motivation in individuals that lean towards learning/mastery goals (task achievement), rather than performance/ego goals (performance with respect to others; Ilgen & Davis, 2000). Conversely, enhanced success perceptions or better performance can lead to lower motivation or effort, as there is less incentive for learners to deploy the same amount of (or more) attentional resources or physical effort on a goal that is deemed easy to achieve (see review by Kluger & DeNisi, 1996). In stereotype threat research (Steele & Aronson, 1995), participants that are provided with negative conceptions about stereotypical ability on an experimental task associated with one's social group (e.g., gender, race) have been negatively impacted in their performance. While several accounts, such as explicit performance monitoring (Beilock, Jellison, Rydell, McConnell & Carr, 2006) and withdrawal of effort (Stone, 2002), have been proposed for this debilitating effect, there is also research showing that when participants are subjected to evaluation under stereotype threats, motivation is increased resulting in improved performance (e.g., Huber, Brown & Sternad, 2016; Jamieson & Harkins, 2007), provided that participants recognize the need to correct their dominant response and are given the time to do so (Harkins, 2006). Overall, the effect of negative feedback on motivation is complex, due to the influence of various contextual and personality factors. These factors need to be appreciated before methods become widely adopted promoting the unqualified use of success-enhancing feedback.

Overall, these data across three sub-sets of experiments, serve to cast doubts on the efficacy of success-related perceptions to impact motor performance and learning, especially when intrinsic feedback is available about performance. Manipulations of goal-criterion and social comparative feedback did influence self-efficacy and success perceptions but did not impact performance or learning. Moreover, measures of process did not point towards arousal (HR) or automaticity (MPF, explicit knowledge or secondary task performance) as candidate explanations for success-related changes in motor performance and control. The current findings add to other literature where there has been a failure to replicate the benefits of success or competency perceptions on motor learning (Carter et al., 2016; Ong et al., 2015; Patterson & Azizieh, 2012).

In terms of practical advice, even if success perceptions exerted little or no effect on learning, it still may be good advice for practitioners to adopt a positive coaching philosophy to encourage activity adherence, effort and persistency. What is potentially worrying about the advice that positive feedback about continual success and enhanced perceptions of competency with little effort should be encouraged is that this could lead to complacency (e.g., Beattie, Lief, Adamoulas & Oliver, 2011; Schmidt & DeShon, 2009) or disinterest from lack of challenge (Guadagnoli & Lee, 2004), which researchers have found to be detrimental to learning. Whilst good or positive feedback may affect perceptions of competency, this does not necessarily mean that more or less effort will be devoted to practice during acquisition, in that being better than others or improving a lot could lead to less effort than performing badly or not improving. This is further complicated by the fact that increased effort may be bad for performance (i.e., over-correcting for errors), especially in balance tasks where a more relaxed state associated with low conscious control may be preferable (see also ideas on implicit learning benefits; e.g., Maxwell & Masters, 2009). Practitioners should be cautioned against setting of unchallenging goals and avoid too much positive feedback indicative of success that is not a true reflection of performance.

6 Conclusion

6.1 Summary of Studies

The focus of this thesis was to consider the influence of subjective perceptions of performance, associated with error or success, on motor learning. According to proponents of self-regulation theories, such as the social cognitive theory (Bandura, 1991), when individuals believe they can achieve their task goal (i.e., high in self-efficacy), they are more likely to be motivated to perform well than those who lack this self-efficacy. Traditionally, enhancement of motivation was understood to benefit motor learning through increased effort or overall time that motivated individuals committed to practice. Yet, when overall practice amount/time (in terms of number of trials, frequency and duration of practice session) was standardized in controlled experiments, learning advantages were still observed for practice manipulations that positively impacted competency or success perceptions. These findings drove the proposal of the OPTIMAL theory, which asserts that focusing on meeting the basic psychological needs of competence and autonomy enhances motor learning chiefly through motivational and dopaminergic means (Wulf & Lewthwaite, 2016; Lewthwaite & Wulf, 2017).

In addition to the motivational perspective of the OPTIMAL theory, low errors have also been considered to have other potential learning benefits with respect to the encouragement of implicit, motor-control related processes. Proponents of practice manipulations based on more implicitly acquired methods, or at least less explicitly acquired methods, argue that successful practice with low error encourages greater automaticity in performance and discourages the accrual of detailed explicit knowledge about a task which can be reinvested in performance in a detrimental fashion. This type of learning is thought to help prevent potential performance decrements in conditions of stress or added cognitive load, but evidence in support of general retention benefits are mixed (e.g., Maxwell et al., 2000; Poolton et al., 2005). Though there appears to be growing evidence for the positive impact of low error and high success on motor learning, there is ambiguity in the results and it is still unclear, when it does benefit learning, what processes/mechanisms underlie its efficacy, or how motivational processes might interact with cognitive processes to impact learning.

To study how perceptions of competency and success affect motor performance and learning, I conducted five studies. My aim was to replicate and extend previous work in order to better determine the processes, which would explain the positive impact of success perceptions on learning. I studied the learning of a discrete motor skill (i.e., dart-throwing), for three of the studies and the learning of a continuous task involving balancing on a raised, moving platform (the stabilometer) for two studies. Measures were taken to assess processing of errors, such as report of self-generated task-relevant knowledge, psychological states (e.g., self-efficacy, anxiety), movement kinematics (e.g., joint amplitude) and measures of psychophysiological and neuromuscular processes (e.g., EMG, EDA and heart rate).

In the first study, I determined if an easy-to-difficult (near-to-far) practice progression would elicit the same errorless (error-reduced) performance and learning advantage compared to a difficult-to-easy (far-to-near) progression as reported by Maxwell and colleagues (2001). Initial pre-existing group differences as a result of random allocation to groups casted doubts on whether immediate performance benefits were attributable to the practice manipulation, which were in a direction opposite to predicted. Hence, additional participants were recruited but these were assigned based on pre-test performance to better match for individual differences. Despite controlling for pre-existing differences, we did not replicate the errorless advantage linked to easy-to-difficult progressions.

In other research, easy-to-difficult progressions have not always been linked to motor learning benefits. Indeed, Sanli and Lee (2014) reported fewer errors in practice and in transfer (to new distance) on a disc-propulsion task when participants engaged in a difficult-to-easy compared to easy-to-difficult progression, even though no learning advantage was evident during retention and secondary task tests. In another disc-propulsion study with two levels of difficulty (4 easy/near targets or 4 difficult/far targets), and two task progressions (easy-to-difficult vs. difficult-to-easy) within each level of difficulty, task progression from difficult-to-easy resulted in improved accuracy on the most difficult target, compared to the reverse progression (Sanli & Lee, 2015). There were neither differences in performance on the other practice targets nor advantages for either progression during transfer and secondary task conditions. If the errorless advantage was replicated in Study 1, we had intended to recruit additional groups that would receive early positive comparative feedback while practising one of the progressions. This

manipulation would have tested whether advantages or disadvantages associated with task difficulty progressions were mediated by perceptions of success over the course of practice. Absence of the errorless learning advantage precluded this testing. We speculated that the absence of group differences may be due in part to the difficulty of the task (leading to greater within and between-subject variability) and the lack of more permanent learning effects. Though participants improved in outcome scores during practice and from pre- to post-test, a pre-test to retention test change was not shown. In future work, it will be important to increase the number of trials (or sessions) of practice, in order to better test for errorless learning effects when multiple target distances are practised. Learning to parameterize a somewhat fine motor skill through variable practice conditions may require more than the one session of practice before consistency of movement and outcome accuracy are achieved.

In Study 2, in lieu of an objective manipulation to task difficulty (i.e., distance from the target) influencing the amount of error or success accumulated in practice (cf. Study 1), we manipulated practice-related success more subjectively. The dart-throwing task was simplified by moving the criterion distance closer to the target (237 cm in Study 2 compared to 275 cm in Study 1). Two groups of participants learned to throw darts at either a small (easy) or a large (difficult) target from the same distance. This study extended the work of Trempe et al. (2012; see also Chiviacowsky et al., 2012) who presented evidence of success affecting how well a visuomotor adaptation task was retained over a retention interval. The results of Study 2 showed that radial error did not differ between the large and small target groups during practice, though the large target group was more successful in hitting their target. Contrary to Trempe et al., the groups did not differ in retention or reported self-efficacy (when reporting on their confidence to hit the centre of the target). Several methodological reasons were considered to explain the lack of effects (see Study 3), but in conjunction with Study 1, there was now reason to doubt hypothesized benefits associated with manipulations to target difficulty and related success perceptions on motor learning.

In Study 3, I further simplified the task by shortening the throwing distance and requiring accuracy only in the vertical-dimension. The new target size manipulation influenced practice success rates, such that they closely followed success rates reported in previous work (Chiviacowsky et al., 2012; Trempe et al., 2012). There were also differences in self-efficacy

and motivation with the easier target (Large-band) group reporting greater self-efficacy, motivation and success than the difficult target (Small-band) group. The groups also differed on duration of pre-throw and post-throw periods, and movement kinematics (i.e., amplitude of shoulder and elbow joint movement) at the start of practice. Despite indicators that the manipulation had differentially impacted the groups, there was no evidence of behavioural outcome differences in practice or in tests of learning.

