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The effects of augmented feedback on pacing and performance of elite combat athletes

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ABSTRACT

Augmented feedback has been shown to improve performance and influence pacing in various physical activities. However, few studies have investigated its effects on performance and pacing in striking combat sports. Additionally, despite the plethora of studies examining the influence of feedback in untrained individuals, there is a lack of research examining the effects of such feedback in trained participants. Considering the important role of feedback in training and competition, the purpose of this thesis is to examine the effects of three different but inter-dependent methods of augmented feedback on performance of combat, and resistance trained athletes.

Study 1 examined the type and frequency of verbal feedback provided by national level coaches to their athletes during important competitions. A microphone was secured on the shirts of 12 coaches and the feedback they provided was recorded, transcribed and categorised into three common feedback themes: attentional focus (internal, external, neutral), autonomy support (controlling, supportive, neutral) and feedback valence (positive, negative, neutral). Collectively, 445 feedback statements from 12 coaches during 26 bouts, of which 14 were won and 11 were lost, were analysed. Coaches provided on average 8 feedback statements per round. Excluding neutral statements, coaches delivered more internal (15%) compared with external focus feedback (6%), more controlling (53%) compared with autonomy-supportive feedback (4%), and more feedback that would affect athletes' expectancies in a positive (29%) rather than negative direction (12%). Furthermore, during winning bouts coaches delivered more positive (36% vs. 18%), less internal (12% vs. 19%) and less controlling (50% vs. 58%) feedback, when compared with losing bouts. Hence, for the most part, coaches used feedback that is sub-optimal accordingly to the existing body of literature. Additionally, winning and losing bouts were associated with different types of feedback which suggests a possible training strategy.

Study 2 examined if internal or external focus of attention effect maximal force production during an isometric mid-thigh pull (IMTP) among 18 trained athletes (8 females & 10 males). Athletes performed three IMTP trials a day for three consecutive days. The first day consisted of a familiarization session in which athlete's received control instructions. In the following two days athletes received either control, internal or external focus of attention instructions in a randomized, within-subject design. Compared to an internal focus of attention, athletes applied 9% greater force using an external focus of attention ($P < 0.001$; effect size [ES]= 0.33) and 5% greater in the control condition ($P = 0.001$; ES= 0.28). A small positive 3% advantage was observed with an external focus of attention compared with control conditions ($P = 0.03$; ES= 0.13). This study demonstrates that even in relatively simple exercises that require maximal force production, external focus leads to superior performance compared to internal focus as well as control conditions, among resistance trained participants.

Study 3 investigated a similar question as *study 2*, but the outcome measures were combat sports related. Specifically, the effects of external, internal and neutral feedback were examined in relation to punching velocity ($m \cdot s^{-1}$) and normalized impact forces ($N \cdot kg^{-1}$) among intermediate ($n = 8$) and expert ($n = 7$) competitive boxers and kickboxers. Athletes completed three rounds of 12 maximal effort punches delivered to a punching integrator on three separate days. Day one was a familiarization session with only control instructions provided. In the following two days athletes randomly received internal, external or neutral instructions prior to each of the three rounds. Athletes punching with external focus were 4% faster and 5% more forceful than internal focus ($P < 0.05$), and 2% faster and 3% more forceful than control ($P < 0.05$). Furthermore, experts punched 11% faster and with 13% greater force compared with intermediate athletes ($P < 0.05$). Punching forces were enhanced with external compared to both internal and control condition, among well-trained combat striking athletes, and should implemented by combat sports coaches.

Study 4 investigated how performing in-front of a mirror influences performance in single and multi-joint tasks, and compared the mirror condition to the established performance effects of internal and external focus instructions in a two part experiment. In the single-joint experiment 28 resistance-trained participants (14 males and 14 females) completed two elbow flexion maximal voluntary isometric contractions under four conditions: mirror, internal, external and neutral instructions. During these trials, surface electromyography (EMG) activity of the biceps and triceps were recorded. In the multi-joint experiment the same participants performed counter-movement jumps on a force plate under the same four conditions. Single-joint experiment: External instructions led to greater normalized force production compared to all conditions ($P \leq 0.02$, ES= 0.46-1.31, 8-30 N). No differences were observed between neutral and mirror conditions ($P = 0.15$, ES=0.15, 5 N), but both were greater than internal focus ($P < 0.01$, ES= 0.79-1.84, 15N). Surface EMG activity was comparable across conditions ($P \geq 0.1$, ES= 0.10-0.21. ~2%). Multi-joint experiment: Despite no statistical difference ($P = 0.10$), a moderate effect size was observed for jump height whereby external focus was greater than internal focus (ES= 0.51, 1 cm). No differences were observed between neutral and mirror conditions (ES= 0.01, 0.1 cm), but both were greater than internal focus (ES= 0.20-22, 0.6 cm). The mirror condition led to superior performance compared to internal focus, inferior performance compared to external focus, and was equal to a neutral condition in both tasks. These results provide novel and practical evidence concerning mirror training during resistance type training.

Study 5 was a two part study set to examine how self-controlled practice effects performance of competitive athletes. Part 1 was a single case-study design with a world-champion kickboxer. We investigated whether giving the athlete a choice over the order of punches would affect punching velocity and impact force. The athlete completed 2 rounds of 12 single, maximal effort punches (lead straight, rear straight, lead hook & rear hook) delivered to a punching integrator in a counterbalanced order over 6 testing days. In one round the punches were delivered in a predetermined order while in the second round the order was self-selected by the athlete. When allowed to choose the punching order, the world-champion punched with greater velocities (6-11%) and impact forces (5-10%). In Part 2, the same testing procedures were repeated with 13 amateur male kickboxers over 2 testing days. Similar to Part 1, the athletes punched with significantly greater velocities (6%, $P < 0.05$) and normalized impact forces (2%, $P < 0.05$) when allowed to choose the punching order. Hence, small choices concerning practice conditions enhance punching performance of competitive striking athletes.

Study 6 investigated the effects of three different versions of false-performance feedback on punching force (N), pacing (force over time) and ratings of perceived exertion (RPE) in 15 elite amateur male boxers. Athletes completed a simulated boxing bout consisting of three rounds with 84 maximal effort punches delivered to a punching integrator on four separate days. Day one was a familiarisation session in which no feedback was provided. In the following three days athletes randomly received false-positive, false-negative and false-neutral feedback on their punching performance between each round. No statistical or meaningful differences were observed in punching forces, pacing or RPE between conditions ($P > 0.05$; $\leq 2\%$). These null results, which differ from previous literature, could stem from the elite status of the athletes involved; indicating that task proficiency might mitigate against changes in performance and pacing variability when false performance feedback is manipulated.

Collectively, this thesis enhances our understanding of: i) the common feedback statements provided by coaches, ii) how such feedback influence performance and pacing of combat athletes, and iii) how this feedback also influence performance during common resistance type exercises.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PUBLICATIONS

The following chapters have been published in, or submitted to, academic journals for peer-review:

Chapter 3

Halperin I., Chapman D.W., Martin D.T., Abbiss C.R. and Wulf G. Verbal instruction in amateur boxing: a descriptive analysis of feedback provided between rounds. *Psychology of Sport and Exercise* 2016; 25, 44-50. (IF= 2.2)

Chapter 4

Halperin I., Williams K., Martin D.T., and Chapman D.W. The effects of attentional feedback instructions on peak force production with the isometric mid-thigh pull. *Journal of Strength and Conditioning Research.* 2015; 30, 919-923. (IF= 1.9)

Chapter 5

Halperin I., Chapman D.W., Martin D.T., and Abbiss C.R. The effects of attentional feedback instruction on punching velocity and impact forces among trained combat athletes. *Journal of Sports Science* 2016; 18, 1-8. (IF= 2.1)

Chapter 6

Halperin I., Hughes S., Panchuk D., Abbiss C.R., and Chapman D.W. The effects of either a mirror, internal or external focus on single and multi-joint tasks. *Frontiers.* 2016 (in press). (IF= 3.2)

Chapter 7

Halperin I., Chapman D.W., Lewthwaite R., Martin D.T., and Wulf G. Choices enhance punching performance of competitive kickboxers. *Journal of Psychological Research* 2016 (in press). (IF= 2.7)

Chapter 8

Halperin I., Chapman D.W., Thompson K.G., and Abbiss C.R. False-performance feedback does not affect punching forces and pacing of elite boxers. *Plosone (submitted).* (IF= 3.2)

Additional Publications Related to this Thesis:

Halperin I., Hughes S., and Chapman D.W. Preparing for a state-title match: a case study of an elite professional boxer. *Journal of Sports Science.* 2015;16, 1-8. (IF= 2.1)

Halperin I., Pynee D., and Martin D.T. Threats in internal validity in exercise science: an overview of overlooked confounding variables. *International Journal of Sports Physiology and Performance.* 2015; *115*, 2031-2048. (IF= 3.0)

Halperin I, Chapman D.W and Behm D.G. (2015). Invited Review: Non-local muscle fatigue: effects and possible mechanisms. *European Journal of Applied Physiology*. 115(10): 2031-2048 (IF = 2.3)

Conference Presentations:

Halperin I., Aboodarda S.J., Basset F.A., Byrne J.M., and Behm D.G. Pacing strategies during repeated maximal voluntary contractions. *Australian Institute of Sports Applied Physiology Conference.* Canberra, Australia, 10-11 November 2014 (oral presentation)

Martin D.T., Dunican I., Reale R., **Halperin I.**, Humberstone C., Dunn E., Maloney M., Lee H., Cormack S. and Iredale F. Reliability and validity of the single leg, 3 hop test in Australian Judoka. *American College of Sports Medicine*. San Diego, USA, 15 May, 2015 (oral presentation)

Halperin I., Hughes S., and Chapman D.W. Preparing for a state-title match: a case study of an elite professional boxer. *Australian Institute of Sports Applied Physiology Conference.* Perth, Australia, 12-13 November 2015 (oral presentation)

Halperin I. Threats in internal validity in exercise science: an overview of overlooked confounding variables. *Australian Institute of Sports SMART talk series* (invited talk). Canberra, Australia, 29 October 2015

Halperin I., Hughes S., Panchuk D., Abbiss C.R., and Chapman D.W. The effects of either a mirror, internal or external focus of attention instructions on single and multi-joint tasks. *Wingate Congress of Exercise and Sport Sciences*. Natanyia, Israel, 2-5 June 2016 (oral presentation)

Halperin I. *Applied principles of motor learning in training and rehabilitation.* Ichilov Hospital, Tel Aviv Sourasky Medical Center, Israel, 8 February 2017 (invited talk)

Halperin I. *Coaching feedback for combat sports.* Combat Conditioning Conference, Boxing Science (online), 8 May 2017 (invited talk)

Competitive Research Grants and awards

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CHAPTER 1

1.1 Overview

This doctoral thesis contains a literature review followed by six research studies and a discussion chapter, with an aim of understanding how various types of feedback influence performance and pacing during punching activities and resistance-type exercises. The goal of the first observational study was to examine the type and frequency of feedback provided in competition by national level boxing coaches. Studies two, three and four examined the effects of attentional focus instructions on maximal punching performance, and maximal force production in common resistance type exercises. Study five investigated the influence of self-choice on punching forces of elite and non-elite kickboxers. Finally, the sixth study analysed the effects of providing an individual with incorrect feedback regarding their performance. Elite boxers were informed that their performance was either lower than their baseline values, higher than their baseline values, or similar to it. The effects of such feedback on their punching forces and pacing (punching forces over time) were measured.

1.2 Background

Augmented feedback has been shown to alter pacing and performance across a range of exercise modalities such as cycling, running and isometric contractions (1-6). Despite the prevalence of feedback in combat sports, few studies have examined the influence feedback has on performance and pacing during punching activities and common resistance type exercise among well-trained participants. Since feedback is fundamental to a majority of coaching behaviours, developing a strong understanding of how feedback influences motor learning and performance is important. Furthermore, feedback has been shown to influence many different types of activities requiring balance, strength and endurance (1, 7), but the majority of studies investigated untrained and/or recreationally trained participants. The extent to which feedback influences performance and pacing of elite and well-trained athletes, and whether specific feedback can offer a competitive advantage to such populations remains unclear. For this reason the current investigations enriches and expands the existing literature on feedback.

Specifically, three feedback strategies are of special interest: i) directing the athlete's attention of focus either externally or internally during different physical tasks, ii) allowing the athletes to self-select a practice variable or controlling them and iii) the provision of positive or negative feedback regarding the proficiency of a physical task. These feedback strategies are commonly implemented by coaches and practitioners (7-10) and have been thoroughly investigated over the years, leading to a large body of literature that can be used as reference and comparison (1, 7, 11, 12).

Instructing subjects to focus on one aspect of a motor task in more detail to another has been show to positively or negatively affect performance (1). External focus refers to instructing leading an individual to focus on the effects of the movement in relation to the environment. For example, instructing a person to focus on the hoop during a basketball shot illustrates external focus. Internal focus refers to instructing an individual to focus on a specific body part and muscle group during the physical task. For instance, instructing a person to focus on the movement of their wrist and elbow during a basketball throw illustrates internal focus. A vast body of literature has demonstrated that an external focus is superior to internal focus in regards to various aspects of exercise performance (13-15). Such findings are commonly explained with the *constrained action hypothesis* proposed by Wulf et al. (1, 16). This hypothesis proposes that external focus promotes an automatic motor response that is in line with the desired outcome whereas internal focus directs participants to be conscious of their movement which disrupts the automatic control of the involved motor systems. Yet, despite the growing number of studies on the topic of attentional focus, few of them have investigated the effects of such instructions on performance of well-trained participants. The limited studies that have been conducted in well-trained athletes reported mixed results (17, 18). To the best of my knowledge, no studies have yet investigated the effects of attentional feedback instructions on punching performance of combat athletes.

Interestingly, despite the growing body of literature on attentional feedback instructions, it seems as if track and field coaches tend to rely more heavily on the inferior, internal instructions in their daily coaching environment (19). Other than feedback that track and field coaches provide, no studies to date examined the frequency of external and internal feedback provided by other sport coaches in their nature training, and competitive environments. A better understanding of the feedback coaches provide to athletes may assist in conducting more ecologically valid studies which mimic the type and frequencies of feedback that coaches implement in real life situations. Knowing what type of feedback coaches utilize in real life can be compared with results from experiments investigating the effects feedback has performance. By doing so, coaches can align their coaching behaviours with the best available evidence.

A number of studies have shown that providing choices related to the motor task (i.e., number of completed repetition and when to receive feedback) enhances motor learning and performance (8, 20-24). Studies attempting to better understand the influence of self-choice on exercise performance commonly divide participants into two groups including a control (at times called “yoked”) and a choice group. While participants in both groups practice the movement task for a comparable number of sessions/repetitions, those in the choice group are free to make a choice concerning one or more of the practice variables. For example, participants within the previous literature have been given a choice when to receive verbal feedback, when to stop the practice session, or the order in which to complete the movement tasks (7). Participants in the yoked group are deprived of such choices, and are "forced" to match the choices made by those in the choice group. The positive effects have been partly explained by the finding that the anticipation of making a choice is associated with greater activity in regions of the brain involved in motivational processing (25). To date, most studies examined the effects of choices within: 1) untrained participants, 2) completing an unfamiliar task, 3) with outcome measures unrelated to sports performance (20, 26). Further research examining the provision of choices offered by coaches and how such choices influence performance of trained participants completing familiar tasks is warranted. It is also of interest to explore the provision of choice offered by coaches in their daily training/competition environments.

A commonly implemented feedback strategy, which has been shown to influence motor learning and performance (7), is feedback describing one's performance in a positive or negative manner (also known as feedback valence) (27). Compared with negative and/or neutral feedback, providing participants with positive performance feedback enhances motor learning and performance (27-29). Furthermore, the provision of false or negative feedback (e.g., deceptively telling participants that they are running 5% slower or 5% faster) throughout an exercise task has been shown to influence pacing (i.e., the distribution of energy expenditure throughout the task) (4, 30-32). However, to date, the effects of positive and negative feedback have mainly been investigated on untrained participants completing novel motor tasks, or on athletes and amateur athletes completing cyclical tasks such as running and cycling (33-35). It is also unclear if such effects are observed in non-cyclical tasks and in athletes that are accustomed to the exercise task, such as punching performance, with athletes who are familiar completing the task.