A number of researchers have suggested that changes to self-efficacy could account for the observed benefits of success perceptions in motor learning (see OPTIMAL theory, Wulf & Lewthwaite, 2016). However, from this study it is evident that the effect of success-manipulations on motor performance/learning when seen, are likely to be a result of other factors, such as pre-existing group differences, rather than just perceptions of success. Perhaps the effect of success perceptions is so small that the theory only holds for learners with certain personality/psychological characteristics (see Section 6.3), and on limited motor tasks. Over the course of the dart-throwing experiments in this thesis (Studies 1-3), we had addressed possible methodological concerns, which might explain a lack of behavioural effects associated with manipulations to error and success, such as low improvements across practice in Study 1 and overall high success rates in Study 2. Despite these modifications, no success-related behavioural effects were shown. At this point we considered whether the lack of effects might have been connected to the nature of the dart-throwing task itself, with salient inherent (visual) feedback indicating actual outcome error for each trial, possibly hampering the effectiveness of the success manipulations. As a result, in the last two studies of my thesis, I switched to a continuous balancing task, where outcome feedback about overall trial success was less easy to ascertain.

The purpose of Study 4 was to bring about changes to success perceptions by manipulating outcome feedback in 60 s balancing trials on a stabilometer. Primarily, we wanted to determine how absolute or relative changes to feedback about success would influence success perceptions, performance and ultimately learning. To implement these performance outcomes, we applied difficult (strict) vs. easy (lax) balance goal-criteria for groups that received low vs. high time-on-target scores respectively during practice. Two other groups were assessed under sliding difficult-to-easy vs. easy-to-difficult goal-criteria conditions, so that time-on-target

was either improving or stagnant/deteriorating during practice. Although we were able to modify participants' self-efficacy during practice, the feedback manipulation did not have a significant impact on motivation or behavioural measures of performance and learning. We had assumed that participants would evaluate more time-on-target to be an index of success (with closer to 100% being highly successful and closer to 0% being poor). However, we did not provide a specific, objective criterion in order to interpret "success" (e.g., telling them that anything over 80% is a good trial) and therefore it is hard to ascertain how participants judged their performance. Without a goal standard or some sort of ego comparative feedback (as has been provided in past studies), feedback manipulations that involve self-comparison and evaluation may be rather erratic. This may be a result of individual differences in standards/expectations and hence subjective interpretations. This provided the rationale for Study 5, that is, to provide social comparative feedback (replicating and extending an earlier balance study by Lewthwaite & Wulf, 2010a) in order to determine if and how perceptions of success impact performance and learning.

In Study 5, we first tested two groups on the balance platform with the intention of replicating Lewthwaite and Wulf's (2010a) work with social comparative feedback, a manipulation that had impacted learning of a balance task. Some adjustments were made to the procedures from Study 4 to maximize our likelihood of replicating these effects. Although the positive comparative feedback group, which received feedback that they were performing above average, had greater ratings of perceived competency in practice than the group that were just told their actual, veridical error (no positive feedback control), the two groups neither differed in terms of ratings of motivation and perceived success in retention, nor on any of the outcome or process measures in practice or retention. In the event that merely receiving veridical feedback indicative of good scores or improvement was sufficient to boost perceived competency, we tested two additional groups. One group received no performance feedback whatsoever and a second group received only negative social comparative feedback. As expected, the negative feedback group reported lower ratings of perceived competency, success, and motivation than its control group, but the groups still did not differ on behavioural outcome measures in practice and other tests of learning. The implication of these results, together with the results of Studies 1-3, is that moderations to success perceptions and motivation do not have large or consistent impacts

on motor learning and that the veracity of these effects shown elsewhere should be treated with caution (cf. Chiviacowsky et al. 2012, Trempe et al. 2012; Wulf & Lewthwaite, 2016).

6.2 Competency or Success as a Mediator of Motor Learning

The OPTIMAL theory asserts that motivational and attentional factors influence motor performance and learning. Practice interventions that enhance performer's expectancies (future competency and success), sense of agency (autonomy) and promote an external focus of attention are expected to enhance performance and learning (Wulf & Lewthwaite, 2016; Lewthwaite & Wulf, 2017). Success-related manipulations, such as selective feedback on more accurate trials, false positive social comparative feedback, and easier task goal criterion/difficulty, have benefitted learning. Although potential mechanisms have been discussed, the exact mechanism(s) leading to such outcomes is/are still unclear. For instance, some motor behaviour researchers (e.g., Lewthwaite & Wulf, 2010a; Trempe et al. 2012) have alluded to motivation or self-efficacy as a potential key mechanism for success-related learning benefits without testing or elaborating on how these psychological states impact motor learning.

In Studies 3 and 5, performance success influenced self-efficacy in a positive manner, yet regardless of changes or differences across conditions with respect to self-efficacy, this variable did not appear to exert a positive (or any) influence on subsequent performance and learning. Similar results were reported by Carter et al. (2016) that underscored a lack of learning benefit in a study that had participants practise tossing mini Koosh-balls. Individuals that were provided with "positive" feedback on the more accurate half of trials, rather than the least accurate, indicated more positive self-judgments of learning, even though there were no performance or learning differences between the groups that received the better or worse feedback.

Research on metacognition (e.g., Simon & Bjork, 2001) has shown that learners typically rely on their (past) practice performance to form judgments or efficacy beliefs about their level of learning or capacity to perform in the future. This is despite the fact that these beliefs are poor predictors of what has been retained, whereby ease in practice lulls people into a false sense of skill acquisition, leading them to overestimate their performance on a delayed test of retention. Hence it was of no surprise that success-related manipulations indicating that one was doing 'well', whether meeting goal standards or performing better than others, would have a positive

effect on judgments of learning or self-efficacy. Yet, like Simon and Bjork, behavioural indices of learning did not follow the trends of these perceptions or judgments. Merely reporting more self-efficacy or greater competency, such as in the present studies, does not necessarily transfer to better learning and likely just reflects the ease of the practice condition.

A review of the motor learning literature featuring manipulations to target goals and provision of social comparative feedback in order to change perceptions of success has returned some findings worthy of discussion. First, two out of the three stabilometer balance studies, where researchers have manipulated feedback, showed that positive feedback had an immediate impact on performance during practice, which was sustained in delayed tests of learning (Lewthwaite & Wulf, 2010a; Wulf et al., 2013). There has been only one other study, featuring a discrete motor task (golf putting) with similar manipulations to target sizes as ours from Studies 2 and 3 (Palmer et al., 2016). The learning benefits observed in delayed tests in this golf-putting task were already present as early as the first block of practice. These studies lead us to question whether pre-existing group differences might account for these success-related effects, especially as it is likely that non-significant group differences are not getting published.

In Study 5 of my thesis, social comparative manipulations did not have an immediate performance advantage for the positive feedback group. The feedback manipulations did not impact practice behaviours in divergent ways. It might be the case that the positive feedback group simply maintained or perhaps decreased their "effort" during practice, perhaps as a result of feeling successful and therefore not needing to increase effort. It is also possible that the negative feedback group exerted more effort in reaction to the negative comparative feedback. There is a clear lack of consideration of this alternative effect of being less than successful and its potential galvanizing effect on motivation in discussions related to OPTIMAL theory. These opposing ways in which "success" can impact motivation is likely to account for the variation in research evidence and difficulties in showing support for one manipulation over another (see Section 6.3 for a more detailed discussion).

Psychophysiological arousal is considered to be a reliable index of the momentary intensity of motivation and effort in goal-directed behaviour (Brehm & Self, 1989; Kahneman, 1973). A rise in task difficulty or demands tends to induce an increase in the level of arousal. In

support of the idea that negative performance feedback, possibly indicative of high task demands, could lead to increased motivation and effort (as indexed by arousal) was shown by the "negative" group in Study 5 (where we measured HR), though this increased arousal was not related to behavioural indices of performance or learning. In a golf-putting study, where participants were selectively given either more accurate or less accurate feedback about their performance, there was no indication that arousal was differentially affected by the manipulation at a between group level, although arousal was shown to be predictive of retention accuracy (Badami et al., 2012). Hence, although arousal might be affected by these manipulations to perceptions of success, and arguably self-efficacy, the relation between arousal and learning/retention is not straightforward. In addition to not having differential behavioural manifestations, changes in arousal may both serve to depress or enhance learning, depending on whether it serves a motivational role or a more anxiety-inducing role. I discuss individual characteristics and interactions with situational context in response to negative performance feedback in the next section.

Behaviours that are rewarded improve success perceptions, affect, and lead to an increase in motivation for the behaviour to be repeated in the future (e.g., Berridge & Robinson, 2003; Schultz, 1997, 2001). Reward has been linked to neurobiological activation in brain regions and dopaminergic pathways that enhance learning (e.g., Suri & Schultz, 1999; Wise, 2004). It appears that expectations can play a role in dopamine signaling. When rewards were unexpected, that is, when outcomes were better than expected, dopaminergic activity was increased (e.g., Holroyd & Coles, 2002; Schultz, 2001). It is conceivable that in our studies, participants were not expecting to perform particularly well given that the recruitment criteria required them to be non-competitive athletes with no or limited experience in activities related to the experimental tasks. In the dart-throwing studies, there was visual feedback indicating that participants aiming at a small target/band were improving (getting closer to the centre of the target) even if they were not hitting the target. Participants practising on the stabilometer had proprioceptive feedback indicating they were balancing better with practice, or would know that the balance platform touched the ground less frequently. As such there may be rewarding signals in the small target or negative feedback/control groups due to unexpected improvement or mastery of the task, even if they received negative goal-related or augmented social comparative feedback. One way to manipulate expectations might be to allow a period of success (or failure) on the task,

before switching to the manipulation, such that an expectation of success or failure has been pre-established.