1.3 Significance of the Research

Feedback is at the heart of all coaching activities. Developing a better and deeper understanding of how feedback effects performance, particularly of well-trained athletes and combat athletes, is a useful research avenue for a number of reasons. From a practical point of view, a better understanding of how feedback influences performance may allow coaches to improve their feedback strategies and thus enhance performance. However, to date, most of the literature pertaining to the effects that feedback have on performance is limited to untrained and/or recreationally trained participants (1, 7, 8, 11, 20, 34). This thesis improves our understanding of how feedback influences performance in well-trained individuals performing unique motor tasks, such as delivering punches and common resistance type exercises. Indeed, the majority of the feedback research investigated simple motor tasks and outcome measures that mainly depend on balance and accuracy measures (e.g., (13, 18, 20, 34-36). Collectively, the results from these series of studies will improve our understanding of the types and frequencies of feedback coaches use in important competitions; how augmented feedback influence physical performance in highly trained people accustomed to the exercise task; how augmented feedback can be used with athletes in training to enhance their performance in training and competition. And finally, this thesis will enhance our theoretical understanding of how feedback effects performance with unique populations and outcome measures.

1.4 Research Aims

The main purpose of this PhD thesis is to examine the effects of augmented feedback on punching impact forces, velocities, and pacing in competitive combat athletes. A secondary aim of this thesis is to explore the effects of feedback on strength and power measures among resistance trained individuals.

Research Questions

1.4.1 Study 1

- What type and frequencies of feedback do boxing coaches provide to their athletes during boxing competition?
- Do coaches in winning bouts provide different types and frequencies of feedback compared to coaches in losing bouts?

1.4.2 Study 2

- Does providing resistance-trained athletes with instructions eliciting external focus of attention improve maximal force performance in the isometric-mid-thigh pull when compared with no feedback or internal focus of attention?

1.4.3 Study 3

- Does providing combat athletes with instructions directing external focus of attention improve punching performance (i.e. peak impact forces and velocity) when compared with neutral feedback or internal focus of attention?

1.4.4 Study 4

- Does providing resistance-trained athletes with instructions directing external focus of attention improve performance in single and multi-joint exercises when compared with neutral feedback, internal focus and a mirror condition?

1.4.5 Study 5

- Will self-selected punch order influence punching forces and velocities compared to a set order of punches among competitive combat sport athletes?

1.4.6 Study 6

- Will providing striking combat sport athletes with false negative and false positive feedback impact the pacing (i.e. time distribution of punching impact forces and speed of impact), performance and rating of perceived exertion during a fatiguing punching protocol?

1.5 Research Hypotheses

1.5.1 Study 1

- There is no clear hypothesis as to the types and frequencies that coaches will use in competitions, and their distribution between losing and winning bouts.

1.5.2 Study 2

- Instructions to focus on external factors will improve maximal forces in the isometric-mid-thigh-pull compared with instructions to focus on internal and neutral instructions.

1.5.3 Study 3

- Instructions to focus on external factors will improve maximal punching forces and velocities compared with instructions to focus on internal and neutral instructions.

1.5.4 Study 4

- Instructions to focus on external factors will improve performance in both the single and multi-joint exercises compared with instructions to focus on internal, neutral and mirror instructions.

1.5.6 Study 5

- Self-selected order of delivered punches will enhance punching forces and velocities compared to a set ordered of delivered punches.

1.5.6 Study 6

- False positive feedback will enhance punching impact forces and speed whereas negative feedback will decrease it.

1.6 Definition of Terms

ANOVA: Analysis of variance

CV: Coefficient of variance

EFA: External focus of attention

EMG: Electromyography

ICC: Interclass correlation

IFA: Internal focus of attention

RPE: Rating of perceived exertion

RM: Repetition maximum

SD: Standard deviation

IMTP: Isometric mid-thigh pull

PI: Punching integrator

MVIC: Maximal voluntary isometric contraction

CI: Confidence interval

CMJ: Counter movement jump

CON: Control

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Introduction

In the field of motor learning, the term augmented feedback refers to information provided by an external source, such as a coach, training apparatus, or video (3, 37). In this thesis the term feedback, rather than augmented feedback, will be used. A large body of evidence has clearly demonstrated that various types of feedback have a considerable effect on motor learning and performance. These effects influence a range of activities that require, among others, balance (20, 38), accuracy (35, 39), movement economy (13, 33) and strength and power (12, 19). Additionally, the effects of feedback are not limited to a particular population, with research showing feedback to influence children (40), young (41) and old adults (22), injured (42), those suffering from motor problems (43) and athletes (17). Hence, the effects of feedback are well established and influence performance and motor learning within a range of situations and populations. Over the past few years, numerous experimental studies have shown that the effectiveness of feedback is heavily influenced by three factors (1, 7, 8) including, the type of attentional focus they induce (internal vs. external focus); the extent to which they support the performer's need for autonomy (autonomy-supportive vs. controlling); and the performance expectancies they promote (positive vs. negative). In the following sections, research findings related to these three factors will be described in detail.

2.1.1 Attentional Focus

Instructions that direct ones attention towards muscles and body parts (internal focus of attention) have been repeatedly found to hinder motor learning and performance (1, 44). Conversely, directing attention towards the movement outcome, or to an external object related to the task (external focus of attention) tends to enhance motor learning and performance (1, 44). To illustrate, focusing on contracting the quadriceps muscle groups during a knee extension exercise elicits internal focus, whereas focusing on the pushing the padded part of the exercise machine elicits external focus. Attentional feedback is one of the most extensively investigated type of instructions and feedback examined with hundreds of studies conducted on the topic to date (1, 7).

Within resistance exercise or activities, an external focus of attention has been shown to enhance force, power and speed in a variety of exercise tasks (14, 45, 46). For example, Marchant et al. (45) found that during a concentric elbow flexion completed at a set speed, subjects produced 7% greater net joint torque with their elbow flexors when asked to focus on the crank bar of the dynamometer (external focus) rather than their arm muscles (internal focus). The advantages of external over internal focus also has been reported in complex, multi joint exercises. Subjects completed more repetitions with 75% of 1RM in a bench press (11 vs. 10 repetitions) and squat (11 vs. 10 repetitions) when instructed to focus on moving and exerting force against the barbell (external focus), compared with focusing on moving and exerting force with the arm/legs (internal focus) (14). Similar results have been reported with exercises requiring power production. It has been shown that jumps, sprinting speeds, and throwing performance are enhanced with external compared to internal focus of attention and/or control conditions (1, 15, 47-49). Specifically, focusing on a distant target (external focus) led participants to jump further in a maximal effort horizontal jump, compared to focusing on their leg muscles contracting (internal focus) (50). Thus, in exercises that require force, power and speed, external focus generally leads to superior performance as tested with both single and multi-joint exercises.

Although external instructions seem to provide a clear advantage in activities that require strength and power, it is important to note that most attentional focus studies have been completed with untrained/recreationally trained subjects. Generally speaking, external instructions seem to benefit trained subjects, but the results are less consistent with this population. For example, studies with trained participants have shown that swimming (17) and sprint running (51) speeds to be improved only following control instructions compared to external instructions. In one study with trained tennis players reported agility performance remained unaffected during testing with three focus conditions (control, external and internal instructions) (52). These results indicate that trained participants may respond differently to such instructions. Thus, research pertaining to high level athletes is warranted as less work has been published with such populations.

Not only measures that require strength and power benefit from external instructions. Activities that require balance and accuracy follow a similar trend. For instance, balance performance was improved when standing on an unstable platform, if subjects were asked to minimize movements of an unstable plate (external focus) rather than movement of their feet (internal focus) (42). Likewise, balancing oneself on an inflated rubber disk while holding a pole horizontally has been shown to be performed more effectively when focusing on the rubber disk and the pole rather than on the feet or hands (53). However, the majority of studies investigating balance and accuracy are limited to untrained/recreationally trained subjects. When tested among highly trained acrobats, balance performance was unaffected by the various instructions (18). Thus, similar to the strength and power studies, it is plausible that trained participants respond differently to attentional focus instructions.

Collectively, the literature generally indicates that irrespective of the activity, whether it depends on strength, power, balance or accuracy, that external focus leads to better performance compared to internal focus and control conditions. However, what remains less clear is how well-trained athletes that are familiar with the motor task response to the focus conditions. This is because the effects of attentional focus on performance of trained athletes are inconsistent (18, 51, 52). This may stem from the possibility that athletes respond differently than non-athletes to such instructions and feedback due to the athlete's extensive familiarity with instructions and feedback compared to non-athletes. Such familiarity could negate common effects such instructions and feedback commonly has on untrained participants.

or alternatively, due to the considerably smaller number studies which have investigated athletes with athletic tasks.

These attentional focus findings in which external instructions lead to superior performance compared to internal and control conditions are usually explained with the *constrained action hypothesis* proposed by Wulf et al. (1, 54). This hypothesis proposes that external focus promotes an automatic response, whereas internal focus directs participants to be conscious of their movement which disrupts the automatic control of the involved motor systems (1, 54). This hypothesis is supported by studies reporting increases in electromyography (EMG) activity of the agonist and antagonist muscles during various tasks preceded by instructions to focus on internal compared with external factors (13, 45, 55). When a skill become automatized through practice, movement becomes more efficient (with less neuromuscular activity) (13, 45, 55). It can thus be speculated that external focus of attention enhances automaticity of movement due to the decreased EMG activity. Other findings supporting this hypothesis are the longer reaction times to various stimuli when completing a motor task following internal compared to external focus (54). Faster reaction time during a task with an external focus is suggestive of greater automatic control and less conscious interference (1, 54).

2.1.2 Autonomy-Support

Letting people make choices, even small ones, concerning the practice/exercise conditions has a positive effects on their performance, motivational drive and perceptions in comparison with no-decisions conditions (7, 8, 56). The positive effects of choices have been demonstrated with various motor tasks requiring balance (20) accuracy (57) as well as motivation to exercise with greater intensity (21). Commonly, to investigate the effects of choices and decisions on motor leaning and performance, a unique between-group study design is employed, whereby participants are randomly assigned to either a choice and no-choice group. In the choice group participants are provided with a choice concerning a training variable (11, 24, 58). For instance, the amount of practice trials they would like to complete, the duration of the practice session, the amount of external feedback they receive, and more. Conversely, participants assigned to the "yoked" group are matched to participants from the choice group. That is, if a participant from the choice group chooses to complete 10 repetitions of the investigated motor task, then participant from the yoked group will complete 10 repetitions as well. However, the participant from the yoked group does not receive a choice concerning the number of repetitions as the participant in the choice group, but rather, he or she will be told by the investigator what to do.

Providing choice has been shown to influence many aspects of exercise performance. Accuracy, as measured with ball tossing tasks, golf putting and basketball shooting is enhanced when participants receive choices in the practices conditions (11, 59, 60). For example, participants provided with a choice of when to stop the practice session involving dart throwing with the non-dominant hand improved their accuracy to a greater extent than participants from the yoked group which threw a comparable amount of repetitions (59). Similarly, participants who were allowed to choose when to receive external feedback about their throwing accuracy in a beanbag toss outperformed those from the yoked group, as well as other comparable groups, such as a control group in which participants received no feedback at all (60). Balance is another physical quality that has been shown to improve in the presence of choices. When received the choice considering when to use the assistance of a pole during balance tasks during the practice trials, participants improved their balance to a greater extent compared with those from the yoked group (61, 62). Remarkably, the superior effects of the self-controlled practice have been shown to persist even when the choices were unrelated to the completed tasks. For instance, Lewthwaite et al. (11) have shown that choosing the colour of golf balls improved golf putting accuracy compared to a prescribed colour control group.

The effects of providing persons with a choice were recently shown to influence exercise behaviour (21). In a study by Wulf et al. (21) subjects chose the order of five calisthenics exercises to be performed (choice group), or were told they would complete the exercises in a specified order (yoked group). Subsequently, subjects in the two groups were asked to decide on the number of sets and repetitions they would like to complete in each of the five exercises (21). While subjects in both groups had comparable baseline fitness, those who were allowed to choose the order of exercises completed 60% more repetitions overall. Thus, a simple choice appeared to increase an individuals' motivation to exercise. However, to date, the effects of choices on performance is mainly limited to accuracy and balance tasks, and to the best of my knowledge no study has directly investigated the effects of choices of strength and power measures in trained athletes.

The persistent superior effects of choices have on people can been explained by psychological and biological pathways. According to the self-determination theory, autonomy, or the ability to make choices, is considered a fundamental psychological need (63, 64). Others proposed that making choices is even a biological necessity (25, 65), as both humans (66) and animals (67) prefer having choices over not having them. It seems as if exercising control is inherently rewarding, and indeed, the act of making choices has been associated with activation in a brain region (anterior insula) associated with a sense of agency, a state associated with dopamine release (68).

The positive effects of choices on motor learning and performance have been reported for a range of populations, including children (40), young (59) and older (22) adults, as well as participants with motor impairments (43). However, an interesting and yet unexplored question is whether the benefits of providing choices would also be seen in the performance skilled and trained athletes who are familiar with the motor task. This is because, among others, trained athletes tend to have different personality profiles than non-athletes (69) which may influence how they response to such training intervention.

This is because most of the studies on choices used motor tasks as outcome measures which the participants had no experience with prior to the study. This is a common study design in the motor learning literature which allows for a deeper understanding of the learning processes. However, there is also a need to investigate if the choices lead to superior performance in tasks which the participants have experience with, and even with tasks that they have reached a level of mastery at. Hence, there is a need to expand the body of evidence and investigate if the provisions of choices also enhance performance of other more complex athletic tasks.

2.1.3 Positive and Negative Feedback

Providing participants with positive or negative feedback concerning their performance before or throughout an exercise task can considerably influence performance (7, 27, 33). Such positive and negative feedback (also known as feedback valence) can be delivered in a number of ways. For example, informing or showing participants false feedback regarding their performance in comparison with previous trials (e.g., “Your performance is 5% lower than your baseline) or peers (e.g., “Your performance is 5% lower than the rest of the group”). Feedback valance has been shown to influence motor tasks that require strength-endurance, movement economy and balance (7, 27, 33).

In regards to strength-endurance, Hutchinson et al. (27) provided active physical education students with false negative, false positive or no feedback regarding their performance in submaximal handgrip endurance test to exhaustion. Specifically, they were told that their performance was very high and ranked in the top 10% of their peers (positive), very low and ranked in the lower 10% of their peers (negative), or they received no performance feedback (control). Time to exhaustion on the second test improved by ~12% after receiving false positive feedback and decreased by ~13% after receiving false negative feedback and remained unchanged in the control group. To my knowledge no other study examined the effects of positive and negative feedback on strength-endurance tasks. Clearly more studies are required to investigate how positive and negative feedback influence a wider variety of exercise performance tasks among participants with various training backgrounds.

Accuracy is perhaps the most investigated outcome in studies that compare positive to negative or no feedback. Golf putting performance has been shown to improve when participants received feedback about their most accurate trails, compared to feedback about the least accurate trials (41). Comparable results were found with tosses to a target (29, 34, 70). Feedback on the most accurate attempts is expected to increase the degree of confidence and perception of task difficulty which is why this type of feedback is associated with positive feedback (41). Balance performance has also been shown to improve with positive feedback. Lewthwaite and Wulf (28) compared the effects of false-positive, false-negative and no-feedback on balance performance measured with a stadiometer device. The two feedback groups received deceptive information about the average performance of those on the second group, being higher or lower, depending on the group. In this study it was found that those who received the false-positive feedback demonstrated more effective balance performance than both groups.

The superior effects found with positive feedback can stem from the influence such feedback has on perception and motivational drive, which in turn, mediates the effects on performance (27, 33, 70). Indeed, false positive feedback has been shown to decrease ratings of perceived exertion and increase the level of enjoyment during an isometric fatiguing task, when compared with the provision of false negative feedback (27). A number of studies have reported that positive feedback which emphasized successful rather than unsuccessful performances increased intrinsic motivation (70), self-efficacy (41), and led to reduction in perceived task difficulty (35).

While the described studies found superior performance with positive feedback, it is important to note that they were untrained/recreationally trained participants. To the best of my knowledge only one study has investigated the effects of positive feedback among moderately trained athletes. Stoate et al. (33) investigated how false-positive performance feedback influence running economy compared to no feedback among trained runners. Remarkably, the positive feedback led athletes to run at a given speed while consuming less oxygen compared to their peers in the control group, absent of feedback. Since most studies to date examined the effects of positive and negative feedback on untrained and/or recreationally trained participants, it is unclear if the identified effects will remained when tested with competitive athletes. This is especially so given that competitive athletes are familiar with receiving instructions in training and competition which could influence their response to various feedback interventions compared to untrained participants (71)

CHAPTER 3

COACHING CUES IN AMATEUR BOXING: AN ANALYSIS OF FEEDBCK PROVIDED BETWEEN ROUNDS OF COMEPTITIONS

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3.1 Abstract

Feedback is commonly employed to enhance motor learning and performance. While numerous studies have investigated the causal effects of feedback on motor learning, an analysis of real-time feedback provided during training and competitive sporting environments is lacking. Therefore, the feedback provided by 12 boxing coaches to athletes between rounds of the 2015 Australian Boxing Championships was recorded and transcribed. The feedback statements were then analysed according to three feedback variables that have been shown to be critical for optimizing performance: Attentional focus (external, internal, neutral), autonomy support (autonomy-supportive, controlling, neutral), and feedback valence (positive, negative, neutral). Collectively, 445 feedback statements provided during 25 bouts, of which 14 were won and 11 were lost, were analysed for each of the three categories. Coaches provided on average 8 feedback statements per round. Excluding neutral statements, coaches delivered more internal (15%) compared with external focus feedback (6%), more controlling (53%) compared with autonomy-supportive feedback (6%), and more positive (29%) relative to negative feedback (12%). Furthermore, during winning bouts coaches delivered less internal (12% vs. 19%), less controlling (48% vs. 58%), and more positive (36% vs. 18%) feedback, when compared with losing bouts. These results demonstrate for the

first time the type and frequency of feedback delivered during amateur boxing bouts. While these findings may or may not reflect causal relationships, it is interesting that feedback that has been found to enhance motor performance was more often used during winning rather than losing bouts.

3.2 Introduction

In the field of motor learning, the term augmented feedback refers to information provided by an external source, such as a coach, training apparatus, or video (3, 37). Over the past few years, numerous experimental studies have shown that the effectiveness of augmented feedback (or just feedback) primarily depends on three factors (7), including the type of attentional focus it induces (internal vs. external focus); the extent to which it supports the performer's need for autonomy (autonomy-supportive vs. controlling); and its valence (positive vs. negative). In the following sections, we describe research findings related to these three factors. We then report on a study in which we recorded and analysed, with respect to each factor, the verbal feedback boxing coaches provided to their athletes between competitive rounds of the 2015 Australian Boxing Championships.

3.2.1 Attentional Focus

How feedback directs an athlete's focus of attention has been shown to play an important role for the performance as well as learning of sport skills (1). Specifically, providing instructions that lead individuals to focus on a body part – resulting in an *internal* focus of attention – hinders performance. Conversely, instructions that direct performers' attention to the intended effects of their movements (e.g., a dart hitting a target) – resulting in an *external* focus – enhance performance and learning. For example, focusing on the movement of the wrist during a basketball shot has been found to impair shooting accuracy relative to a focus on the hoop (13). Accuracy in dart throwing has also been improved with an external focus on the dart or target (72, 73). Likewise, force production is affected by the attentional focus. Maximum vertical jump height (e.g., (55)) or standing long-jump distance (e.g., (15)) increased when an external focus was adopted rather than internal focus (and no instructed focus). Discus-throwing performance has been demonstrated to benefit from external focus instructions (48). Also, greater forces were produced with external focus in single joint (45) and multi-joint exercises (74). As exercises are executed more efficiently with an external focus (e.g., on the weight lifted), muscular endurance in trained individuals is reported to increase (44). The benefits of external focus for movement effectiveness (e.g., accuracy, balance) and movement efficiency (e.g., force production, speed, endurance) generalize across tasks, skill levels, and age groups (1).

According to the constrained action hypothesis (54), an internal focus promotes a conscious type of control, causing individuals to constrain their motor system and interfere with automatic control processes. In contrast, an external focus promotes a more automatic mode of control by utilizing unconscious, fast, and reflexive control processes. Several studies have provided evidence for increased automaticity with an external focus by showing reduced attentional-capacity demands (75), high-frequency movement adjustments (76), and reduced pre-movement times, representing more efficient motor planning (77).

The performance advantages resulting from an external focus are often seen immediately (45, 47, 74). Therefore, coaching cues that refer to body parts or movements, for example, during a boxing bout would not be expected to be optimal for the athlete's subsequent performance.

3.2.2 Autonomy-Support

Feedback allowing participants to make choices and exert control over practice environments typically results in enhanced learning and performance, when compared with controlling feedback, absent of choices and/or a sense of control (8, 78). For example, allowing participants to choose when to receive feedback has been found to enhance the learning of movement form in overhand throwing (60), and a serial martial art sequence (23). Similarly, allowing learners to decide on the number of basketball shots to be completed (59), when to view video demonstrations of the skill (26), or the order of balance exercises (20) leads to more effective learning compared with control conditions without choices. Interestingly, even giving individuals choices that are incidental to the task has a positive effect on learning (11).

Autonomy-support also includes providing a rationale, asking for an opinion, or making a suggestion. There is evidence indicating that the type of instructional language (i.e., autonomy-supportive versus controlling) has an impact on motor learning (58). Hooyman and colleagues varied the way in which instructions for performing a novel task (cricket bowling action) were presented. Autonomy-supportive language, that is, instructions that gave the participant a sense of choice (e.g., “When starting the approach of the pitch you may want to cradle and deliver the ball in a windmill fashion so the ball travels over the shoulder and not to an angle or to the side.”), led to superior learning than controlling language that offered little leeway for how to execute the skill (e.g., “When initiating the approach of the pitch you must cradle the ball so it travels in a circular pattern. At the apex of the pitch the ball must be directly over the shoulder. Do not throw it at a side angle.”). Throwing accuracy was higher for the group that received autonomy-supportive rather than controlling language instructions.

Allowing individuals to exercise control over the environment satisfies a basic psychological need for autonomy (e.g., (63, 64)). Supporting performers' need for autonomy has consistently been found to have positive effects on motor learning, independent of which factor the learner is given control over, and the benefical effects on performance are sometimes seen immediately (20). The benefits of autonomy support are robust and generalize across tasks, age groups, populations, etc. (see (56)). It is interesting to note that providing autonomy support also enhances performers' motivation to engage in exercise activity (21). Thus, respecting athletes' need to be autonomous would seem to be important not just in practice or training sessions, but possibly in competitions as well.

3.2.3 Positive and Negative Feedback

Lack of confidence or concerns about one's capabilities are not conducive to optimal performance. Over the past few years, there has been converging evidence that practice conditions that enhance learners' expectancies of future performance result in improved performance as well as more effective learning (e.g., (34, 35, 79); for a review, see (80)). Some of this research has specifically investigated the effects of feedback valence. It has been shown, for example, that feedback emphasizing successful rather than unsuccessful performances enhances motor learning (e.g., (29)). Subsequent studies demonstrated increases in performers' intrinsic motivation (e.g., (70)) and perceptions of competence or self-efficacy (41, 70) resulting from positive feedback. Furthermore, positive social-comparative feedback has been found to enhance movement accuracy (57), performance in a continuous submaximal force production task (27), and balance (28). Importantly, the performance benefits resulting from positive feedback generalize to experienced athletes. In one study, positive feedback improved running economy among trained runners relative to a control condition (33).

Feedback has an influence on individuals' expectancies – which are an important factor in motor performance contexts. Indeed, enhanced expectancies resulting from positive feedback have consistently been found to be more effective for subsequent performance and learning than reduced expectancies resulting from feedback highlighting errors, or even "neutral" control conditions. High performance expectancies appear to prepare the performer for successful movement through diverse effects at cognitive, motivational, neurophysiological, and neuromuscular levels – ensuring what Wulf and Lewthwaite (7) termed *goal-action coupling*. Higher performance expectancies are assumed to serve as protection against responses that would detract from optimal performance, including off-task activity or self-referential thinking (e.g., (81)). That is, enhanced expectancies serve to maintain a focus on the task goal and prevent or reduce a self-focus (or other non-task activity). In contrast, low expectations for a positive outcome, promoted by negative feedback, may act in the manner of a self-invoking trigger (81) and produce performance-related concerns, anxiety, negative affective reactions, and neuromuscular activity that are incompatible with optimal performance (see (7)).

3.2.4 Additive Effects

Interestingly, three recent studies reported that a combination of two of the three factors described above (external focus of attention, autonomy support, positive feedback) led to superior motor learning and performance compared to either one in isolation (36, 82, 83). Each of the three studies was dedicated to the examination of the combined effects of these factors (external focus and autonomy support, external focus and positive feedback, autonomy support and positive feedback) on motor learning, when compared with each feedback type alone and/or a control condition. The result indicated that not only did each factor alone lead to superior learning, but each combination of two factors further increased the learning benefits. Furthermore, a recent study demonstrated that the presence of all three factors resulted in more effective learning than all combinations of two factors (84). These findings are in line with the OPTIMAL theory of motor learning (7), according to which an external focus, autonomy support, and enhanced expectancies for performance contribute – in additive and non-competing fashion – to optimize motor performance and learning.

3.2.5 Present Study

As illustrated, a large number of experimental studies report strong causal effects of described types of feedback on learning and performance. However, to our knowledge only Porter et al. (10) have previously reported the types and frequencies of feedback coaches provide in training and competition. In their study, highly-trained track and field athletes completed a questionnaire about the types of feedback coaches provided, with an emphasis on attentional focus. The authors reported that 85% of feedback provided in training, and 70% in competitions promoted an internal focus of attention, which is not very effective according to the experimental literature. The study provides important initial information concerning the type of feedback provided in real-life sporting environments. However, some limitations of that study, including the use of close-ended questions and the reliance on the athletes' ability to accurately recall the feedback. Also, Porter and colleagues were not concerned with other aspects of feedback, such as those related to its valence or autonomy support. Hence, further investigation is warranted to allow for systematic examination of the gap between factors that have been shown to enhance motor performance in studies and the real-life practices of coaches.

Amateur boxing is a popular Olympic sport in which athletes attempt to score points by delivering fast and forceful punches to their opponents in a tactical and strategic manner (85). Depending on gender, boxing bouts are comprised of 3-4 rounds lasting 2-3 minutes with 1 minute of rest between rounds manner (85). Importantly, during the rest period athletes commonly receive feedback from their coaches in their respective corners. Such feedback is of great importance as it holds the potential to impact punching performance (86) and change the strategy and/or tactics of the athletes in the subsequent round(s). Thus, the sport of amateur boxing is well suited for the investigation of ecologically valid, real-time feedback provided in competitions due to its expected impact on subsequent performance. Accordingly, we sought to record and analyse real-time verbal feedback provided by boxing coaches to their athletes during the rest periods of boxing competitions, and categorize these recordings based on the previously described feedback themes. Furthermore, we sought to investigate if differences exist in the type and frequency of feedback provided by coaches and the outcome of the bout.

3.3 Methods

3.3.1 Participants

During the 2015 Australian amateur boxing championships twelve coaches (11 males and 1 female [age: 42±6]) representing different states in Australia agreed to participate in this study, which was a sample of convenience. Boxing coaches who had athletes compete in this specific event were approached, provided with a verbal description of the study, and then asked if they would be willing to participate. Two coaches did not wish to participate, and those who agreed were provided with a written informed consent. All coaches who participated had over 8 years of coaching experience (range: 8-20) and coached athletes that regularly competed in national level events, and most have also coached athletes that competed in international-level events. The study was approved by the Australian Institute of Sport and Ethics committee and was conducted in accordance with the Declaration of Helsinki.

3.3.2 Experimental Design

An observational single-group design was used to describe the style of verbal coaching feedback used between a coach and athlete during a boxing bout (between rounds). The verbal feedback was recorded with the use of a digital voice recorder (Olympus 4GB VN31PC) and tie clip microphone secured to the lapel or collar of the shirt worn. The recorded coaching feedback provided between rounds was transcribed and then categorized independently by the first (IH) and last (GW) authors. All feedback statements were coded once for each of three feedback categories. Thus, each feedback statement was coded three times (see Analysis).

3.3.3 Statistical Analysis

Prior to the coding procedure, extensive discussions were held concerning the most appropriate ways of analysing the feedback data. After transcribing and reading the feedback statements, the authors decided that analysing each sentence within each of three categories would be the most suitable approach. Pilot scores of the first twenty feedback sentences were completed simultaneously by both coders to ensure inter-rater reliability. This allowed for detailed discussions as to which feedback should be placed within which category, and to develop a strong rationale for the categorisation procedure.

Overall, coaching feedback was recorded from 25 bouts, totalling 57 rounds. Specifically, six coaches were recorded over a single bout; six coaches were recorded twice over two bouts; and three coaches were recorded during three bouts. Of the bouts recorded nineteen bouts included male athletes, and six included female athletes, and 14 bouts were won and 11 were lost. All matches went for the entire duration (i.e., no knockouts occurred). Each verbal feedback recording was transcribed by a single investigator. After transcribing, each sentence was considered as a separate entity, but only if the following cue was different in content to the previous one. The identified feedback statements were independently scored by two investigators once per feedback category: Attentional focus, autonomy support, and feedback valence. Each feedback category included a "neutral" option for situations in which the investigator determined the feedback was different or irrelevant to the specific category. Scoring each feedback statement once per category was based on an initial subset of scoring (20 feedback statements) and observing that there were occasions that the identified feedback was applicable to more than one category. Thus, each feedback statement was coded three times: once in the attentional focus category as external focus, internal focus or neutral; once in autonomy support category as either autonomy-supportive, controlling, or neutral; and once in the feedback valence category as either positive, negative, or neutral. The definitions used for each feedback category are described next,

Statements leading the athlete to focus on a body part or muscle group were defined as internal focus feedback (e.g., "lifts your hands" and "move your feet"). Conversely, instructions leading the athlete to focus on the intended movement effect, including aiming at a target, such as the opponent's body part (e.g., "punch his chin" or "aim for a liver shot"), or an external object such as the ring (e.g., "push off the ground when you punch") or a boxing glove (e.g., "whenever you see her gloves move counter with a hook") were scored as external focus feedback (see Table 3.1 for more examples).

Feedback that involved suggestions, included a rationale or asking for the athlete's opinion, or was generally stated in a way that gave the athlete options, was scored as autonomy-supportive (e.g., "try to avoid leaning on the ropes this round, ok?", and "when working the inside, try to roll under her punches, ok?"). Thus, feedback statements that were phrased as questions allowing athletes to decide whether or not they adopt the recommendations in subsequent rounds were coded as autonomy-supportive. In contrast, feedback that specifically instructed the athletes on a course of action, absent of the possibility of making a choice (e.g., “you need to settle on your legs more” and “start throwing long uppercuts”), was scored as controlling (see Table 3.2 for more examples).

Feedback describing the athlete’s performance, tactics, round scores, abilities, effort, etc. in a positive (e.g., “perfect round, mate, keep it up” and “your punches are all landing perfectly”) or negative manner (e.g., “he keeps catching you with your hands down” and “you are looking messy in the inside”) were coded as such (see Table 3.3 for more examples).

The neutral statement examples provided in each of the three tables (Tables 3.1, 3.2 and 3.3) were considered as such only in view of the specific category. Thus a specific feedback statement could have been considered as neutral in one category, but not in another category. For example, the statement “excellent round” was coded as neutral in the attentional focus category, but as positive in the feedback valence category.

The percentage of feedback provided within each round was calculated by category and score (e.g., positive or negative), and separately for winning and losing bouts. A chi-square test of independence was used to examine differences between the feedback in winning and losing bouts. Statistical significance as accepted at $P \leq 0.05$. All data are presented as mean ± SD counts or as a percentage.

Table 3.1 Examples of Attentional focus feedback provided by coaches between the rounds.