According to the expectancy theory of motivation, an individual's valence (i.e., affective orientation from positive/desirable to negative/undesirable) towards expected outcomes moderates the influence of outcome expectations on motivation (Vroom, 1964). Learners with strong positive valence towards performance success and high self-efficacy should be motivated to excel in practice. However, if learners were indifferent to outcome, with valences close to zero (neither positive nor negative), expectancy levels may have negligible impact on motivation. In further experiments involving success perceptions and expectancies, groups could be matched on task valence and motivation before acquisition, or external rewards could be provided to incentivize participants to desire for success in the task.

In studies of memory consolidation, dopaminergic activity has been shown to enhance synaptic plasticity and neural connectivity, aiding the stabilization and enhancement of memory offline (e.g., McGaugh, 2000). Consolidation processes have been suggested to be the cause of learning enhancements that emerge after a retention period. To our knowledge, goal manipulations have elicited consolidation benefits in just two studies. The tasks that were practiced involved a coincident-anticipation timing task without visual feedback (Chiviacowsky et al., 2012) and a visuomotor adaptation task in the presence of a perturbation to the visual stimuli representing their hand (Trempe et al., 2012). Importantly, there is little useful inherent feedback for self-evaluation of performance in these simulated environments, compared to tasks such as, dart-throwing and balancing. In the absence of useful intrinsic feedback, augmented feedback embodying success and goal achievement would likely exert greater influence on competency and success perceptions, and potentially consolidation of motor memories. To address this concern, practice could be situated in simulated environments, or KR should be withheld from participants in future investigations, particularly in feedback-rich tasks.

6.3 Individual Differences in Response to Performance Feedback

In applied psychology, researchers have started questioning the relationship typically reported between self-efficacy and performance (e.g., Heggestad & Kanfer, 2005; Schmidt & DeShon, 2010; Vancouver, Gullekson, Morse & Warren, 2014). Earlier studies confirmed a positive

correlation between later performance and self-efficacy, but when past performance was accounted for within participants, a weak negative-to-null relationship was found between self-efficacy and subsequent performance. Opposite to predictions of the OPTIMAL theory (Wulf & Lewthwaite, 2016), control theorists of self-regulation (e.g., Powers, 1991) applied a negative feedback loop model to the relationship between self-efficacy and performance and asserted that a negative relationship existed between the two. When individuals believe they are meeting or exceeding their task goals, they become less likely to allocate more resources (i.e., time and effort) to the task, particularly when resources are scarce and there are multiple task demands (cf. Bandura, 1991). By this argument, when a discrepancy (or error) exists between goals and performance, individuals ought to be motivated to reduce the discrepancy or dissatisfaction in most circumstances and therefore exert greater effort in subsequent performance. As discussed earlier, we had collected psychophysiological measures of EDA and HR in Studies 3 and 5 respectively. Contrary to predictions of the OPTIMAL theory, we showed greater arousal for the negative feedback or less successful group in Study 5. This supports the negative feedback loop model that when performance is subpar or does not meet standards, greater effort is dedicated to the task (although it is also possible that the psychophysiological measures are signaling anxiety rather than or in addition to effort).

A negative feedback model proposed by Ilgen and Davis (2000) incorporated the influence of individual characteristics, such as self-efficacy and goal orientation, and other situational factors on motivational responses to negative performance feedback. For instance, a person's goal orientations (which are beliefs reflecting reasons for engagement in a task) impacts how negative feedback is interpreted (Dweck & Leggett, 1988; Nicholls, 1984). If a participant is highly task/mastery oriented (when one's goal is to learn or master a task and evaluation of success is self-referenced), the reaction to negative feedback may be to increase effort (Dweck, 1986). In contrast, an ego/performance goal orientation is other-referenced and success is attained through exceeding the performance of others. When ego-orientation of an individual is low and task-orientation is high, the influence of negative social comparative feedback would be weakened. Dart-throwing participants in Studies 2 and 3 might have been highly task/mastery-oriented, such that those in the easy (large) target group may have evaluated their overall performance in terms of more stringent goals of hitting the centre of the target, even when they had successfully hit the large target.

Responses to negative feedback are also impacted by perceived ability and individual motivation (Bandura, 1982; 1991; Schunk, 1995). In a recent doctoral dissertation (Eliasz, 2016), positive social comparative feedback did not facilitate learning in medical trainees who were expected and found to be high in intrinsic motivation and self-esteem (favourable or unfavourable attitude towards one's worth that is strongly associated with self-efficacy; Rosenberg, 1965; Sherer et al., 1982). Instead, it was negative social comparative feedback that was detrimental to learning, in comparison to no-comparative feedback control conditions. This suggests that learners with different backgrounds and task motivations are likely to respond differently to different types of feedback. The absence of high physical self-efficacy or self-esteem (i.e., low performance expectations) in our participants, could have inoculated them from any debilitating effects of ego-comparisons. An interaction of perceived ability with achievement goal orientation was reported in a study of children performing a pattern recognition task (Elliott & Dweck, 1998). Positive affect and effortful problem solving was reported for individuals with ego-orientation accompanied with high perceived ability, as well as individuals with high task-orientation regardless of perceived ability. People with an ego-orientation and low perceived ability tended to display low effort, negative affect and worry about failure.

Individual attributions of successes and failures would influence the impact of success-manipulations on motivation and performance (Weinberg & Gould, 2003; Weiner, 1985). Singer and colleagues studied the psychological consequences of primed attributions on 'failure', which were negative social comparisons of performance (Singer, Grove, Cauraugh & Rudisill, 1985). Participants who were made to believe that strategy or effort and strategy, rather than natural ability, was the determinant of success, were more motivated after receiving negative comparative feedback. This was indexed by the amount of task (i.e., stabilometer balancing) activity that the participants voluntarily engaged in, in the absence of the experimenter. If negative outcomes were thought to be due to unstable, internal causes, which were within a person's control, failure would be attributed to a lack of effort or inadequate use of strategies. Post-failure expectations of future success, when effort/strategies matched the demands of the task, would help maintain/increase the motivation of a performer. Attributing failures to an external cause, such as luck or high task difficulty, might inoculate a performer from lowering perceptions of ability/competency and motivation. This could have been the case in some of our participants that experienced low scores or success rates. There is also a tendency for failure or

poor performance to be attributed to external causes (especially high task difficulty), instead of one's abilities, particularly when one is highly self-efficacious (Bandura, 1991), or when an individual's self-esteem is in the balance (see Miller & Ross, 1975).

Other individual traits, such as high conscientiousness, also moderate the impact of negative feedback on motivation and performance (Yeo & Neal, 2008). When task difficulty was perceived to be high, likely coinciding with poor performance, highly conscientious individuals maintained high levels of cognitive effort for longer periods than individuals with low conscientiousness. In fact, some self-doubt (i.e., moderately high self-efficacy), in individuals can benefit subsequent performance. A significant inverted-U relationship has been reported between baseline self-efficacy and subsequent performance on a set of isometric muscular endurance tasks (Ede, Sullivan & Feltz, 2017). Depending on individual and situational factors, negative conceptions about a particular race or gender's stereotypical ability can be seen as a threat leading to debilitated learning (e.g., Steele & Aronson, 1995), or as a source of motivation to seek corrective adjustments and enhance learning (e.g., Huber, Brown & Sternad, 2016). When tasks are of significance or relevance to peoples' identity, failure has motivated them to improve in subsequent performances (Brunstein, 2000). Considering the multitude of individual factors and interactions with situational context that positively or negatively impact performance perceptions and influence performance strategies and goals, it might be fruitful to further assess how individual characteristics mediate the impact of success-manipulations on motivation and learning.

6.4 Conscious Processing Effects on Performance and Learning

Several theorists have proposed that acquisition of motor skills begins in a cognitively demanding ("cognitive") stage, where factual information or declarative knowledge is accumulated through instruction, observation or trial-and-error, with heavy involvement of working memory and attentional resources. As learning progresses to a late, or autonomous stage, where skill execution is mostly automatic, little cognitive effort or attention is required (Anderson, 1982; Fitts & Posner, 1967). At this autonomous stage, performance is negatively impacted by an inward shift towards the self, known as "self-focused attention" (e.g., Baumeister, 1984; Wegner & Giuliano, 1980). There is also evidence that at this stage, a shift

towards use of declarative knowledge and step-by-step, explicit cognitive processing of skills, is bad for performance. This has been discussed in reference to "skill-focused attention" (e.g., Gray, 2004), "explicit monitoring hypothesis" (Beilock & Carr, 2001), "constrained action hypothesis" (e.g., McNevin et al., 2003; Wulf, McNevin & Shea, 2001), and the "reinvestment hypothesis" (e.g., Masters & Maxwell, 2004; Masters & Poolton, 2012). The principle central to these accounts is the regression towards an early explicit/cognitive control stage and monitoring of skill that interferes with automaticity and effectiveness of skill execution. In high-stake contests, this regression leads to something akin to "choking", the term that describes uncharacteristic performance decrements for an individual performing under pressure conditions (e.g., Beilock & Carr, 2001; Lewis & Linder, 1997). In accordance with the reinvestment hypothesis, experienced performers who are predisposed to "reinvest", i.e., revert to step-by-step, explicit control, would more likely choke under stressful or attentional demanding situations had they accumulated a wealth of declarative knowledge through rules and hypothesis testing in the cognitive stage (see Masters & Maxwell, 2008).