External:	**Internal:**	**Neutral:**
“Long lead to her head.”	*“Chin down, hands up.”*	*“Big work rate, you want to take the next 3 rounds.”*
“If her hands are low, punch high, if her hands are high, punch low.”	*“Toes in and out.”*	*“Back her up as much as you can.”*
“Punch his chest when you go in.”	*“Keep your hands up.”*	*“You need to fire up this round.”*
“Aim your hooks to his body.”	*“This lead hand of yours needs to do more work.”*	*“What are you waiting for? He hasn’t hit you with anything, mate you have to engage to win this fight ok?”*
“You are missing when going for the head, so aim a bit lower, to his chest.”	*“Keep your front foot on the outside.”*	*“You have to start dictating now, you need the next round.”*
“Work on getting that hook to his body.”	*“Go forward on your feet.”*	*“You have got to lead her to the middle.”*
“Come in, hit her body, and then come up to the head.”	*“On the inside let your hands go.”*	*“You have got to be as aggressive as you possibly can this round, ok?”*
“After the right to the body, end with a lead hook over her arms.”	*“You need to settle in your legs, too much falling around.*	*“Throw a second punch after those little punches, ok?”*

Table 3.2 Examples of autonomy-support feedback provided by coaches between the rounds.

autonomy-support:	**Controlling:**	**Neutral:**
"Let's try not and go back too much, ok?" *"Try to drive that straight through his guard if you can."* *"Try a few more liver shots today."* *"If you want to do that then let's switch the tactics – let's pull it in."* *"Put this guy away if you can this round, ok?"* *"When we go 1-2-3 then let's try 1-2-3-4, ok mate?* *"Let's try not and go back too much ok?"* *"How about we go for her body this round?"*	*"Listen – move and jab and use a second attack if it's there."* *"Take a half step back and let your punches go as you come in."* *"Throw a few more punches when working the inside.* *"Hold your ground, stay in the centre of the ring."* *"You have got to win this fight."* *"Stick that back foot out and move off when you are on the ropes."* *"Back her up as much as you can."* *"Follow in on him when he is tired."*	*"It was close round."* *"Breath, buddy, breath."* *"You are judging the distance perfectly."* *"She doesn't like exchanging and locks everything away."* *"You won the first two rounds easily."* *"Your punches are getting on, and he tagged you only once the whole fight."* *"He is just as tired as you."* *"Look at him, he is wide open."*

Table 3.3 Examples of feedback valence provided by coaches between the rounds.

Positive:	**Negative:**	**Neutral:**
"You are scoring good points."	*"You are forcing your punches out as you are out of range; you are probably half a foot out of range."*	*"Look he is wide open."*
"You are doing brilliant, stay in the moment."	*"One thing you're doing wrong – you are throwing your lead punches and then you are falling in."*	*"Faint him when he comes, when he misses get on it again."*
"Going well, keep picking him off and letting those big shots go, I can hear them from here."	*"Keep your hands up a bit; you are getting caught on the way in with your hands down."*	*"When he is coming in bang that left."*
"That was a better round, much better."	*"Don't fall in on him like that."*	*"Move and get your double jab going."*
"You are beating him with your work rate."	*"You are getting caught with little punches you don't need to get caught with."*	*"Draw him in and bring that upper cut."*
"You had a few brilliant attacks in there mate."	*"Listen, last part of the round we lost, too passive when going backwards."*	*"Use a long lead to the head and long rear to the body."*
"You are looking good, looking sharp."	*"The timing of your jab is a little bit out."*	*"Bring that right hand over the top."*
"This is your fight; you are looking 100% focused in there."	*"You need to settle in, too much falling around.*	*"Jab and look for a second attack with your head on the other side."*

3.4 Results

Tables 3.1-3.3 provide examples of feedback in each of the three categories – attentional focus, autonomy support, and feedback valence. The tables include examples from different coaches and from both winning and losing bouts. Within the 25 bouts 445 feedback statements were identified and analysed per category. The average number of feedback statements provided to each athlete per round was 8±2. On a few occasions a feedback statement was scored twice within a given category, for example, if it was partly positive and negative. Specifically, one feedback statement was scored as both autonomy-supportive and controlling, and five were scored as influencing performance expectancies positively and negatively (e.g., "You're punching your way in perfectly and scoring good points, but then you drop your guard and get caught."). The agreement between the investigators was high with only 28 disagreements out of a total 1347 feedback statement scored (2% disagreement rate). In the small number of cases in which disagreement existed, a discussion was held in order to understand its causes. All disagreements were on sentences which were coded as controlling by one of the coders, and as neutral by the other. It was decided to listen to these specific feedback statements again, and determine whether they were stated in a controlling fashion or in a neutral tone. All disagreements were resolved after listening to the feedback statements the second time. Further, out of all feedback statements provided, only 6% (25 of 445) were coded as neutral in all three categories. This statistic demonstrates that most feedback statements were categorized in at least one of the three categories.

Across all bouts, the feedback distribution for attentional focus was 5.8% external, 15.2% internal, and 78.8% neutral (Figure 1); for autonomy support, the distribution was 5.8% supportive, 52.5% controlling, and 41.6% neutral (Figure 1.1); and for feedback valence the distribution was 12.9% positive, 29.0% negative, and 58.0% neutral (Figure 1.2). The observed distribution with respect to attentional focus feedback in winning bouts was

5.2%, 12.4% and 82.2% for external, internal, and neutral, respectively. Coaches in losing bouts implemented 7% more internal feedback (external: 6.6%, internal: 19.4%, neutral: 73.8.5%), but the differences between winning and losing bouts were not statistically different [X^2 (2, N=445)= 4.7, *P*= 0.09] (Figure 1). The observed distribution with respect to autonomy support in winning bouts was 6.7%, 48.8% and 44.4% for autonomy-support, controlling, and neutral, respectively. Coaches in losing bouts implemented 10% more controlling feedback (autonomy-support: 4.4%, controlling: 58%, neutral: 37.4%), although the differences between winning and losing bouts were not statistically different [X^2 (2, N=445)= 3.9, *P*= 0.14] (Figure 1.1). In winning bouts the observed distribution feedback related to the valence of feedback was 36% positive, 12.5% negative, and 51.4% neutral. In losing bouts it was 18.5% positive, 13.6% negative, and 67.7% neutral. The 18% difference in positive feedback between winning and losing bouts was statistically significant [X^2 (2, N=445)= 17.4, *P*< 0.001] (Figure 1.2).

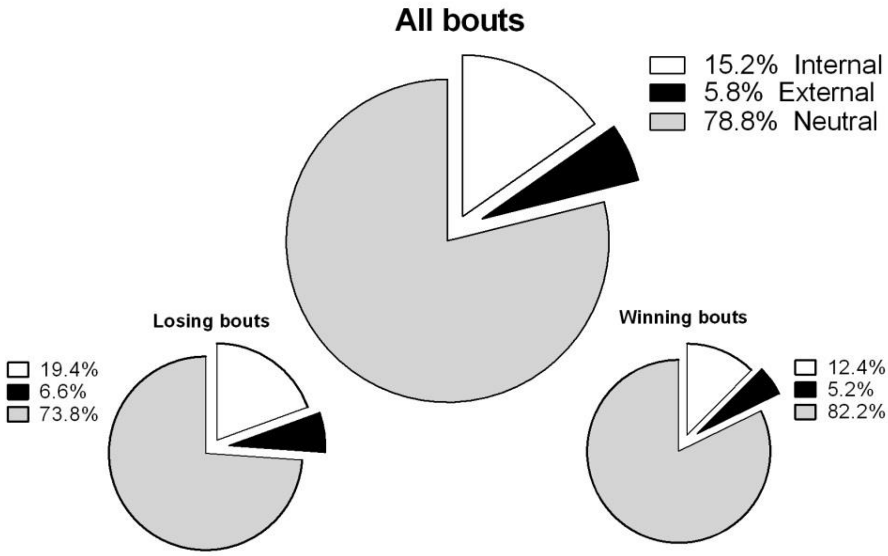

Figure 3.1 Percentage distribution of attentional focus feedback provided by boxing coaches between rounds of comeptitions. The larger, upper pie, represents the feedback

distribution across all bouts from all coaches, irepspective if the bout was won or lost. The samller pie on the right represents the feedback distribution of winnings bouts whereas the left pie chart reperesnts the distribution of feedback delivered in losing bouts.

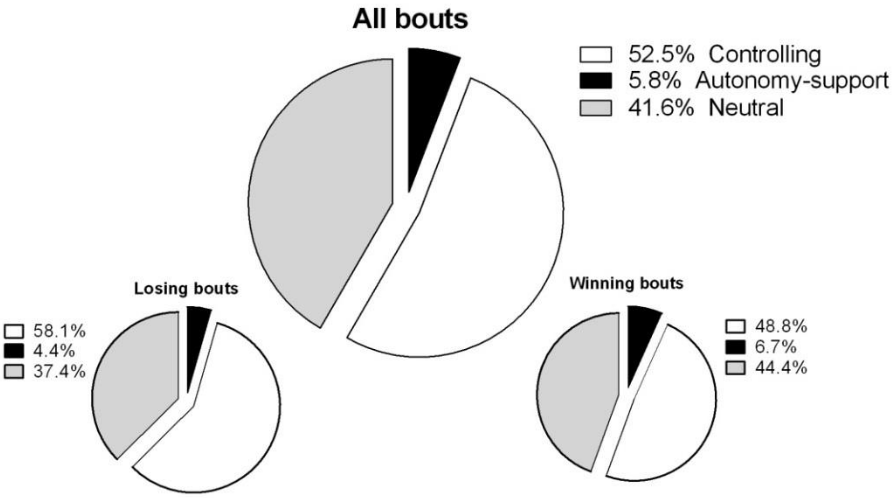

Figure 3.2 Percentage distribution of autonomy-support feedback provided by boxing coaches between rounds of comeptitions. The larger, upper pie, represents the feedback disterbution across all bouts from all coaches, irepspective if the bout was won or lost. The samller pie on the right represents the feedback disterbution of winnings bouts whereas the left pie chart reperesnts the disterbution of feedback delivered in losing bouts.

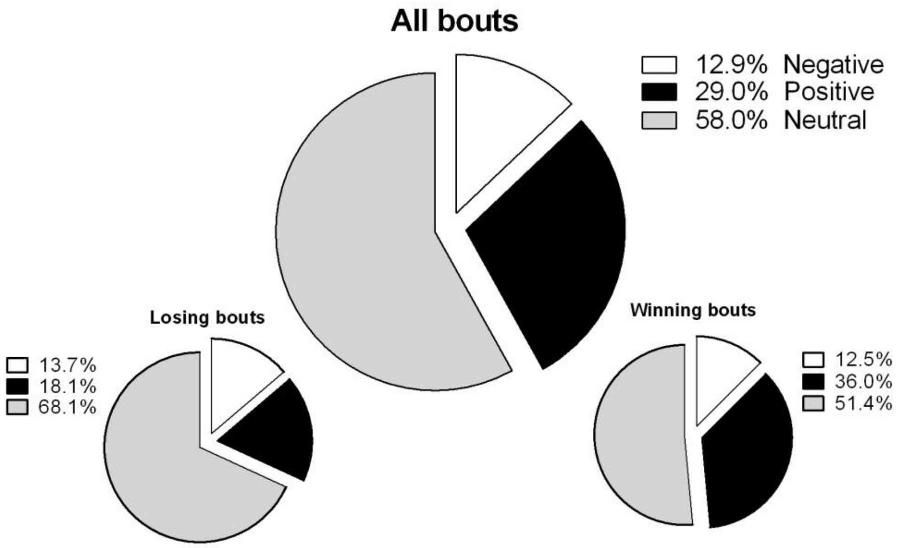

Figure 3.3 Percentage distribution of feedback valence provided by boxing coaches between rounds of comeptitions. The larger, upper pie, represents the feedback disterbution across all bouts from all coaches, irepspective if the bout was won or lost. The samller pie on the right represents the feedback disterbution of winnings bouts whereas the left pie chart reperesnts the disterbution of feedback delivered in losing bouts.

3.5 Discussion

Coaches delivered an average of 8 verbal feedback statements per round, irrespective if it was a winning or losing bout. Excluding the neutral feedback, coaches provided more feedback that promoted an internal (15.2%) compared to an external focus of attention (5.8%), was controlling (52.5%) compared to autonomy-supportive (5.8%), and more positive (29%) compared to negative (12.9%). Moreover, coaches provided considerably more positive feedback in winning bouts (36% vs. 18.6%), compared with losing bouts. Furthermore, despite not reaching statistical significance, coaches in losing bouts provided 7% more internal and 10% more controlling feedback. In the following sections we discuss the results in view of each factor as it relates to the sport of boxing.

Coaches underutilized feedback promoting an external focus relative to that inducing an internal focus. Such use of attentional feedback is in contrast to experimental research and recommendations (1). A large body of evidence demonstrates that external focus instructions or feedback are superior to internal focus and neutral/control instructions, and this effect has consistently been found for different populations, untrained, trained and competitive athletes, numerous different motor tasks (1). Of specific relevance to boxers, Halperin et al. (86) investigated the effects of attentional focus instructions on punching velocity and impact forces among intermediate and elite level boxers and kickboxers. Athletes were asked to punch a punching integrator with maximal effort under three focus conditions: external ("Focus on punching the pad as fast and as forcefully as you possibly can"), internal ("Focus on moving your arm as fast and as forcefully as you possibly can"), and neutral/control ("Focus on punching as fast and as forcefully as you possibly can"). Irrespective of the athlete's level, external instructions led athletes to punch 4% faster and 5% more forceful compared with internal, and 2% faster and 3% more forceful compared with control conditions. While it can be justifiably argued that the punching integrator does not replicate a boxing bout, it does highlight a possible competitive advantage. This is especially the case in amateur boxing in which the winning/losing margins are typically very close and thus a small advantage could be of a considerable value.

Within the present study we found that boxing coaches heavily relied on controlling feedback (52.5%) and implemented little autonomy-supportive feedback (5.8%). This is in direct contrast with expectations based on experimental research demonstrating superior motor performance and learning, as well as exercise behaviour, under autonomy-supportive conditions (8, 78). A recent study examined the effects of self-selected (autonomy-supportive) versus controlling conditions on punching performance with a world champion kickboxer and in a competitive amateur cohort (87). The athlete delivered two sets (rounds) of 12 maximal effort punches to a punching integrator separated by 5 second, over six testing days. In one round the punches were delivered in an order selected by the athlete but in the other round the order was predetermined. Across all days the athlete punched harder and/or faster in the self-selected condition. It is not clear if similar effects would be observed during a boxing match, which is an open dynamic environment and differs to the constrained situation of striking a punching integrator. It is also plausible that the 1-minute time constraint might make it too challenging for coaches to provide relevant feedback allowing the athletes to make choices. Yet, the wording of instructions has been shown to have an impact on performance (e.g., (58)). Thus, this finding highlights a possible discrepancy between the real world practices of coaches in competitions and optimal feedback based on current research findings.

Coaches used positive feedback (29%) more frequently than negative feedback (12.9%), which is in line with literature demonstrating superior learning and performance outcomes with positive compared to negative feedback (e.g., (27, 29, 36, 88). For example, it has been found that providing participants with false-positive feedback about their performance in a submaximal grip test to task failure elicited superior performance in the following test, compared to subjects who received false-negative feedback and even neutral feedback (27). Running economy has also been shown to be enhanced when trained runners received positive feedback about their running efficiency compared to a no-feedback control group (33). Furthermore, highlighting good performances rather than poor ones (29) or providing positive social-comparative feedback (e.g., (20, 27, 28) has been shown to improve the performance and learning of tasks requiring movement accuracy, balance, or force production. The ability to sustain effort, and to move efficiently and accurately, are of importance to the sport of boxing.

A comparison of winning and losing bouts provides some interesting findings. The percentage of external focus feedback provided per round in winning and losing bouts was the same. However, coaches provided more internal focus instructions in the losing compared to winning bouts (12.4% vs. 19.4%). This finding points to a possible relationship between greater usage of internal instructions and the match outcomes. Furthermore, coaches in losing bouts tended to implement more controlling feedback (58%) compared to coaches in winning bouts (48.8%). It can be speculated that controlling feedback reduces the athlete's inclination to attempt alternative tactics developed with experience, which may in turn be successful. Moreover, controlling language undermines self-efficacy and positive affect relative to autonomy-supportive language (58), which is not conducive to optimal performance. Conversely, it is also possible that coaches felt the need to be more controlling in their language when the match was not going in favour of their athletes. Hence, the controlling feedback can also occur as a result of the athlete failing to perform as expected, as indicated by the losing outcome. Finally, it is interesting to note that coaches in both winning and losing bouts delivered a comparable amount of negative feedback (13.7% vs. 12.5%), while coaches of winning bouts provided double the amount of positive feedback (36% vs. 18.6%). Of course, it is not possible to draw conclusions about cause-effect relationships from the present study. Due to its possible important implications, this topic requires further investigation.