To deal with potential reinvestment, researchers have suggested that learners need to avoid accumulating declarative or explicit knowledge of a skill by supporting skill acquisition through implicit processes (Masters & Maxwell, 2004; Masters & Poolton, 2012). With a lack of explicit knowledge about the task, performers would be unable to reinvest or revert to a conscious mode of control. Adopting implicit learning practice methods, such as dual-task practice (e.g., Hardy, Mullen & Jones, 1996; Masters, 1992), errorless learning (e.g., Capio et al., 2013a, 2013b; Maxwell et al., 2001; Poolton et al, 2005), and analogy learning (Lam, Maxwell & Masters, 2009; Liao & Masters, 2001), has been effective for minimizing explicit knowledge and counteracting potential reinvestment, even in short-term motor learning studies. By promoting implicit control processes during acquisition, performers would have greater working memory capacity to cope with the performance of a simultaneous (secondary) cognitive task, unlike performers who have learned in an explicit mode and are highly dependent on working memory for performance of the primary motor task.

In my thesis, one of the ways we assessed the degree of automaticity or reliance on explicit processing in performance of the primary task was through a secondary (dual) task test. Overall, control processes and strategies did not seem to be differentiated by the success-

manipulations we applied in the present studies. The experimental and control groups were not distinguished in behavioural outcomes or explicit knowledge reported. There are, however, concerns regarding the validity of the secondary task test for assessing automaticity or control processes on balancing-type tasks, as other studies have shown that participants tended to balance better when simultaneously engaging in a cognitive task (e.g., Fearing, 1925; Swan et al., 2004; see Section 5.2.3). The use of video cameras throughout the dart-throwing studies (Studies 1-3) could have caused some anxiety and self-focused attention in our participants that may have attenuated the purported learning benefits due to success-manipulations. In future experiments, concealing the video camera before and during the experiment might better control and avoid this type of attentional shift.

Converging evidence from neuroscience and computational modeling research reveals that error detection leads to increased cognitive control helping an individual avoid subsequent error or improve future performance (e.g. Holroyd & Coles, 2002). In studies of event-related potentials (ERP), at least two post-error neural adjustments have been documented. Mu suppression recorded by electroencephalography in the alpha frequency band signaled an increase in attentional control after error committal, while increased phase coherence between medial frontal and visual cortices reflected increased top-down control over sensory processing areas (Navarro-Cebrian, Knight & Kayser, 2013). Post-error behavioural adjustments, such as post-error slowing, have also been reported in reaction-time and motor tasks (e.g., Crump & Logan, 2013; Danielmeier & Ullsperger, 2011). Slowing down allows more time for an individual to evaluate performance outcomes, and make decisions on preventative or corrective strategies in subsequent performance (see Wilson, Smith & Holmes, 2007). Though differences in measures of explicit processing were not shown in the present studies (i.e., dual-task interference or number of generated rules or strategies), temporal differences were shown in analyses of pre- and post-throw periods of dart-throwing in Study 3. Both pre- and post-throw durations, reflecting planning and processing time, were longer for the Small-band compared to the Large-band group. These differences were likely due to a combination of increased precision, planning and processing demands associated with aiming to a small target (e.g., Wilson et al., 2007) and the increased error and associated error processing in the former group. These results are neither congruent with the OPTIMAL theory nor with the reinvestment hypothesis.

Heightened cognitive processing was not detrimental to skill acquisition or performance under cognitive loads.

In the Introduction (Chapter 1), I presented two areas of empirical research and conceptual thinking about motor learning, which directly or indirectly advocate for the conscious cognitive processes that go together with making errors in practice. One of them is Schmidt's (1975) schema theory, which holds that schemas (i.e., rules or relationships) for a generalized motor programme are formed and updated based on information or feedback about initial conditions, parameters assigned, outcome feedback and sensory consequences of movement. The more varied the practice, so that different initial conditions, parameters, outcomes and sensory feedback are experienced, the stronger the schemas, even if more errors are made during variable practice than constant practice of a task. Research related to the notion of cognitive effort as a beneficial practice for motor learning supports the idea that acquisition should promote error committal and enhanced cognitive processing. A common principle underlying the contextual interference effect (e.g., Magill & Hall, 1990) and guidance hypothesis of augmented feedback (e.g., Winstein & Schmidt, 1990) is that effortful practice benefits learning, but suppresses practice performance (Lee, Swinnen & Serrien, 1994). Practice with infrequent augmented feedback or practising multiple motor tasks requires more cognitive effort than practice with frequent KR or practice of a single skill. More cognitively effortful practice promotes increased understanding and leads to more accurate and robust memory representations (e.g., Shea & Morgan, 1979; Winstein & Schmidt, 1990). Taking into account functional task difficulty, which is subject to the skill level of the performer, Guadagnoli and Lee (2004) proposed the challenge point framework to highlight the idea that some degree of practice difficulty or challenge, based on functional task difficulty for each individual, is optimal for learning. This is similar to Bjork's (1994) notion of introducing desirable difficulties when learners have the capacity or skill to cope with such difficulties, such as varying conditions of practice or spacing out practice, to boost learning. In accordance with these challenge and desirable difficulties concepts, easy or errorless practice schedules that inculcate a sense of "more than adequate" performance/learning are not likely to benefit learning.

One potential way to study this cognitive effort hypothesis of learning in relation to one based on perceptions of success is to manipulate task difficulty through variable practice

conditions. Here, lower success in practice would be expected to lead to improved performance on a criterion task in retention. One example of such a task could be one where the weight of a dart or ball or disc is varied across blocks of trials. If participants are unaware of the variations, then they should experience more errors, but not attribute these to external causes. Therefore, an implicit, variable practice group would be expected to both have and perceive lower success in practice than a constant-weight group and an explicit, variable practice group. The question of interest would be whether differences in success perceptions would influence the expected acquisition-retention reversal.

In Chapter 4 (Study 3) and Section 6.1, I have noted that the saliency of outcome feedback in dart-throwing may have diminished the impact of other success information on motor learning. Hence feedback (especially visual feedback) of the exact outcome of performance should be removed, so that participants cannot use this information to form alternative perceptions of success. Previous work, supporting OPTIMAL theory predictions, has mostly involved tasks where actual outcome feedback is removed during execution, but provided after each trial or in a summary fashion after a block of trials (e.g., Abbas & North, 2018; Ávila et al., 2012; Carter et al., 2016; Chiviacowsky & Wulf, 2007). As discussed at the end of Section 6.2, consolidation of motor memories are more likely to be elicited by success-related feedback in the absence of useful intrinsic feedback.

6.5 Limitations and Future Directions

In the present studies, we applied similar manipulations and methods to other studies that have corroborated the OPTIMAL theory, but achieved different results generally pointing towards a lack of learning differences between groups differing on perceived success. It is important to consider task-, individual-, and measurement-related factors that might have contributed to the lack of learning benefits.

6.5.1 Task- and practice-related factors

To date, enhanced expectancy effects have been demonstrated with a limited range of motor tasks, such as beanbag/tennis ball tossing (e.g., Ávila et al., 2012; Chiviacowsky & Wulf, 2007; Pascua et al., 2015; Wulf, Chiviacowsky & Cardozo, 2014), golf putting (e.g., Badami et

al., 2012; Palmer et al., 2016), or stabilometer balancing (e.g., Lewthwaite & Wulf, 2010a; Wulf et al., 2012, 2013). These tasks involve rather gross movements and engage muscles used in everyday tasks. In the case of balancing, we would certainly be familiar with similar movements needed to maintain dynamic balance while standing in a moving bus or train. Because of our experience with these actions, these tasks may be conceived as relatively low in task complexity even though they involve whole-body movements However, the last two experiments of my thesis involved stabilometer balancing, so it is unlikely that differences in results across studies are due to the task. However, a case could be made that dart throwing is relatively more difficult than golf putting or bean-bag tossing. Dart-throwing involves more precision and fine motor control than tasks which have been used in the past. Very small errors in execution can result in accentuated flight and dart landing outcomes. Tasks that have greater precision demands, potentially impose greater processing demands on the learner, which necessitate greater effort (see Bjork, 1994; Guadagnoli & Lee, 2004; Wulf & Shea, 2002). As such, success-related manipulations which are thought to work on processes related to effort are less likely to have an impact on such challenging tasks.

With the exception of a few studies where outcome of performance was accessible or visible to learners (e.g., Badami et al., 2012; Palmer et al., 2016), the majority of studies that support the OPTIMAL theory have employed procedures or tasks that either did not provide useful inherent feedback for error detection or correction (e.g., timing tasks, Chiviacowsky et al., 2012; Wulf et al., 2010), or occluded outcome feedback (e.g., Ávila et al., 2012; Carter et al., 2016; Chiviacowsky et al., 2009). In these cases, participants are almost completely reliant on the augmented feedback provided by the experimenters. This may be a critical reason why the success-related feedback has had an effect in past studies.

Learning benefits have been reported for a practice manipulation, termed bandwidth feedback, whereby participants were not given augmented feedback for trials that were accurate within a certain error bandwidth (e.g., 10 %) of the goal or target (e.g., Sherwood, 1988; Smith, Taylor & Withers, 1997). In the bandwidth feedback scenario, participants would not know exactly how well they performed when they were successful (e.g., how close they were to the target). As they improve over practice, frequency of error feedback would be reduced. According to the guidance hypothesis of augmented feedback (Winstein & Schmidt, 1990), this reduction in

frequency was thought to be the primary reason for benefits involving bandwidth feedback in comparison to feedback on every trial. However, when compared with a yoked schedule control group, bandwidth feedback groups still demonstrated a learning benefit (Lee & Carnahan, 1990). Therefore, greater performance consistency as a consequence of fewer unnecessary corrections to minor variations in motor output would more aptly account for the benefits of this feedback. What is less considered, is the potential motivational aspect of bandwidth feedback procedures. When responses are considered correct or successful, within a larger than zero bandwidth, participants will experience success, that is not moderated by knowledge of the exact outcome of the throw. Elevated success perceptions and motivation that accompany this heightened success would also be expected to enhance learning (Wulf & Lewthwaite, 2016).