To conclude, this study is the first to use recorded real-time feedback provided by coaches to athletes in a stressful and important competitive event. The results are of value as they provide a reference point allowing to differentiate between feedback delivered in real life events, the research findings, and the gap between them. Indeed, it seems coaches do not take full advantage of the possible benefits of certain feedback in competitions. This finding is in line with the report of Porter et al. (10) who examined feedback provided in track and field events and found that coaches frequently use internal instructions despite their negative effects. The results also provide context for future feedback research to be conducted with a greater degree of ecological validity. Importantly, given the design of the present study, it is not valid to draw causal conclusions. Thus, further experimental research should attempt to mimic more ecologically valid environments when manipulating feedback and examine the effects on performance.

CHAPTER 4

THE EFFECTS OF ATTETNIONAL FEEDBACK INSTRCTIONS ON PEAK FORCE PRODUCTION WITH THE ISOMETRIC MID-THIGH PULL

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Halperin I., Williams K., Martin D.T and Chapman D.W. The effects of attentional feedback instructions on peak force production with the isometric mid-thigh pull. *Journal of Strength and Conditioning Research.* 2015; 30, 919-923. (IF= 1.9)

4.1 Abstract

Verbal instructions play a key role in motor learning and performance. Whereas directing one's attention towards bodily movements or muscles (internal focus) tends to hinder performance, instructing persons to focus on the movement outcome, or an external object related to the performed task (external focus) enhances performance. The goal of this study was to examine if focus of performance attention affects maximal force production during an isometric mid-thigh pull (IMTP) among 18 trained athletes (8F & 10M). Athletes performed three IMTP trials a day for three consecutive days. The first day consisted of a familiarization session in which athlete's received control instructions. In the following two days athletes received either control, internal or external focus of attention instructions in a randomized, within-subject design. Compared to an internal focus of attention, athletes applied 9% greater force using an external focus of attention (P< 0.001; effect size [ES]= 0.33) and 5% greater in the control condition (P= 0.001; ES= 0.28). A small positive 3% advantage was observed with an external focus of attention compared to control conditions (P= 0.03; ES= 0.13). Focusing internally on body parts and/or muscle groups during a movement task that requires maximal force hinders performance, whereas focusing on an

object external to the self leads to enhanced force production even when using a simple multi joint static task such as the IMTP.

4.2 Introduction

Verbal instructions have been reported to play a central role in motor learning and performance, and have been shown to have different effects on motor tasks. Specifically, instructions that direct ones attention towards bodily movement and muscles (internal focus of attention; IFA) were found to hinder motor learning and performance (1, 44). In contrast, directing attention towards the movement outcome, or to an external object related to the task (external focus of attention; EFA) tends to enhance motor learning and performance (1, 44). For example, instructing a person to focus on shoulder and wrist motions during a basketball free throw illustrates IFA instructions, whereas focusing on the basket hoop represents EFA instructions. Indeed, fine motor tasks that require accuracy such as a basketball free throw (13) golf shot (39), and dart throws (72) were enhanced with EFA compared to IFA. Similar findings were reported with balance tasks measured by standing on an inflated disc (53) and a Biodex Stability System (42).

Of specific relevance to strength and conditioning professionals, a growing number of researchers are examining the effects of EFA and IFA on activities that require greater levels of force and power generation with the results supporting previous literature (44-46, 49, 50, 55, 89). Movement tasks such as jumping for distance and height (50, 55), shot put throwing performance (89), sprinting starts (49), and the number of completed repetitions in the bench press and squat were all enhanced with EFA compared to IFA (14). However, only two studies have investigated tasks requiring maximal force production. Marchant et al. (45) reported greater elbow flexion net joint torque with EFA (e.g. focus on pulling the strap) compared to IFA (e.g. focus on contracting the arm muscles) when tested with a dynamometer in a constant velocity ($60°·s^{-1}$). In furthering this work, Greig and Marchant (46) investigated the effects of attentional focus (68) instructions during elbow flexion contractions completed in velocities of 60°, 180° and $360°s^{-1}$. Interestingly, the net joint torque remained greater with EFA in slower speeds (60^{o}), but no differences were observed at the faster contraction velocities between EFA and IFA. However, the electromyographic activity of the elbow flexors was lower with EFA in both of the described studies suggesting greater movement efficiency. Thus, although the literature provides some evidence for EFA to be more effective in movements requiring maximal force, the available studies have only been conducted using isolated joint movements, did not employ a control condition, and tested recreationally trained subjects. Hence, further research is required examining the effect of attentional focus instructions on peak maximal forces in multi joint tasks among trained athletes while implanting a control condition as well.

The isometric mid-thigh pull (IMTP) is a commonly used multi joint, maximal force task in which participants are required to isometrically pull a stationary Olympic bar located at the mid-thigh area while standing on a force plate. The IMTP is a reliable test (90, 91) which is regularly used to monitor athletes' progression and to assist in the design of training programs (91-94). The majority of published studies and guidelines emphasize the need to instruct participants to perform the IMTP exercise in a "hard and fast" manner (92-96). Such guidelines are supported by a number of studies reporting optimal force and speed production in various tasks when instructions were provided using this combination of these words compared to each word in isolation (97-99). However, reference to attentional focus instructions in relation to maximal effort isometric tests such as the IMTP is lacking. In fact, some published guidelines suggest that during maximal effort isometric tests "the subject should be instructed to contract as hard as possible throughout the test to ensure that force is maximized" (100). While the "hard and fast" instructions have been shown to be useful, instructing one to “contract” a muscle group may shift the attentional focus inwardly and hinder performance. Accordingly, the purpose of this study was to investigate the effects of EFA, IFA, and control instructions on peak force during the IMTP among trained athletes. In line with previous research conducted, it was hypothesised that EFA instructions would lead to greater peak force compared to IFA and control instructions.

4.3 Methods

4.3.1 Participants

Twenty-two healthy and trained athletes from various sporting backgrounds (Rugby, Judo, Australian football, and athletics) volunteered for this study, with their physical characteristics presented in Table 1. All athletes performed at least three weekly sport training sessions, and had experience with resistance training for a minimum of 2 years consisting of at least two weekly sessions. Other than one athlete none had performed the IMTP test prior to the study. Subjects were provided with a verbal description of the study, which was carefully presented so as to not compromise the design. Informed consent was obtained from each participant or from participant and parent or guardian if under the age of 18 years. The study was approved by the Australian Institute of Sport and Ethics committee and was conducted in accordance with the Declaration of Helsinki.

4.3.2 Experimental Design

The aim of this study was to examine the effects of three different verbal instructions on peak force production in the IMTP in a randomized, counter balanced, blinded, within-subjects study design. Well-trained and motivated athletes performed three maximal effort trials of the IMTP a day for three consecutive days. The first testing day consisted of a familiarization session in which participants received similar control instructions, whereas in the following two days subjects received three types of instructions in randomized counter-balanced order. Detailed information about the three days and instructions are presented below.

All data collection was carried out in a noise sensitive exercise physiology laboratory by the same two investigators, thereby controlling for possible influence of audience and noise effects. Importantly, testing on the second and third occasion occurred at the same time of day (8:00-10:30am) to control for any possible diurnal effects on performance. Participants were also asked to avoid a heavy meal an hour prior to testing, and any type of training before the tests. Subjects were blind to the true goal of the study and were told that the test was conducted to measure the reliability of their force production. During the first testing day subjects were familiarized with the IMTP. They received a detailed explanation on the test, how it should be performed, and the importance of performing it with maximal intent on every trial. Additionally, the athletes were informed about the importance of maintaining a straight gaze during the test thereby eliminating possible vision confounders as a result of the instructions. Athletes performed a standardized warm up which was passed by the same investigator prior to testing. The warm up consisting of 3 min of cycling at a constant intensity on a Watt bike, a series of dynamic stretches of the major muscles groups, a set of 10 body weight squats and push-ups, two 3 s IMTP trials while applying 50% and a trial at 80% of their perceived maximum. Following the warm up, 30 s rest was provided prior to completing the first of 3 maximal efforts, with each contraction lasting 3 s. After each maximal effort athletes were seated for 150 s, they then completed a 3 s 50% of perceived maximum effort warm up trial, rested for a further 30 s and then completed the next maximal effort contraction.

On the first day athletes only received control instructions prior to each of the three maximal effort trials. These control instructions consisted of “focus on going as hard and as fast as you possibly can”. This set of instructions was considered a control condition as no internal or external point of reference was provided to the athlete. On the second and third day athletes repeated the same procedure as in first day with one exception: three types of instructions (control, IFA, EFA) were provided once prior to each of the three maximal trials in a randomized, counter-balanced manner. To further control for a possible order effect, each subject received different order of instructions in each of the testing days. The IFA instructions consisted of “focus on contracting your leg muscles as hard and as fast as you possibly can”. In contrast, the EFA instructions were “focus on pushing the ground as hard and as fast as you possibly can”. Other than the single instructional sentence no other guidelines, encouragement, verbal or visual feedback was provided.

The IMTP was performed in a customised power rack (Crossrig, Aussie Strength Equipment) with the athlete standing on a commercially available portable force plate (9290AD Quattro Jump, Kistler, Switzerland) to record ground reaction forces. The force plate was interfaced with a personal computer via an 8 channel data acquisition system (ADInstruments, Australia) with PowerLab software (ADInstruments, Australia) sampling at 1000 Hz that allows for direct measurement of force-time characteristics (force plate). The ground reaction forces were analysed using PowerLab software and custom macros of the operating software. Prior to all data collection procedures, the force plate was calibrated using a range of known loads. Each athlete's initial positioning was set such that their knee flexion angle ranged between 130-145 degrees, and the Olympic bar height was individually positioned to maintain these joint angles as described elsewhere. (96). Participants were asked to hold the bar shoulder width apart, and individually choose their grip (overhand or mixed grip) which remained constant across the two testing days. Unfortunately, due to undesired movements of the power rack during the IMTP, rate of force development values were not reliable and thus excluded from the final analysis.

4.3.3 Statistical Analysis

The control condition maximal contractions performed on each of the two testing days were analysed using interclass correlation coefficient (ICC) and coefficient of variation (CV). This was done to determine the between day reliability of the athletes, and to assure that the investigated effects are due to the interventions, and not because of inconsistency in performance. A two-way ANOVA with repeated measures (instructions [3] x gender [2]) was used to compare the collapsed mean peak forces across the two days. If the assumption of Sphericity was violated, the Greenhouse–Geisser correction was employed and an LSD post hoc test was used if a main effect was identified. Significance was accepted as $P \leq 0.05$. Cohen *d* effect sizes (ES) were calculated and the magnitudes of these ES were classified using the scale advocated by Rhea (101) for highly trained athletes of <0.25, 0.25-0.5, 0.50-1.0 and >1.0 which were termed trivial, small, moderate and large, respectively. All data is presented as means+SD, as well as 95% confidence intervals (CI) for the mean difference when appropriate.

Table 4.1 Characteristics of the athletes age, height and bodyweight. The data is presented as mean (SD) and range.

	Age (years)	Height (cm)	Weight (Kg)
Males (n= 10)	21±2.6	180±6.3	83±13
Females (n= 8)	24±4	168±7	63±7

4.4 Results

The ICC and CV of the control condition for the peak force was 0.81 and 15% respectively. However, due to variations in peak force production ≥15% between the two testing days, four male subjects were excluded from the final analysis as their values were larger than two standard deviations between testing days in the control condition. This was done to insure that the reported effects are a result of the instructions, and not due to random variability in performance. Excluding these four subjects increased the ICC to 0.95 to and decreased the CV to 6%. It should be noted that other than increasing the ICC and decreasing the CV, the exclusion of the four participants did not change the overall results of the final analysis. Thus, the two-way ANOVA analysis was performed with an n=18. No significant interaction was identified between instructional conditions and gender (P= 0.134) however, a significant main effect was observed for the instructional conditions (P< 0.001) (Figure 2). Peak force production in EFA was significantly 9% greater compared to IFA (P< 0.001; ES= 0.33; CI 95% [114, 280 N]) and 3% greater than control (P= 0.025; ES= 0.13; CI 95% [9, 133 N]). Athletes applied 5% greater peak force in control compared to IFA (P= 0.040; ES= 0.22; CI 95% [42, 209 N]). A gender effect was observed (P< 0.001) with males producing 29% greater force than females across all conditions (P< 0.001; ES= 1.84; CI 95% [496, 1066 N]).

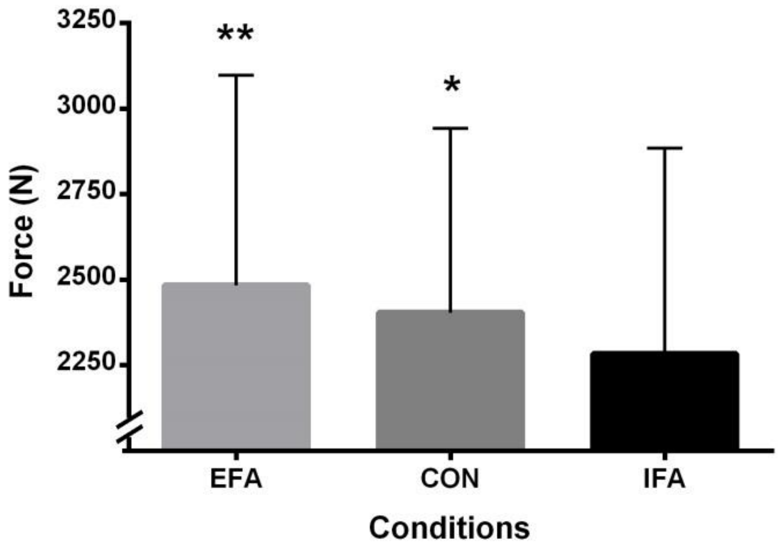

Figure 4.1 Absolute mean (SD) force during three instructional conditions; external focus of attention (EFA), control instruction (CON) and Internal focus of attention (IFA). (**) Illustrates significantly ($P< 0.05$) greater peak force compared to control and IFA. (*) Illustrates significantly ($P< 0.05$) greater peak force between Control and IFA.

4.5 Discussion

We report that IFA instructions lead to substantial decrements in peak force production compared to both EFA (9%) and control (5%) conditions in motivated trained athletes. Furthermore, EFA instructions result in a significantly greater (3%) peak force than control instructions. Considering that the athletes were trained and motivated, and that the IMTP is a reliable and relatively simple test, the 9% difference in peak force output between EFA and IFA is a small meaningful effect. While males were found to be considerably stronger than females (29%), both genders responded to set of instructions in a similar fashion.

The observed outcomes support previously published investigations demonstrating the negative effects of IFA on performance during activities requiring high force and power production. For example, instructing subjects to focus on the vanes of the Vertec device (EFA) led to enhanced jumping performance compared to focusing on the tips of the fingers (IFA) (55). Comparable results were found with horizontal jumps (50). Focusing on exerting force against a loaded barbell (EFA) allowed resistance trained subjects to complete more repetitions in the free weight bench press and squat exercises compared to focusing on exerting force with the legs or arms (IFA) (14). Likewise, focusing on the crank hand bar (EFA) led to greater elbow flexion net torque compared to focusing on the arm muscles (IFA) (45). Lastly, trained athletes were able to throw a shot put further after instructed to focus on throwing the put to a visible target (EFA) compared to focusing on extending their arms rapidly (IFA) (89). Makaruk et al. (89) included a control condition in which subjects were asked to focus on performing the task to the best of their abilities. Similar to the present study, control instructions led to better performance compared to IFA and to slightly inferior results compared to EFA conditions.

The results of the current study are consistent with the *constrained action hypothesis* proposed by Wulf (1, 54). This hypothesis proposes that EFA promotes an automatic motor response that is in line with the desired outcome, whereas IFA directs participants to be conscious of their movement which disrupts the automatic control of the involved motor systems. Particularly, it can be speculated that IFA instructions led athletes to focus on just one component of a complex movement that is typically completed by an integration of many muscles and body parts. Thus, IFA may degrade the overall contribution of other body parts and muscles leading to sub-optimal performance. In contrast, the EFA allowed athletes to organize all the relevant contributors around the task i) without omitting any one of the contributors and ii) allowing of greater automaticity of the movement.