The goal in the dart-throwing task of this thesis was to score points by hitting the target and precise outcome feedback was available on every trial. In this regard, our procedures differed from typical bandwidth study procedures in that even when participants were successful at hitting the targets (small or large), there was salient and relevant information as to where the dart actually landed. The informational aspect of this feedback could potentially lead to strategic adjustments in the subsequent practice trials, potentially resulting in unnecessary corrections. The precise feedback that our participants received may supersede the success/target feedback (hit or miss) that is simultaneously perceived on each trial. To test this hypothesis, it will be necessary to occlude outcome feedback pertaining to dart landing position. Participants are only given precise feedback about landing position when they miss (as in typical bandwidth procedures). In this way, error feedback is low for the large target group, no other feedback is available and there should be heightened perceptions of success in comparison to the small target group. It is worth noting that in Study 3 (dart throwing to target bands), although there was not more variability in outcomes for the Small-Band group, this group did show more variability in their kinematics, at least early in practice. To control for the amount of KR given, it might be necessary to yoke exact KR feedback across groups, so that the small target group gets the same frequency of exact KR as the large group (even though they would still be privy to information on every trial about whether they hit or missed). To enhance success perceptions, rather than giving exact feedback on missed trials, it could be given only on hit trials (potentially with the amount of feedback controlled).

In our balance-task studies, though the exact time-on-target or average deviation of a 60 s trial was difficult for participants to ascertain, it is likely that they could assess whether there was an improvement or deterioration in performance. This task was still rich in intrinsic proprioceptive feedback, such as how wobbly they felt, or how often the board hit and stayed on the ground. Participants' interpretation or evaluation of their practice may have deviated from the expected or intended manipulation of outcome scores and social comparative feedback. This limitation could be avoided in other experimental tasks, where knowledge of performance and KR were not visible/available, or if inherent feedback was not useful to participants, such as in coincident-anticipation timing tasks. Recruiting and testing children who are more naïve about their physical ability and lack the motor experience to evaluate their performance, unlike adults, might also mitigate such conceivable deviations in interpretation. However, children have been shown to benefit from positive social comparative feedback during motor practice (e.g., Ávila et al., 2012; Gonçalves et al., 2018).

Another limiting factor in the present studies may have been related to the lack of asymptotic or saturated practice performance, which is suggested to be important for effective memory consolidation (e.g., Hauptmann et al., 2005). It may be that more practice trials or practice sessions are needed to get such asymptotic performance for a relatively difficult, fine-motor aiming task, such as dart-throwing.

6.5.2 Individual-related factors

Success or competency perceptions may benefit learning only when the task does not require much effort, or is low in task-related motivation to achieve or improve, such as when the task is lacking in interest to the learner. Further examination of this topic could involve a non-interesting task of easy to moderate difficulty, so that motivation to improve is low. If the task were computerized, or feedback was given on a board rather than verbalized by the experimenter so that human interaction was minimized, experimenter-participant interactions (e.g., Abbas & North, 2018; Singer & Llewellyn, 1973; Stevenson & Allen, 1964) or other subject-experimenter artifacts (Rosenthal & Rosnow, 2009) could be avoided. To mitigate against subject-experimenter artifacts, in particular opposite-sex, experimenter-participant interactions (e.g., Singer & Llewellyn, 1973; Stevenson & Allen, 1964) that might have moderated participants'

motivation to perform well, recruitment was restricted to females (given that our experimenters were female). We also assumed that adult female participants were more likely to be novices at dart-throwing than adult males, which would increase our potential participant-pool and help to minimize between-subject variation in initial performance. It may be of interest in future work to include both male and female participants to test for any potential sex-related effects that may have moderated the impact of success-related manipulations on motor learning.

On the subject of sampling, it would be important to note that the present studies were generally under-powered (with the exception of Study 2). Sample size calculations based on effect sizes from other related studies, would require us to recruit groups of 30-64 participants each, to achieve a power of 0.80. However, studies showing support of expectancy-enhancing effects have typically been based on group sizes of n =12-20. When sample size was increased to ~28/group in Study 2, there was still an absence of an effect. Moreover, because we have conducted at least two or three experiments using similar tasks and manipulations and still failed to show expected effects, it is likely that lack of power is not the reason for the absence of group differences. As is clear from many of the graphs and other descriptive and inferential statistics, there was a distinct absence of any trends which would speak to group differences.

In Studies 4 and 5, participants were engaged in a continuous, dynamic balance task. As discussed in Chapter 5, we were concerned that the performance and learning benefits elicited through positive social comparisons in other stabilometer balance studies were potentially owing to existing individual differences in ability/performance before the study, as performance advantages emerged for the enhanced competency groups after merely one or two practice trials (Lewthwaite & Wulf, 2010a; Wulf et al., 2012, 2013). In future endeavours, researchers should check for potential high, positive correlations between initial and later performances, to determine how strong task-related manipulations are in accounting for performance differences in acquisition and retention, beyond those due to pre-existing group differences.

A well-researched area of motor learning on attentional focus has shown performance and learning advantages for learners that maintained an external over internal focus of attention when balancing on a stabilometer (e.g., McNevin et al., 2003; Wulf, Höß & Prinz, 1998). An alternative possibility for the benefits of positive social comparative feedback or conceptions of

ability in past studies (Lewthwaite & Wulf, 2010a; Wulf et al., 2012; Wulf et al., 2013; Wulf & Lewthwaite, 2009) is that participants receiving this positive feedback/information might have been able to avoid the debilitative self-focused attention described in the previous section (e.g., Baumeister, 1984), and instead focused on task-relevant or external aspects of the balance task that benefitted performance. Participants in previous studies that received no feedback, negative comparative or poor ability feedback might have turned to self-focused/internal focus of attention without the assurance of positive feedback. While this does not explain the lack of learning benefits in our balance studies, it raises the possibility that attentional focus could explain advantages associated with enhanced competency/success and learning in previous work.

Compared to other studies where support has been garnered for OPTIMAL theory, we had adopted rather strict recruitment criteria in our studies. Besides recruiting only novice performers, some of our participants were not current competitive athletes in related sports or activities. Although we had not taken objective measures, some of our participants had expressed feelings of ineptness, and projected low expectations for their performance in the experimental tasks owing to their lack of experience or athleticism. Participants that had chosen to take part in the present studies, in response to our advertisements and monetary compensation, were likely more interested and motivated than participants that might have received course credits for participation. Earlier, we discussed the negative feedback model (Ilgen & Davis, 2000) that takes into account situational and individual factors which affect motivational responses to negative performance, and underscored some individual dispositions, such as goal achievement orientation and attribution tendencies, that could moderate an individual's response to performance outcomes. Principles of motor learning advocated by the OPTIMAL theory may be more effectively applied towards individuals with certain dispositions. Hence it might be worthwhile to explore how and why success-manipulations would be advantageous for learners of specific individual characteristics, related to ability perceptions and expectations, motivational dispositions, achievement goal orientation or outcome attribution. These dispositional factors would also need to be considered in relation to particular task situations, such as simple (or familiar) tasks where performance expectations are high versus difficult (or unfamiliar) tasks where performance expectations are low. Therefore, there is a need in future work to measure and potentially match or assign people to groups based on differences in individual characteristics. It may be that only individuals with low motivation, or individuals with stable,

internal (i.e., ability-related) attributions for success and failure will be sensitive (or maximally sensitive) to these success manipulations.

6.5.3 Measurement-related factors

In studies of motor behaviour, a participant's degree of motivation is often assessed with questionnaires or other self-report measures that are typically competed after an activity. While there are advantages to using well-established and tested questions for a measure of motivation, existing challenges, such as the imprecision of Likert scales, would warrant the use of additional measures of motivation to supplement self-reported motivation (Fulmer & Frijters, 2009). Another issue lies in the accuracy or credibility of self-reported motivation, as self-reports are likely biased by traits, values and self-projections related to social desirability (Paulhus & Vazire, 2005). They are also constrained by an individual's extent of awareness regarding their psychological state while the activity was performed (Touré-Tillery & Fishbach, 2014).

In future examinations of motivational influences on motor learning, it would be ideal to administer more than one measure of motivation. Besides self-reports, think aloud protocols could potentially provide greater insight to learners' motivation states and cognitions and how they unravel over the course of practice. Researchers could also consider obtaining ratings of perceived effort after particular (good or bad) practice trials or a general rating of mental/cognitive effort to assess motivation (Zijlstra, 1993). Behavioural assessment of motivation might consist of video analysis of on-task versus off-task durations or the amount of time for which participants are engaged with the task in a waiting period when the experimenter is not present ("free choice time"; Reeve & Cole, 1987 or Wicker, Brown, Wiehe & Shim, 1990). Physiological measures of the dilation of the pupils (Fulmer & Frijters, 2009; Kahneman, 1973), and psychophysiological measures of skin conductance level, heart rate or blood pressure could provide a measure of attention and effort indicative of motivation state, although there are potential issues associated with interpretation of these measures in isolation.