While studies have examined the effect of attentional focusing instructions on maximal force production activities, to the best of our knowledge the present study is the first to investigate this question with the IMTP test. The present study demonstrated the significance of verbal instructions on the performance of this test. Common guidelines on the verbal instructions for the IMTP emphasise the need to perform it “hard and fast”. This guideline is based on a number of studies that have shown better performance with the combination of these words compared to emphasising a single word in isolation (97-99). However, few, if any studies referred to the attentional feedback literature when discussing verbal instructions during the IMTP. In fact, one guideline suggests focusing on contracting as hard as possible throughout the maximal effort isometric test (100). Collectively, IFA instructions should generally be avoided whereas EFA instructions should be favoured during physical performance tests and exercises that require maximal levels of force and/or power, like the IMTP.

The reported results offer practical and relevant information for sports scientists and coaches, which can be applied to learning and maximising performance. The IMTP is a test that requires the application of maximal force and is commonly used to monitor training progress and to design training programs. The results point to the importance of maintaining consistency with verbal instructions across testing days due to their substantial effects on performance even during a relatively simple isometric, complex multi-joint exercise. Specifically, instructing athletes to “contract” a specific muscle group hinders performance and should be avoided, whereas instructing athletes to focus on an external object, enhances performance and should be favoured.

CHAPTER 5

THE EFFECTS OF ATTENTIONAL FEEDBACK INSTRUCTION ON PUNCHING VELOCITY AND IMPACT FORCES AMONG TRAINED COMBAT ATHLETES

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Halperin I., Chapman D.W, Martin D.T and Abbiss C.R. The effects of attentional feedback instruction on punching velocity and impact forces among trained combat athletes. *Journal of Sports Science* 2016; 18, 1-8. (IF= 2.1)

5.1 Abstract

Research indicates that instructing athlete's to focus on bodily movements (internal focus of attention; IFA) may hinder performance, whereas instructing them to focus on the movement outcome (external focus of attention; EFA) often enhances performance. Despite the importance of instructions in striking combat sports, limited research has examined the influence of IFA and EFA on performance in well-trained combat athletes. This study investigated the effects of different instructional cues on punching velocity ($m \cdot s^{-1}$) and normalized impact forces ($N \cdot kg^{-1}$) among intermediate (n=8) and expert (n=7) competitive boxers and kickboxers. Athletes completed three rounds of 12 maximal effort punches delivered to a punching integrator on three separate days. Day one was a familiarisation session with only control instructions provided. In the following two days athletes randomly received IFA, EFA or control instructions prior to each of the three rounds. Athletes punching with EFA were 4% faster and 5% more forceful than IFA ($P < 0.05$), and 2% faster and 3% more forceful than control ($P < 0.05$). Furthermore, experts punched 11% faster and with 13% greater force compared with intermediate athletes ($P < 0.05$). EFA led to a positive effect on punching performance and should be favoured over IFA and control instructions.

5.2 Introduction

Striking combat sports include, but are not limited to boxing, kickboxing and taekwondo. The goal in such sports is to win a bout by scoring points or knocking the opponent out with punches and/or kicks (85, 102, 103). While each striking combat sport has specific physiologic demands, common attributes of successful athletes include the ability to strike hard, fast and repeatedly (85, 104-107). Indeed, Smith et al., (107) found that elite boxers punch with greater impact forces compared to non-elite and novice boxers when measured with a punching integrator. Likewise, it was shown that the average impact forces measured with an embedded accelerometer in a boxing glove during six professional boxing matches was higher among winners, compared with losers (108). Such findings indicate that enhancing punching performance is of importance to striking combat sport athletes, which is commonly achieved through deliberate technical training and strength and conditioning sessions (109, 110).

Verbal instructions can be used as another strategy to enhance punching performance. Specifically, instructing athletes to focus on one aspect of a motor task more so than another can lead to meaningful enhancement or deficit in the outcome measure(s) (1). External focus of attention (EFA) refers to instructing an individual to focus on the effects of the movement in relation to the environment. For example, instructing a person to focus on the hoop during a basketball shot. In contrast, internal focus of attention (IFA) refers to instructing an individual to focus on a specific body part or muscle group during the physical task such as, instructing a person to focus on the movement of their wrist and elbow during a basketball shot. A large number of studies have demonstrated that EFA results in superior exercise performance when compared to IFA instructions (For review see (1)). For example, Marchant et al., (45) found that recreationally trained subjects applied greater elbow flexion net joint torque with EFA (e.g., focus on pulling the strap) compared to IFA (e.g., focus on contracting the arm muscles) when tested with a dynamometer at a constant velocity. Furthermore, movement tasks such as jumping performance (50, 55), agility drills (19), balance drills (42, 53), dart throwing accuracy (73) and golf putting accuracy (111) were all enhanced with EFA among untrained and/or relationally trained subjects.

Despite the accumulating research showing positive effects with EFA, a number of studies have either lacked, or failed to counterbalance the control condition with the other set of instructions (15, 49) thereby not controlling for a possible order effect. A control condition in this context is a set of instructions absent of an internal or external point of reference. It should be noted that the inclusion of a control condition in such research is considered to be of great importance (112). Furthermore, to date, limited research has examined the effects of attentional focus instructions on trained/skilled athletes with those examining performance reporting mixed results (17, 18, 52). In trained/skilled athletes there is evidence for jumping distance (15), shot put throwing performance (89), running (49) and swimming (113) speeds to be enhanced with EFA compared to IFA and control instructions. Conversely, balance performance (18), swimming (17) and sprinting (51) speeds, were observed to only benefit from control instructions compared to EFA, while in one study with trained tennis players agility performance remained unaffected during testing with three focus conditions (control, EFA and IFA) (52). These results suggest that athletes of different levels may respond differently to such instructions.

A limitation of previous research has been a lack of consideration given to the expertise level in the skill to be tested, while the available literature suggests that athletes of different ability levels may respond differently to EFA or IFA instructions. Accordingly, more research is needed to further illuminate if EFA is superior to control instructions, or rather, if its IFA that is hindrance irrespective of the alternative set of instructions, be it EFA or control instructions. Specifically, such research is especially warranted in respect to trained and skilled athletes of different competitive or skill levels. Lastly, despite the prevalence and importance of verbal coaching cues in striking combat sports in both training and competitions, to the best of our knowledge no studies to date examined its influence on striking performance. Accordingly, the purpose of this study is to compare the effects of three sets of instructions (EFA, IFA and control) on punching velocity ($m \cdot s^{-1}$) and normalized impact forces ($N \cdot kg^{-1}$) when tested on four types of punches (lead straight, rear straight, lead hook, rear hook) among intermediate and expert level boxers and kickboxers.

5.3 Methods

5.3.1 Participants

Fifteen competitive boxers and kickboxers volunteered to participate in this study, with their physical characteristics presented in Table 1. Seven athletes were categorised as experts due to their participation in at least one international level competition, and having more than ten bouts. The remaining eight athletes were categorised as intermediate as they had only competed in national level events and participated in a minimum of three and a maximum of ten competitive national level bouts. All athletes trained at least 4 times a week on a regular basis, and between 6 to 10 sessions a week leading up to a competition. Athletes were provided with a verbal description of the study, which was carefully presented so as to not compromise the study design after which each athlete provided written informed consent. The study was approved by the Australian Institute of Sport and Edith Cowan University Ethics Committees.

Table 5.1 Characteristics of the striking combat athletes age, bodyweight and number of competitions in the two groups (experts and intermediate). The data is presented as mean (SD) and range.

	Age (years)	Body mass (kg)	Number of competitions
Expert (n=7; 1 female)	26±3 [24-32]	69±9 [61-82]	43±23 [27-81]
Intermediate (n=8; 2 females)	28±3 [23-31]	73±9 [57-80]	6±2 [3-10]

5.3.2 Experimental Design

Athletes were asked to attend the laboratory on three separate occasions. On the first day they were familiarised with the testing protocol, and on the two subsequent days they completed the experimental sessions (described below). Athletes were required to complete the three testing days within a 10 day period to avoid possible physiological adaptations that may occur due to training, with at least a one rest day between trials. During the familiarising session athletes were introduced to the punching integrator (Figure 1). Athletes received a detailed explanation on the device and how the test should be performed. Specifically, they were asked to punch as fast and as forcefully as they possibly can, while making sure it would simulate a punch thrown in training or competition thereby maintaining a high degree of ecological validity. The punches were delivered in self-initiated manner after the investigator signalled the athletes that the device is recording. Additionally, the athletes were informed about the importance of maintaining a straight gaze during the test thereby eliminating possible vision confounders as a result of the instructions. The starting distance from the punching integrator prior to each punch, as well as punching techniques, were loosely controlled for. That is, only under circumstances in which the distance or the way an athlete punched seemed unrepresentative or unrealistic would the punch be discounted by the main investigator. This ensured each athlete delivered punches with minimal constraint and without detailed guidelines, which may have shifted their attention away from the focus instructions. Note, however, that no punches were discounted. All data collection was carried out in a quiet room by the same investigator.

Prior to testing on each of the three days, athletes performed a self-selected warm up lasting 10 to 15 minutes which included jogging, dynamic stretching, shadow boxing and punching the punching integrator with increasing intensity. The athletes were requested to repeat the same individualized warm up on all three testing days. Thereafter athletes rested for a minute and then completed the first of three rounds of punches. Each round consisted of 12 punches. Specifically, four types of punches were delivered three times each in a set order: lead straight, rear straight, lead hook and rear hook. Based on the results of a pilot study, an a-priori decision was made to only analyse two of the three punches with the greatest impact forces. This decision was made because athletes may occasionally hit the punching integrator off-centre, thereby affecting the recorded impact forces and velocity. Athletes had 5 s rest between each punch. All subjects wore the same 16 ounce boxing gloves (Sting, Australia) during testing and their own hand wraps. Athletes were asked to avoid a large meal two hours prior to testing, and any strenuous exercise on the day of testing.

On the familiarising session athletes only received control instructions prior to throwing the first of the four types of punches. Once prior to throwing the first of three lead straights, once before the first of three rear straights, etc. The frequency and timing of the provided instructions were maintained across the subsequent testing days. The control instruction consisted of “focus on punching as fast and as forcefully as you possibly can”. This set of instructions was considered a control condition as no internal or external point of reference was provided to the athletes. On the two experimental days the athletes repeated the performance procedure as in the familiarisation day but with different instructions. During the experimental trials athletes were given three types of instructions (control, IFA, EFA) in each round in randomized, counter-balanced order. That is, one of the three sets of instructions was provided during one of the three rounds on each day. To further control for a possible order effect, each subject received the three set of instructions in a different order on each of the two experimental sessions. The IFA instructions consisted of "focus on moving your arm as fast and as forcefully as you possibly can". In contrast, the EFA instructions were "focus on punching the pad as fast and as forcefully as you possibly can". The rationale for using these instructions was based on results from a study in which the instructions provided by boxing coaches to their athletes during boxing competitions were recorded and analysed (9). Thus, the instructions used in this study were commonly implemented by boxing coaches in real setting. In addition, we attempted to control for the overall length of the sentences, and to use as many comparable words as possible with the goal of eliminating confounders, such as sentences length and the influence of unfamiliar terminology. Other than the single instructional sentence no other guidelines, encouragement, verbal or visual feedback were provided.

All punches were delivered to a custom built punching integrator (Figure 1), which is mounted vertically and composed of a load cell with an integrated amplifier (AST brand) bolted to a metal plate which is covered with a large foam pad wrapped by leather envelope. The load cell voltage signal is collected by Data Translation 12bit USB data acquisition module using QuickDAQ software (Australia) sampling at 1000 Hz and converted to units of force (N) which were then normalized to the bodyweight of the athletes ($N \cdot kg^{-1}$). The punch velocity ($m \cdot s^{-1}$) was determined by recording the time interval (Agilent oscilloscope) between two phototransistor infrared LED light gates (Vishay) with one gate located 0.01 m from the striking surface and the other 0.05 m. Velocity was then calculated by dividing the distance (0.04m) by the time interval between the two beams being broken. The punching integrator instrument reliability was previously determined as less than 1% for both impact forces and velocity, using a protocol of dropping a pendulum of known weight, and known height, on to the impact surface, on numerous occasions over several months. The high instrument reliability was maintained irrespective of the number of pendulum drops (impacts), time interval between drops, and days between tests.

Figure 5.1 Image of a participant punching the punching integrator device. The punching integrator device collects peak impact punching forces and velocity prior to impact.

5.3.3 Statistical Analysis

The interclass correlation coefficient (ICC) and coefficient of variation (CV) of all punches performed during the familiarisation session were assessed. This was done to determine the between rounds reliability of the punches, and to assure that the investigated effects are due to the interventions, and not because of inconsistent performance, or due to fatigue as a result of the ongoing rounds. Second, a three way ANOVA with repeated measures (instructions [3] x type of punches [4] x level of athletes x [2]) was used to compare the collapsed means of the following two variables: peak normalized impact forces ($N \cdot kg^{-1}$) and velocity ($m \cdot s^{-1}$) across the experimental sessions. If the assumption of Sphericity was violated, the Greenhouse–Geisser correction was employed. A Bonferroni post hoc test was used if a main effect was identified, and paired *t*-tests with Holms-Bonferroni corrections were used if an interaction was found. Significance was accepted as $P < 0.05$. Furthermore, 95% confidence intervals (CI) of the mean differences as well as Cohen *d* effect sizes (ES) are reported when appropriate. The magnitudes of these ES were classified as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (0.80 and greater) using the scale advocated by Cohen (1992).

5.4 Results

Impact forces: The ICC and CV of the peak impact forces between the three rounds in the familiarising session of all punches, and all athletes ranged from 0.85-0.95 and 4-7%, respectively. No significant interaction was observed between instructional conditions and athletes level ($P = 0.177$) for normalized peak impact forces. However, a significant interaction was observed for normalized peak impact forces between instructional conditions and punch type ($P = 0.008$). Compared to IFA, EFA instructions led to significantly greater normalized impact forces across all punch types: lead straight ($P = 0.007$; ES= 0.2; CI 95%: [0.22, 1.33 $N \cdot kg^{-1}$]), rear straight ($P < 0.001$; ES= 0.3; CI 95%: [1.2, 2.5 $N \cdot kg^{-1}$]), lead hook ($P = 0.04$; ES= 0.2; CI 95%: [0.4, 1.9 $N \cdot kg^{-1}$]) and rear hook ($P < 0.001$; ES= 0.3; CI 95%: [1.4, 3.1 $N \cdot kg^{-1}$]) (Figure 3.1). EFA instructions led to significantly greater normalized peak impact force compared with control instructions in the rear straight ($P = 0.007$; ES= 0.17; CI 95%: [0.3, 1.7 $N \cdot kg^{-1}$]) and lead hook ($P = 0.031$; ES= 0.15; CI 95%: [0.1, 1.4 $N \cdot kg^{-1}$]), but not in the lead straight and right hook ($P > 0.1$; ES< 0.05) (Figure 3.1). Superior impact forces were also observed with control instructions compared to IFA with the lead straight ($P = 0.021$; ES= 0.15; CI 95%: [0.1, 1.0 $N \cdot kg^{-1}$]), rear straight ($P = 0.031$; ES= 0.13; CI 95%:

[0.07, 1.66 N·kg^{-1}]) and rear hook (P< 0.001; ES= 0.26; CI 95%: [1.1, 2.88 N·kg^{-1}]), but the lead hook showed no difference (P= 0.131; ES= 0.03) (Figure 3.1).

A significant interaction was observed for normalized peak impact forces between athlete expertise level and punch type (P= 0.038). Expert athletes delivered punches with significantly greater impact forces across conditions compared to intermediate athletes in all punch types: lead straight (P< 0.001; ES= 0.71; CI 95%: [1.6, 4.0 N·kg^{-1}]), rear straight (P< 0.001; ES= 0.88; CI 95%: [3.4, 6.9 N·kg^{-1}]), lead hook (P< 0.001; ES= 0.91; CI 95%: [3.1, 6.2 N·kg^{-1}]) and rear hook (P< 0.001; ES=0.72; CI 95%: [3.2, 7.7 N·kg^{-1}]) (figure 3.3A).

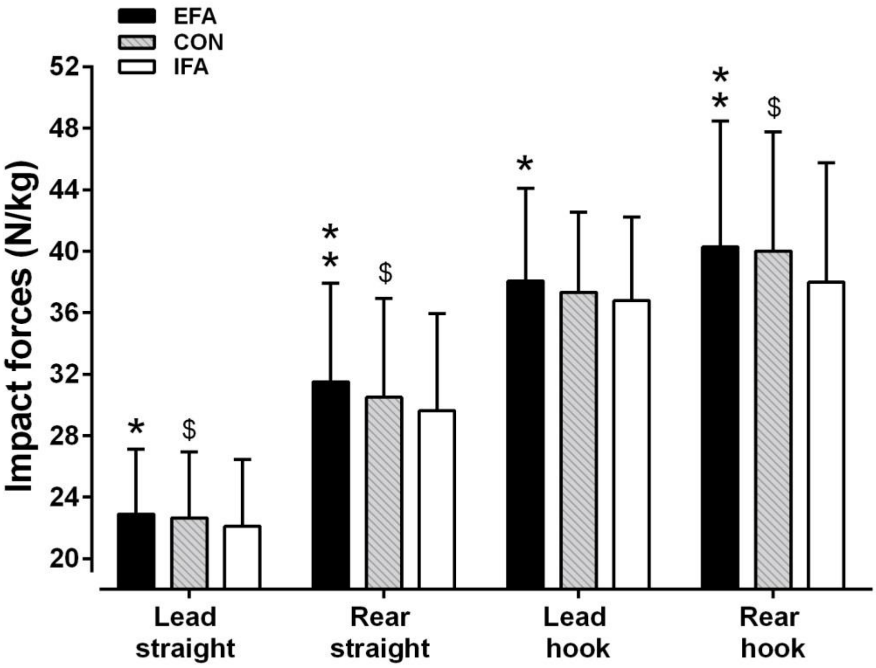

Figure 5.2 The mean (SD) normalized to body weight impact force differences between the three instructional conditions; external focus of attention (EFA), control instruction (CON) and internal focus of attention (IFA). (*) Illustrates significantly (P< 0.05) greater forces with EFA compared to IFA. (**) Illustrates significantly (P< 0.05) greater forces with EFA

compared to IFA and CON. ($) Illustrates significantly (P< 0.05) greater forces with CON compared to IFA.

Velocity: The ICC and CV of the punch velocities between the three rounds in the first testing day of all punches and all athletes ranged from 0.86-0.90 and 4-6%, respectively. No significant interactions for speed were identified (P= 0.165). However, a main effect for instructions (P< 0.001) was observed. Overall, EFA lead to faster delivery of punches compared to IFA (P< 0.001; ES= 0.20; CI 95%: [0.16, 0.47 $m \cdot s^{-1}$]) and control instructions (P<0.001; ES= 0.13; CI 95%: [0.05, 0.31 $m \cdot s^{-1}$]). No differences were shown between IFA and control instructions (P= 0.269; ES= 0.06) (Figure 3.2).

A main effect for athlete level was observed in punch velocities (P< 0.001). Collectively, expert athletes punched faster than intermediate athletes across the four punches (P< 0.001; ES= 1.41, CI 95%: [0.75, 1.64 $m \cdot s^{-1}$]) (figure 3.3B).

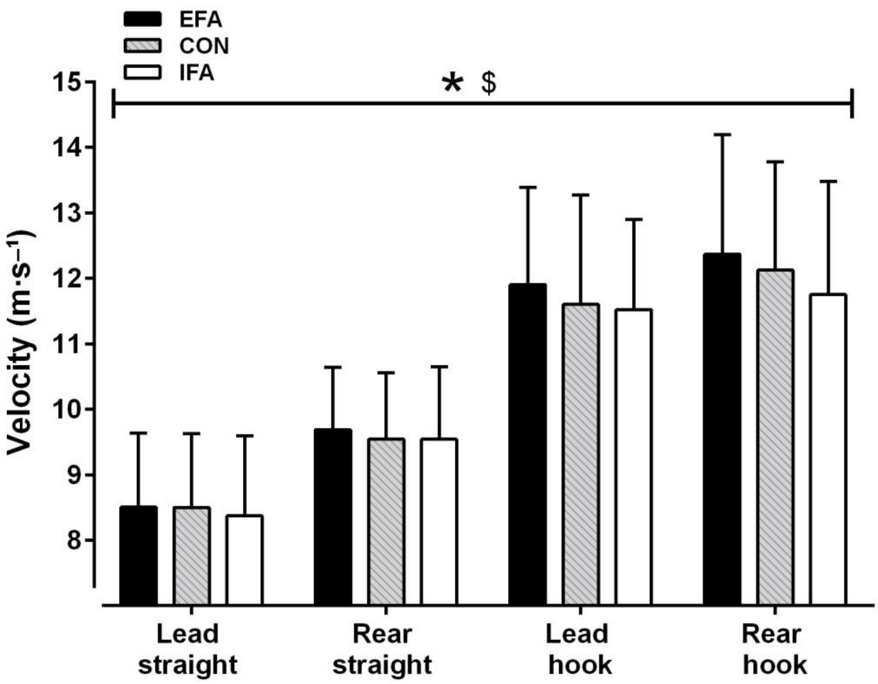

Figure 5.3 The mean (SD) punch velocity differences between the three instructional

conditions; external focus of attention (EFA), control instruction (CON) and internal focus of attention (IFA). (*) Illustrates significantly (*P*< 0.05) greater velocities with EFA compared to IFA. (**) Illustrates significantly (*P*< 0.05) greater velocities with EFA compared to IFA and CON. ($) Illustrates significantly (*P*< 0.05) greater velocities with CON compared to IFA.

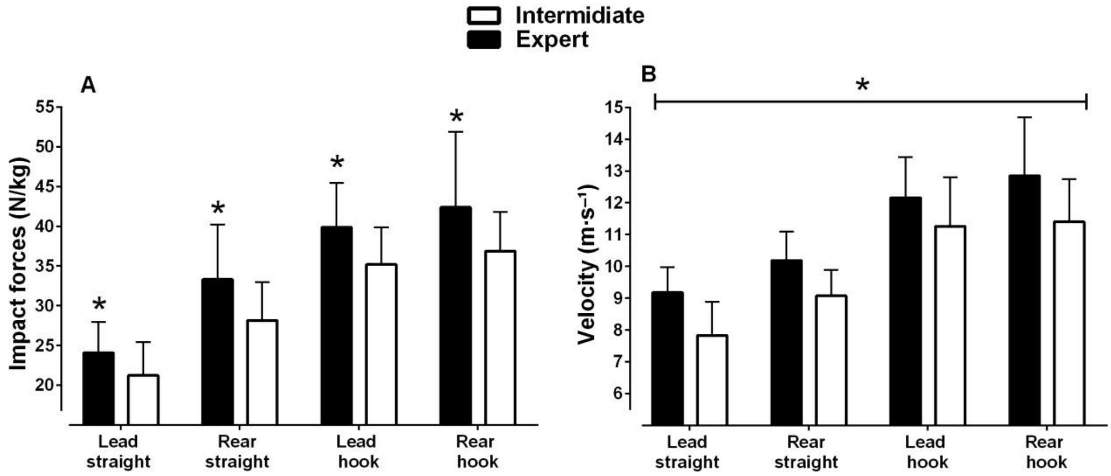

Figure 5.4 The mean (SD) normalized impact forces (A) and punching velocity (B) of expert and intermediate level athletes. (*) Illustrates significant (*P*< 0.05) difference between expert and intermediate athletes.

5.5 Discussion

The purpose of this research was to investigate how attentional focus instructions affect punching impact forces and velocities among intermediate and expert level striking sports athletes. We observed that both expert and intermediate level athletes punched with 5% greater impact forces when receiving EFA compared to IFA, and 3% harder compared with control instructions in two of four punches (lead hook and rear straight). Furthermore, EFA instructions leads to 4% superior punching velocity relative to IFA, and 2% faster compared to control instructions. Additionally, despite no difference in their overall responses to the instructions, expert athletes punched 11% faster and with 14% greater impact forces compared to intermediate athletes. Such findings further supports the notion that punching velocity and impact forces are valuable attributes of striking combat athletes. Despite the growing number of studies examining the effects of attentional focus instructions with skilled athletes, to the best of our knowledge the present study is the first to examine the influence of such instructions on punching performance among competitive combat athletes. This is of particular relevance given that coaches can provide useful instructions to athletes during the rest periods between rounds of striking combat sports competitions (9, 85).

Our results of enhanced performance with EFA compared to IFA and control instructions are in line with most, but not all previous investigations on the topic. Makaruk et al., (89) observed that trained athletes throw a shot put further when asked to focus on throwing the put to a target (EFA) compared to extending their arms rapidly (IFA), and slightly further compared to control instructions. The relevance of this result is the biomechanical similarities between shot put throws and punching, coupled with the use of shot put throws as a marker of explosive strength for boxers (114). Two other studies investigated the effects of attentional focus instruction on lower body power, a quality that has been shown to be associated with the delivery of powerful punches (115). Porter et al., (15) reported that trained athletes jumped further when receiving EFA compared to both IFA and control instructions, and Ille et al., (49) observed faster 10 m sprinting performance among novice and expert runners alike, with EFA compared to IFA and control instructions.

However, not all studies have observed an enhanced performance of skilled athletes with EFA, when compared to control instructions. Indeed, Porter et al., (51) found that trained athletes completed a 20 m running sprint test faster with control instructions compared to EFA and IFA. Furthermore, Bartholomew (52) did not report any difference in performance of a t-test agility test among female collegiate level tennis players. Collectively these findings indicate that the literature is somewhat conflicting in regards to how different level of trained athletes response to attentional focus instructions.

Within the present study both expert and intermediate level athletes responded in a similar fashion to attentional focus instructions, which is in contrast to that reported for swimmers. Intermediate swimmers swam a 25 yard sprint fastest with EFA compared to both IFA and control instruction (113), in contrast, expert swimmers were faster with control instructions compared to EFA and IFA (17) when using the same set of instructions. While most studies conducted with intermediate and expert level athletes do not observe an effect for the athlete skill or competition level, this is not conclusive across the literature, even with outcome measures of relevance to striking combat sports such as sprinting speed, agility and throwing tasks.

Alternatively, discrepancy in the influence of attentional focus instructions in intermediate and expert level athletes in this and previous studies may be due to several methodological differences. First, while any set of instructions can be grouped as EFA, IFA or control, there are numerous variations to such instructions. A particular instruction can be clearer and more relevant to a given participant, thereby influencing the motor outcome, irrespective of the intended focus condition. For example, focusing on an external object of a greater distance enhances jumping performance compared to an object at a closer distance, despite both being categorized as EFA (15). Second, being familiarised with any one of the instructions, or lack of therefore, could also affect the results. Indeed, recently Maurer and Munzert (71) reported enhanced basketball shooting accuracy with familiar, compared to unfamiliar focus condition, irrespective of the focus condition. Considering that most studies implemented different sets of instructions to represent the three focus conditions, the familiarity of the various participants to any one of them could have influenced the overall results. While finally, some studies have not counterbalanced the use of control instructions with EFA and IFA (49, 51), which can further confound the results due to a possible order affect.

Whereas in the majority of the attentional focus literature control and IF instructions lead to comparable effects, in the present study control instructions were superior to IF. A common explanation for the comparable effects is that control instructions naturally lead participants to adopt an IF (1). While this may be the case, it could be that participants naturally adopt an IF that is superior to the IF instructions provided by the investigators. For example, instructing athletes to focus on rotating their trunk when punching may elicit superior performance compared to focusing on the movement of their arm, despite the fact that both instructions lead to IF. Indeed, different types of IF instructions have been reported to vary in their effects (116). Also, compared to IF and EF, control instructions are commonly unspecific and broad. This allows participants greater freedom to choose what to focus on. Depending on the participants' preferences and familiarities, they may focus on alternative task aspects that provide less performance hindrance compared to IF instructions. We also highlight to the reader that in the present study, the control instructions were counterbalanced with the IF and EF instructions. This experimental design approach was not followed by some researchers (e.g., (15, 49), which could confound the results due to a possible order affect.

The results of this study are consistent with the *constrained action hypothesis* proposed by Wulf (1, 54). This hypothesis proposes that EFA promotes an automatic motor response that is in line with the desired outcome, whereas IFA directs participants to be conscious of their movement which disrupts the automatic control of the involved motor systems. Particularly, it can be speculated that IFA instructions led athletes to focus on just one component of a complex movement, in this case the arms, which is typically completed by an integration of many muscles and body parts. Indeed, a powerful punch is speculated to result from of the rotation of the trunk, the drive off the ground by the legs and the arm musculature (109). Thus, it may be that IFA degraded the overall contribution of other body parts and muscles leading to sub-optimal performance. In support of this assumption, a number of studies reported greater muscle activation in the agonist and antagonist muscle groups involved in the motor task in respond to IF compared to EF instructions (45, 55, 117). Such muscle activation patterns, which can result in larger co-contractions values, are expected to be hindrance to motor activities requiring larger power outputs, such as punching. In contrast, the EFA allowed athletes to organize the appropriate contributors to punching performance around the task i) without omitting any one of the contributors and ii) allowing of greater automaticity of the movement.

This study has a number of limitations worthy of discussion. First, while punching velocity and impact forces are of great importance in combat sports, they are usually delivered in combinations rather than as single punches, as delivered in this study. This limitation resulted from a technical software situation which only allowed for single punches to be delivered. Thus, further investigations should seek to examine the topic with punching combinations to increase ecological validity. Second, the sample size of the study was relatively small as recruiting athletes of such competitive calibre is a difficult task due to their rigorous training schedules and limited numbers. However, the limitation of the small sample was mitigated by the experimental design. The investigation included a large number of data points, reflecting 1080 analysed punches which strengthen the observations. Furthermore, the athletes completed a familiarizing session in which the reliability of the punching performance across the three rounds was high. The familiarizing session assisted in reducing the variability in punching performance in the subsequent testing days making the observed effects more robust. Additionally, special attention was also afforded to eliminating confounding variables, such as the number and gender of observers, the time of testing and the intensity of the warm up (for a review see (118)).

The results of this study offer practical and relevant information for striking combat sport coaches and athletes, as well sports scientists who plan to further investigate similar topics. Slight modifications of the instructions had a considerable effect of punching performance among expert and intermediate level athletes. Specifically, instructing athletes to focus on punching an external target as fast and as forcefully as they possibly could lead to superior performance compared to instructing them to focus on moving their arm as fast and as forcefully as they possibly could. A similar, yet smaller advantage was found with external focus compared to control instructions which was absent of internal or external point of references. Thus, external focus of attention instructions should be favoured with boxing in particular, and with explosive whole body movements in general.

CHAPTER 6

THE EFFECTS OF EITHER A MIRROR, INTERNAL OR EXTERNAL FOCUS INSTRUCTIONS ON SINGLE AND MULTI-JOINT TASKS

This chapter was published in 2015 as follows:

Halperin I., Hughes S., Panchuk D., Abbiss C.R. and Chapman D.W. The effects of either a mirror, internal or external focus on single and multi-joint tasks. *Plosone.* 2016 (in press). (IF= 3.2)

6.1 Abstract

The purpose of this study was to investigate how performing in-front of a mirror influences performance in single and multi-joint tasks, when compared with neutral, internal focus (IF) and external focus (EF) instructions. Twenty-eight resistance-trained participants completed two separate experiments. In the first single joint condition, participants performed two maximal voluntary isometric contractions (MVIC) of the elbow flexors in front of a mirror following neutral instructions or without a mirror following IF, EF and neutral instructions. In subsequent multi-joint experiment participants performed counter-movement jumps in the same four conditions as the single-joint experiment. Following both experiments, participants were asked if the mirror condition was perceived as IF or EF. Single-joint experiment: EF led to greater normalized force production compared to all other instructions ($P \leq 0.02$, effect-size [ES]= 0.46-1.31). No differences in force were observed between neutral and mirror conditions ($P= 0.15$, ES= 0.15), but both were greater than IF ($P< 0.01$, ES= 0.79-1.84). Multi-joint experiment: Despite no statistical difference ($P= 0.10$), a moderate effect was observed in which EF led to greater jump heights compared to IF (ES= 0.51). No differences were observed between neutral and mirror conditions (ES= 0.01), but both were greater than IF (ES= 0.20-22). In both experiments the majority of participants

perceived the mirror condition to provide EF. The mirror condition leads to superior performance compared to IF, inferior performance compared to EF, and was equal to a neutral condition in both tasks. This was despite the majority of participants perceiving the mirror to better represent their interpretation of EF. This study expands our understanding of the effects of attentional focus and provides novel and practical information on the effects of training in front of a mirror.