6.6 Conclusion

The five studies in this thesis have not corroborated the OPTIMAL theory (Wulf & Lewthwaite, 2016) and the importance of success-related expectancy and motivation as moderators of

learning. The present studies suggest that as long as the same amount of practice is administered, manipulations to task-difficulty progressions, target size/goal-criteria, relative practice improvement, and social comparative feedback have no impact on behavioural indices of performance and learning. If success perceptions are able to moderate motor learning, it is likely that the effects are small, which would explain why there is a lack of consistency in reporting of such effects in the literature (e.g., Carter et al., 2016; Ong et al., 2015; Ong & Hodges, 2017; Patterson & Azizieh, 2012). Because the relation between psychological variables, such as self-efficacy, judgments of learning and motivation, and behavioural measures of learning are not one-to-one and are not consistently evidenced, it should not be too surprising that success perceptions do not have a reliable or large influence on learning.

Thus, although it is possible to bring about change in perceptions of success through manipulations to target size or feedback, these perceptions show no relation to behavioural measures of learning. Group differences were shown in some of our process measures, indicating larger amplitude movements (Study 3), more time in movement planning and processing (Study 3) and greater arousal (Study 5) for the less successful groups. It may be that these changes need to be heightened for them to result in actual outcome differences, or that such differences in control processes are not related to performance effects.

It is also possible that individual or contextual factors might have moderated the relationship between success perceptions, motivation and learning. These might have served to remove effects or even change the direction of effects. As suggested, if participants are intrinsically motivated to do well, or have low expectations, our feedback or target size manipulations signaling low performance may actually have had an energizing effect. Although this is not considered in OPTIMAL theory, underperforming can motivate people to do better, rather than succeeding on relatively easy goals, which can potentially lead to complacency.

There are a number of empirical studies demonstrating a direct link between success perceptions/expectancy and motor learning, as posited in the OPTIMAL theory (e,g., Ávila et al., 2012; Chauvel et al., 2015; Chiviacowsky et al., 2012; Lewthwaite & Wulf, 2010a; Trempe et al., 2012; Wulf et al., 2014). Yet, the proposed mechanisms for this association have either been untested (reward/dopaminergic-based and neuromuscular facilitation accounts), or findings have

been mixed (cognition and motivational accounts; e.g., Carter et al., 2016; Grand et al., 2017; Levac et al., 2017; Ong et al., 2015; Ong & Hodges, 2017). Furthermore, the principle that more cognitively effortful (hence often less successful) practice is more beneficial for motor learning, as shown in the guidance hypothesis (Winstein & Schmidt, 1990) and contextual interference literature (Shea & Morgan, 1979), appears to be in conflict with the idea that heightened practice success (often due to less demanding tasks or success criteria) benefits learning. OPTIMAL theory researchers have tried to address this mismatch between literatures by suggesting that a mechanism for the success of challenging or more difficult practice protocols (for later learning), may be related to the heightened dopamine response on the unexpectedly successful trials, or an increase in attention and effort (Wulf & Lewthwaite, 2016). Despite this suggestion, participants in relatively difficult, effortful practice conditions are found to have low expectancies about future performance compared to people who practice under easier conditions (e.g., Simon & Bjork, 2001). This is in contrast to the purported association between success perceptions and learning. As a result of these discrepancies and the current studies, it seems premature to advocate high success practice conditions, especially at the expense of conditions which add challenge and promote cognitively effortful activities. It is yet to be determined how practitioners might strike a balance between the level of challenge and learner success that should be structured into practice. Some unanswered questions include: when and what is the level of success a learner must achieve to reap the benefits of expectancy as expounded by the OPTIMAL theory? How much error is beneficial to learning? Are success-related effects highly task and (intrinsic) feedback dependent? What is the role of individual differences in moderating the effects of success perceptions and which individual characteristics would best lead to benefits of practice conditions that promote success?

Moving forward, further research is needed to test the relationship between success perceptions and motor learning. Attempts to replicate the expectancy effect hypothesized by the OPTIMAL theory should include more diverse or complex tasks, variations to practice conditions, and potentially control for individual characteristics, such as level of motivation and outcome attribution. In light of a known bias in the psychological sciences for statistically significant findings to be published more expansively than null effects, greater transparency is needed in reporting (Ferguson & Heene, 2012). Registration of rationale and protocol prior to conducting a study might be one way forward. A meta-analysis that consists of both significant

and null effects across multiple laboratory groups would help us evaluate the overall direction and magnitude of the effect of success perceptions on learning.

In conclusion, although I have shown no evidence that enhanced success perceptions, through reduced target size, easier or sliding goal-criteria and positive social comparative feedback, impact learning an overall positive approach to coaching is likely beneficial for learning and performance (Smith, 2015). This approach is likely to involve lots of positive and encouraging feedback, personalized practice pegged at difficulty levels that result in moderate to high success and feelings of competency for the learner, as well as learners' choice/say in training activities and positive team interactions to enhance the other basic psychological needs of autonomy and relatedness. Presently, with a sizable number of studies in support of the OPTIMAL theory, practitioners may be tempted to take manipulations of success and positive feedback to the extreme. Doing so could lead to undesired consequences. We still do not know how motivation is influenced by changes to self-efficacy/expectancies. Other empirical evidence suggests that lack of difficulty or challenge during practice, and unwarranted praise or peer comparisons can promote complacency, disinterest and extinction of effort in learners. We caution practitioners from excessive use of such success manipulations in their work that is not a genuine reflection of learners' capabilities.

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Appendices

Appendix 1: Summary of Task, Procedure, and Dependent Measures of Study 1

Table A1.1 Summary of task, procedure, and dependent measures of Study 1 (Chapter 2).

Task and Procedure (#trials)	Dependent Measures	
	First Half of Participants (n = 5/gp)	**Second Half of Participants (n=7-8/gp)**
Dart-throwing @ 275 cm <u>Day 1</u> 1. Warm-up (3) 2. Pre-test (6) 3. Acquisition (210) • Easy-to-difficult (200 – 350 cm) • Difficult-to-easy (350 – 200 cm) 4. Post-test (6) <u>Day 2</u> 1. Warm-up (3) 2. Retention (6) 3. Secondary Task (6) 4. Vision-Occlusion (6) 5. Weighted-Transfer (6)	<u>Behavioural</u> • Accuracy score (max 8 per throw) • Secondary tone-counting response • Outcome-prediction response <u>Questionnaire</u> • Self-efficacy rating (close to bullseye): Pre-test, 7 x Acquisition, Post-test, Retention • Explicit knowledge: Post Day 2 • Customized motivation/ability items: Post Day 2 a) Given the opportunity will you play darts again? b) With some practice, do you think you will become a decent darts player?	<u>Behavioural</u> • Accuracy score (max 8 per throw) • RE, CE and BVE • Secondary tone-counting response • Outcome-prediction response <u>Questionnaire</u> • Self-efficacy rating (close to bullseye): Pre-test, 7 x Acquisition, Post-test, Retention • CSAI: Pre-Day 1, Pre-Day 2 • SMS: Pre-Day 1, Pre-Day 2 • Customized motivation items: Post Day 1 a) During practice I was motivated to improve; b) I look forward to playing darts again. • Explicit knowledge: Post Day 2

Appendix 2: Summary of Task, Procedure, and Dependent Measures of Study 2

Table A2.1 Summary of task, procedure, and dependent measures of Study 2 (Chapter 3).

Task and Procedure (#trials)	Dependent Measures
Dart-throwing @ 237 cm <u>Session 1</u> 1. Warm-up (3) 2. Pre-test (9) 3. Acquisition (90) • Large-T • Small-T 4. Post-test (9) <u>Session 2</u> 1. Warm-up (3) 2. Retention (9) 3. Secondary Task (9) (Ret and Sec counterbalanced for order between participants)	<u>Behavioural</u> • # Target hits • RE, CE and BVE • Secondary tone-counting response <u>Questionnaire</u> • Self-efficacy rating (3 areas): Pre-test, Post-test and Retention • Self-efficacy rating (target area): 3 x Acquisition • Explicit knowledge: Post Session 1 • SMS: Post Session 1 **(not reported in publication)** • Customized motivation items: Post Session 1 **(not reported in publication)** a) During practice I was motivated to improve; b) I look forward to playing darts again.

Appendix 3: Summary of Task, Procedure, and Dependent Measures of Study 3

Table A3.1 Summary of task, procedure, and dependent measures of Study 3 (Chapter 4).

Task and Procedure (#trials)	Dependent Measures
Dart-throwing @ 200 cm Day 1 1. Warm-up (1) 2. NV Pre-test (6) 3. Acquisition (90) • Large-band • Small-band Day 2 1. Warm-up (1) 2. NV Retention (6) 3. Retention (9) 4. Occlusion (9) 5. Secondary Task (9) 6. Slowed/speeded (9+9)	Behavioural • # Target hits • AE, CE, VE • Secondary tone-counting response • Outcome-prediction response Questionnaire • Self-efficacy rating (target area): 3 x Acquisition • IMI – Perceived competency: Pre Day 1, Post Day 1, Pre Day 2 • IMI – Interest/enjoyment: Post Day 1 • SMS: Post Day 1 • Success perception check: Post Day 1 • Customized motivation items: Post Day 1 a) I look forward to practising a throwing activity like this in future; b) During practice, I was motivated to do well. • Explicit knowledge: Post Day 2 • Goal acceptance and success check: Post Day 2 **(not reported in manuscript)** Process • EMG (biceps and triceps) • EDA • Kinematics • Temporal

Appendix 4: Summary of Task, Procedure, and Dependent Measures of Study 4

Table A4.1 Summary of task, procedure, and dependent measures of Study 4 (Chapter 5).

Task and Procedure (#trials)	Dependent Measures
Stabilometer balancing Day 1 1. Warm-up (2 x 10 s) 2. Acquisition (12 x 60 s) • Easy (5°) • Difficult (1°) • Easy-to-difficult (5° → 1°) • Difficult-to-easy (1° → 5°) Day 2 1. Warm-up (2 x 10 s) 2. Retention (5 x 60 s) 3. Secondary Task (2 x 60s)	Behavioural • % TOT feedback • RMSE • Secondary tone-counting response Questionnaire • Self-efficacy rating (full range % TOT): 4 x Acquisition, 2 x Retention • SMS: Post Day 1 • CSAI-2: Post Day 1 • Success perception check: Post Day 1 • Customized motivation items: Post Day 1 a) I look forward to practising a balance activity like this in future; b) During practice, I was motivated to do well. • Explicit knowledge: Post Day 2 • Credibility and success check (only asked half of participants): Post Day 2

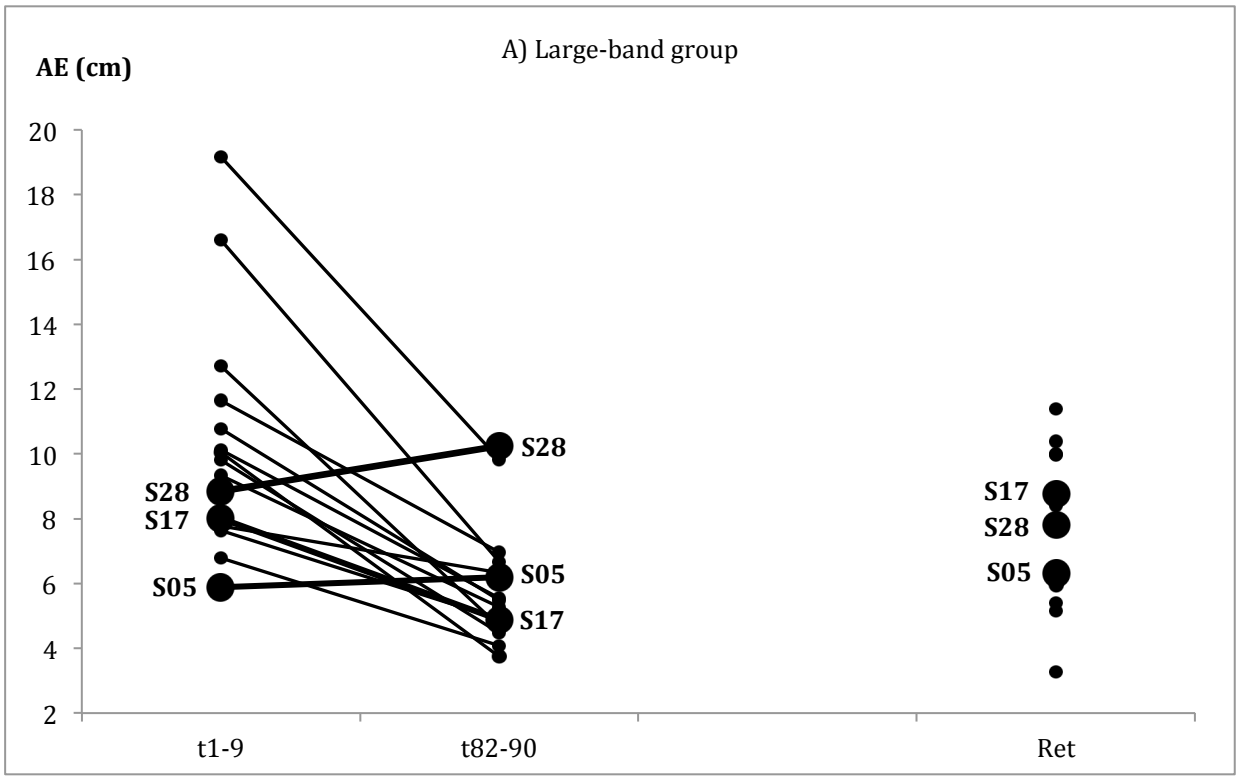
Appendix 5: Summary of Task, Procedure, and Dependent Measures of Study 5

Table A5.1 Summary of task, procedure, and dependent measures of Study 5 (Chapter 5).

Task and Procedure (#trials)	Dependent Measures
Stabilometer balancing Day 1 1. Warm-up (2 x 10 s) 2. Acquisition (7 x 60 s) • Positive • Pos-Control • Negative • Neg-Control Day 2 1. Retention (7 x 60 s) 2. Secondary Task (1 x 60s)	Behavioural • RMSE • MPF • Secondary tone-counting response Questionnaire • (Exp. 2a) Self-efficacy rating (full range % TOT): 3 x Acquisition, 3 x Retention • (Exp. 2b) Average probes: 3 x Acquisition, 3 x Retention • IMI – Perceived competency: Pre Day 1, Post Day 1, Pre Day 2 • IMI – Interest/enjoyment: Post Day 1 • SMS: Post Day 1 • Customized motivation items: Post Day 1 a) I look forward to practising a balance activity like this in future; b) During practice, I was motivated to do well. • Explicit knowledge: Post Day 2 • Credibility and success check: Post Day 2 Process • HR

Appendix 6: Additional Analyses from Study 3

The following figures, A6.1A and B, are from Study 3 and illustrate the average error of all participants in the Large and Small-band groups. However, on these figures, we have made salient participants who did not decrease AE from the first to last block of practice (Large-band, A: S05, S28; Small-band, B: S14, S20) and of participants who did not demonstrate a learning effect, that is no decrease in AE from the first block of practice to the retention block (Large-band, A: S05, S17; Small-band, B: S25).



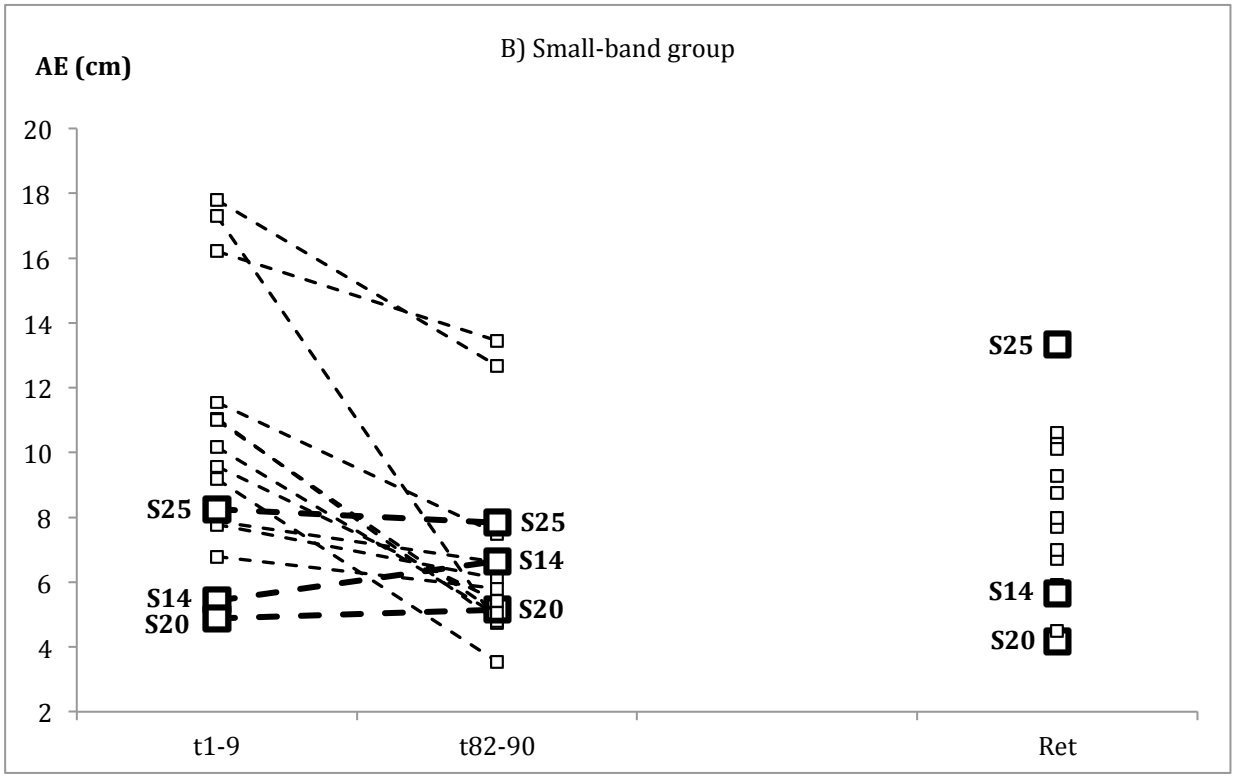
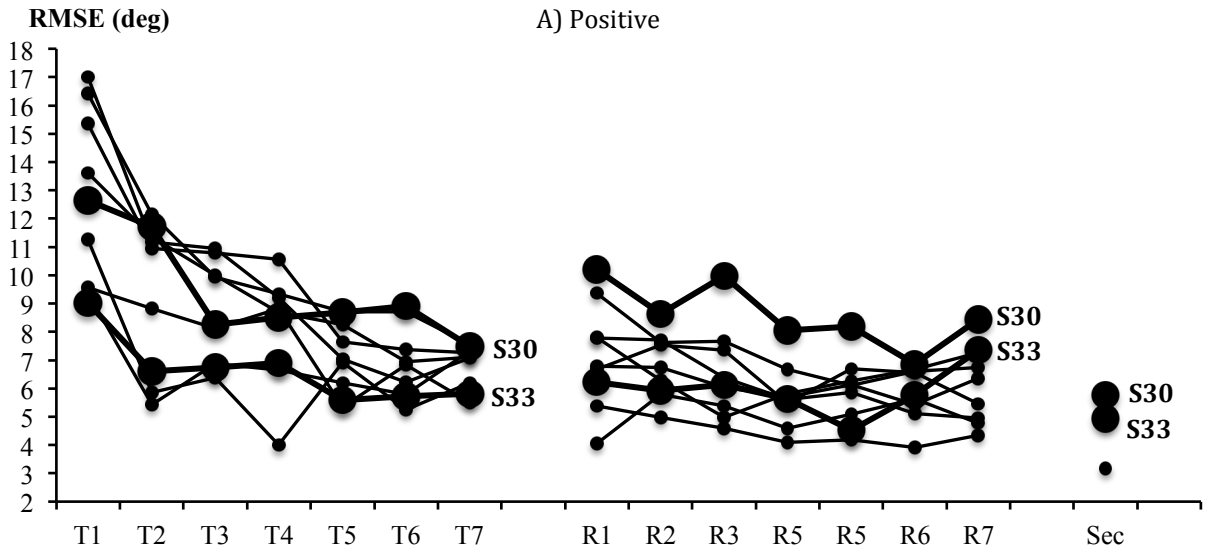


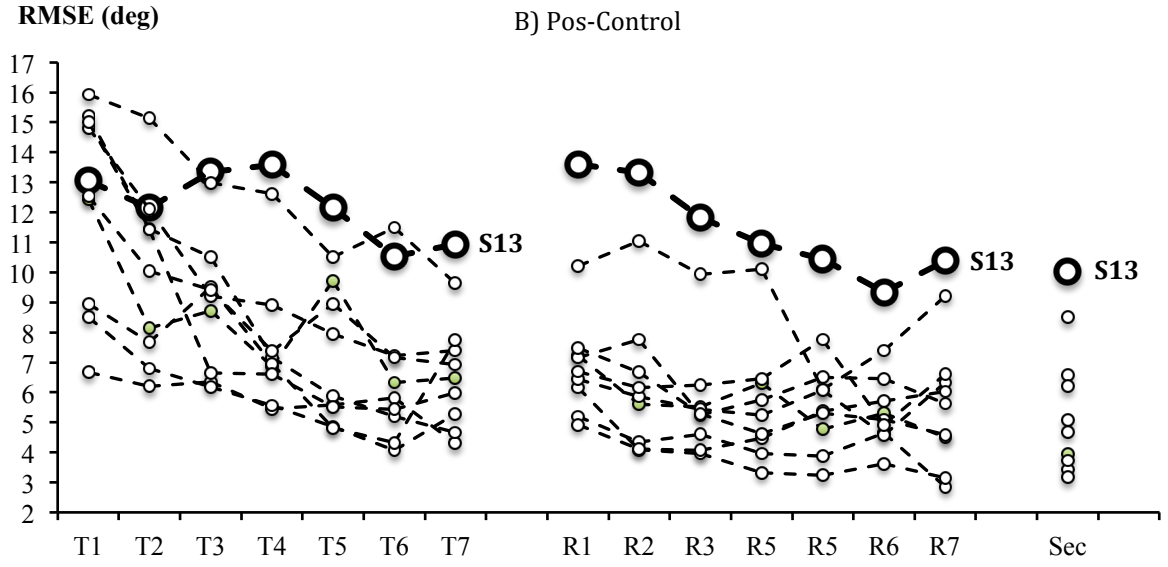
Figure A6.1 Average error of all individual participants in Study 3 across practice and retention. Larger and darker data points in the A) Large-band and B) Small-band groups pertain to individuals that did not exhibit a positive practice effect (decrease in AE from the first block of practice (t1-9) to the final practice block (t82-90), or did not demonstrate a learning effect (decrease in AE from the first block of practice (t1-9) to the retention practice block (retention trials 1 to 9, Ret).

From these individual analyses, it was evident that several participants either showed an improvement in dart-throwing accuracy across practice, or at delayed retention. One participant (S05), showed no improvement across practice or in comparison of early practice to retention, such that this participant was excluded from analyses.

Appendix 7: Additional Analyses from Study 5

Figures A7.1, A – D, illustrate the RMSE of all participants in the four groups tested in Study 5, Exp 2. To note, two participants (Pos-Control, B: S13; Neg-Control, D: S60) did not demonstrate savings in balance performance from the first trial of acquisition (T1) to the first trial of retention (R1). Five participants (Positive, A: S30, S33; Pos-Control, B: S13; Negative, C: S46, S47) did not show an average improvement in performance from acquisition (T) to retention trials (R).





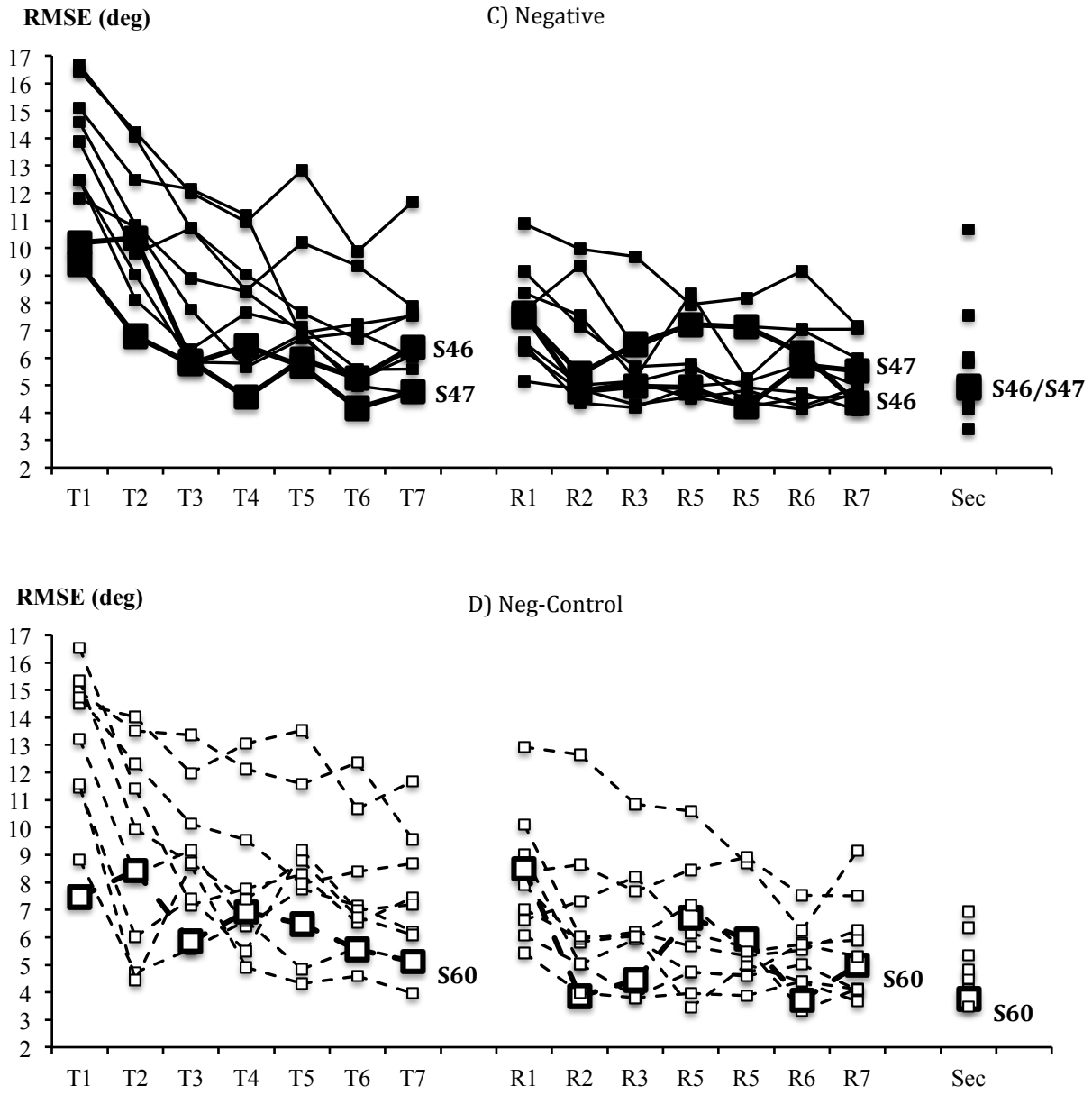


Figure A7.1 (A-D). RMSE of individual participants across the four groups (A = Positive, B = Pos-Control, C = Negative, and D = Neg-Control groups) tested in Study 5, Experiment 2. Larger and darker data points illustrate participants that did not exhibit savings, that is a decrease in RMSE from acquisition trial 1 (T1) to retention trial 1 (R1), or did not show an average improvement in performance, that is a decrease in average RMSE from acquisition to retention.

After individual performance curves analyses, Subject S13 (Pos-Control) was excluded from analyses of RMSE and MPF as this was the only participant that neither indicated any savings from T1 to R1, nor showed an average improvement from Day 1's acquisition to Day 2's retention trials.