6.2 Introduction

Over the past two decades a large body of research has investigated the effects of attentional focus conditions on motor learning and performance (1, 44). Specifically, the effects of instructions that elicit an internal focus (IF) or external focus (EF) of attention on exercise performance have been commonly compared. IF leads individuals to focus on a specific body part, or muscle group, whereas EF leads individuals to focus on the intended effects of their movements on the environment. Generally, research has found that EF enhances motor learning performance, when compared with IF instructions, and compared to neutral instructions, which are deprived of an internal or external point of reference (1). For example, instructing participants to focus on the movement of their wrist during a basketball shot hinders accuracy, when compared with focusing on the basket (13). Superior performance with EF is observed with tasks requiring large power output, such as long jump (15), sprint running (49), and in tasks requiring maximal force such as single joint elbow flexion (45), and multi-joint exercises, such as the isometric mid-thigh pull (74). While preference for instructions/focus conditions has been shown to have a small effect on performance (119, 120), the benefits of EF are consistent across tasks, skill level, and age groups (1).

Physical training is commonly performed in front of mirrors in numerous environments, such as fitness gyms, martial arts and dancing studios. Despite the mirrors apparent popularity, the studies investigating the influence of mirrors on motor performance report mixed results (121-128). For example, Bennett and Davids (122) observed that novice and intermediate level powerlifters benefited from performing the squat exercise in front of a mirror when asked to descend to a very precise and optimal depth. In contrast, advanced powerlifters remained unaffected by the mirror when completing the same task. Furthermore, while studies have found a mirror improves static balance performance in young (126) and old (127) adults, other investigators have not observed differences between mirror and no mirror conditions (129). In regards to dancing, practicing in front of mirrors enhanced learning and performance of a dance sequence among experienced dancers (123), but hindered dancing performance with untrained participants (124). These experiments highlight the inconsistent findings on the effects of mirror training on motor learning and performance. Furthermore, all of the investigated tasks required movement accuracy, precision and balance, yet many gym goers perform motor tasks that require maximal muscular tension in front of mirrors, such as a barbell squat and biceps curls. However, to the best of our knowledge there are currently no studies which have examined the effects of mirrors on performance during such tasks.

There is also conflicting findings as to the emotions and perceptions elicited when training in front of a mirror. For example, studies have found that exercising in front of mirrors increase self-efficacy (130), have no effect on self-efficacy (131), lead to a self-conscious negative body imagine (132), and elicit negative feelings (133). An analysis of interviews with dancers reported that mirrors may be a necessary tool to improve dancing technique (134). Yet within this study the dancers also stated that mirrors can lead to body objectification due to comparisons of oneself to the image in the mirror. It is interesting to consider that the potential self-conscious response elicited by mirrors is also associated with IF, which is known to hinder motor learning and performance (81). In summary, the relevant literature concerning how mirrors may affect emotions, perceptions, and feelings during physical training is conflicting. Given that mirrors may influence perceptions and emotions as a result of visual feedback during exercise, it is also of interest to understand how exercise in front of mirrors may affect one's attentional focus and overall performance. Finally, since females were the participants in the majority of described studies above, it is of interest to compare the effects of mirrors on perceptions as well as on performance between the genders.

It is plausible that looking at a mirror focuses one's attention to the body part or muscle groups being observed, and elicits IF. Conversely, since the body part being observed in the mirror is external to the self the use of mirrors may elicit EF. Thus we sought to directly investigate this question using a two part study design. Specifically, the goals of these experiments were fourfold: the first was to compare the effects of four sets of instructions: IF, EF, Neutral and Neutral with the addition of a mirror, on maximal voluntary isometric contraction (MVIC) and electromyography (EMG) activity of the elbow flexors, and on countermovement jumping performance. The second purpose was to examine if participants' preference for instructions/focus conditions was matched with their performance outcome, as indicated by previous studies (119, 120). The third was to understand whether the use of a mirror is perceived as either IF or EF by participants by use of a questionnaire. Finally, since most mirror studies used females as participants, a comparison was made between male and female participants since the use of mirrors has a possible gender effect.

6.3 Methods

6.3.1 Participants

Twenty-eight resistance-trained participants volunteered for both experiments (14 males and 14 females, age: 26±5 y, weight: 70±11 kg). All participants had performed resistance training at least twice a week for the past year, and participated in various sporting activities such as soccer, Rugby and Judo once to three times a week. Participants were provided with a carefully presented verbal description of the study, so as to not compromise the study design. Thereafter, each athlete provided written informed consent. The study was approved by the Australian Institute of Sport Ethics Committee and conformed to the declaration of Helsinki for human research.

Participants attended the laboratory on a single occasion with the maximal voluntary isometric contraction (MVIC) single-joint experiment performed first followed by the countermovement jump (CMJ) multi-joint experiment, after which they completed the questionaries for both experiments. On arrival each participant was familiarised with the MVIC testing protocol, and thereafter completed the experimental session as described below. During a 5 minute resting period between experiments each participant was familiarised with the CMJ testing protocol, and thereafter completed the CMJ experimental session as described below.

6.3.2 Experimental Design

6.3.2.1 Single-Joint Experiment

All data collection was carried out in a quiet room by the same two investigators, in which the same investigator provided the instructions to all participants. Participants were informed about the importance of maintaining a straight gaze during all trials (other than the mirror condition) with the goal of eliminating possible vision confounders as a result of the instructions. In an attempt to control for gaze, a large mono-tone boarding was placed in front of participants in both tests to block out potential vision confounders that they may focus on otherwise (Figure 5A).

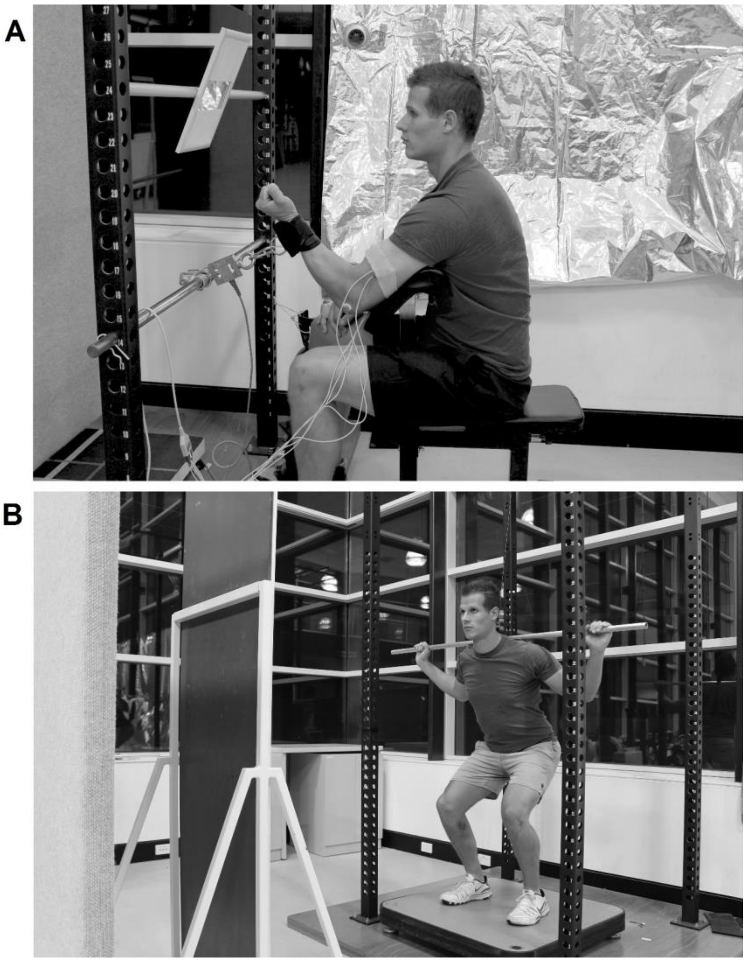

Figure 6.1 Illustrates the research set up in the single (A) and multi-joint (B) experiments.

Prior to initiating the MVIC test, sEMG electrodes were attached to participant's biceps and triceps brachii muscles. Each participant was then seated on the preacher curl bench (RM, China) with the seat height adjusted so that the elbow joint was at a 90° angle during each isometric contraction and a strap was secured around their wrist which was attached to a force transducer (Figure 5A). Participants then performed a warm up consisting of ten elbow flexion contractions at an intensity equal to ~50% of their perceived maximum (work to rest ratio of 2/2 s) and one 3 s contraction at an intensity equal ~80% of their perceived maximum. Thereafter participants rested for two minutes and then completed two baseline MVICs, lasting 3 s, separated by 30 s of rest. Instructions for the baseline contractions were the same as the Neutral instructions which were “Attempt to produce as much force as you possible can”. After completion of the second contraction participants were given two minutes of rest. Participants then received one of four instructions in a randomized order prior to completing two MVICs per condition separated by 30 s of rest. Two minutes of rest were provided between each instructional condition.

The instructions provided to each participant are described in Table 1 for each of the investigated conditions. In the Mirror condition a 0.2 x 0.08 m mirror was installed ~0.6 m away from the participants at eye level (Figure 5A). The size of the mirror was constrained so it only allowed participants to see their elbow flexors contracting. To reduce the possibility of participants focusing on the EMG electrodes, a small skin coloured wrap was placed around them. Other than the single instructional sentence no other guidelines, encouragement, verbal or visual feedback were provided.

Maximum Voluntary Isometric Contraction (MVIC). Subjects were seated on a preacher curl device with their upper arm supported and elbow flexed at 90°. Secured around the wrist was a padded strap attached by a high-tension wire to a load cell (200 kg; Sensitivity = 10.2μV/N, Vishay, Australia) to measure elbow flexion forces. All force data were sampled at a rate of 1000 Hz by a personal computer via an 8 channel data acquisition system (PowerLab, ADInstruments, Australia) operated by Labchart software (ADInstruments, Australia) sampling at 1000 Hz, allowing direct measurement of force-time characteristics. Mean force was determined for all contractions. The mean was determined over a 2-s window defined as 0.5 s after the initiating of the contraction and 0.5 before it ended. Due to the expected large inter-subject variability between genders in maximal force production all mean force values were normalized to the baseline condition, and thus reported and analysed as a percentage.

Electromyography (EMG). Surface electromyography (sEMG) recording electrodes (Viasys, USA) were placed approximately 3 cm apart over the proximal, lateral segment of the biceps brachii and over the lateral head of the triceps brachii. Skin preparation included shaving and cleansing of the area with an isopropyl alcohol swab and allowed to air dry prior to placing of the electrodes. sEMG was collected using a 8 channel data acquisition system (PowerLab, ADInstruments, Australia) with Labchart software (ADInstruments, Australia) sampling at 1000 Hz with a 2 MΩ impedance, common mode rejection ratio >110 dB min (50/60 Hz), and noise >5 μV. A bandpass filter (10–500 Hz) was applied prior to digital conversion. Using the same 2 s window as the force analysis, mean root mean square (RMS) of the sEMG was determined using a window width of 50 ms and then a mean value was calculated selected. Analysis of these values was performed in two separate ways; first, they were normalized to baseline and reported as a percentage and second, the absolute mV Biceps brachii values were divided by absolute mV Triceps brachii to provide a co-contraction ratio.

6.3.2.2 Multi-Joint Experiment

The warm up for this experiment included low-intensity cycling for 5 minutes, followed by 5 minutes of self-selected dynamic stretching. Participants were positioned on a force plate while holding a lightweight (0.4 kg) aluminium bar across their shoulders. As an extension of the warm up, participants completed 10 submaximal CMJ equal to ~50% of their perceived maximal height, and then one CMJ equal to ~80% of their perceived maximum. The instructions provided to each participant in this experiment are described in Table 1 for each of the investigated conditions. In the Mirror condition a 1.76 by 0.56 meters mirror was placed ~2 m away from the centre of the force plate (Figure 5B) whereas in all other conditions a large mono-tone boarding was placed in front of participants to block out potential vision confounders. In contrast to the more controlled routine of the single-joint experiment in which participants could only see their elbow flexors, in this experiment participants were free to choose what they would look at in the mirror. Other than the single instructional sentence no other guidelines, encouragement, verbal or visual feedback were provided. Finally, after the completion of this experiment, participants answered a questionnaire on their preferred instruction and reported if the neutral-mirror instruction elicited a stronger EF or IF response for both the single and multi-joint experiments (see below).

Countermovement jumps. The countermovement jump (CMJ) trials were completed on a commercially available portable force plate (9290AD Quattro Jump, Kistler, Switzerland). Additionally, a single linear position transducer (Ballistic Measurement System, Fitness Technology, Adelaide, Australia) was mounted directly above the participant and utilised to directly measure displacement via a tether attached to the centre of the aluminium pole held by the participant across their shoulders during each CMJ trial. The force plate and a linear position transducer were synchronised and interfaced with a personal computer via an 8 channel data acquisition system (PowerLab, ADInstruments, Australia) with Labchart software (ADInstruments, Australia) sampling at 1000 Hz, allowing direct measurement of force-time characteristics. Ground reaction forces and linear position transducer were analysed using Labchart software and custom macros. Prior to all data collection, the force plate was calibrated using a range of known loads and the linear position transducer was calibrated using a two point calibration process and a known distance. The utilisation of the aluminium bar across the shoulders eliminated arm swing from the movement and thus our outcome measures provide a reflection of only lower body performance capabilities and not the general vertical jumping capacity. Due to the expected large inter-subject variability between genders in maximal jump height, and due to a possible order effect resulting from completing a repeated number jumps, all mean maximal jump values (cm) were normalized to baseline condition, and thus reported and analysed as a percentage.

6.3.2.3 Common Procedures

Questionaries. Participants answered a two part questionnaire after the completion of the multi-joint experiment. Participants were asked to rank the four listed instructions in accordance with their preference for eliciting their best performance, with 1 being the most preferred and 4 being the least preferred. Participants were then asked to report if the mirror instructions were perceived as more of an IF or EF. This was achieved by having participants mark a line over a 20 cm horizontal line which had EF instructions listed on the left side, and IF instructions on right side. The distance of the drawn vertical line from the midpoint was then measured with a ruler to provide a quantification of how strongly a participant rated the mirror condition as either IF or EF.

6.3.3. Statistical Analysis

In the single joint experiment the data from each of the MVCs completed in each of the five conditions were averaged and used for further analysis. A two-way ANOVA with repeated measures was used to compare the mean normalized forces and EMG activity, between the four conditions, and to investigate if a gender effect exists (instructions [4] x gender [2]). An additional two-way ANOVA with repeated measures was used to compare the order of preferences on normalized force production, and to investigate if a gender effect exists (instruction preferences [4] x gender [2]) on normalized force production. If the assumption of Sphericity was violated, the Greenhouse–Geisser correction was employed with an LSD post hoc test if a main effect was identified. In the multi-joint experiment the data from each of the CMJs completed in each of the five conditions were averaged and used for further analysis. Using a similar statistical approach as in the single joint experiment a two-way Analysis of Variance (ANOVA) with repeated measures was used to compare the mean jump height, peak vertical concentric force and peak concentric velocity, between the four conditions, and to investigate if a gender effect exists (instructions [4] x gender [2]). An additional two-way ANOVA with repeated measures was used to compare the order of preferences on jump height, and to investigate if a gender effect exists (instruction preferences [4] x gender [2]) on jump height. Statistical significance was accepted as $P < 0.05$. Furthermore, 95% confidence intervals (CI) of the mean precent differences and Cohen *d* effect sizes (ES) were reported when appropriate. The magnitudes of these ES were classified as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (0.80 and greater) using the scale advocated by Cohen (135).

6.4 Results

6.4.1 Single-Joint Experiment

The mean (±SD) absolute force (N) produced in the MVIC in each of the conditions were: EF (268±74 N), IF (240±72 N), Neutral (260±74 N), Mirror (255±72 N) and IF (240±72 N). In this experiment a main effect for instruction type was identified ($P < 0.001$), however no significant interactions were identified between gender and instruction ($P = 0.741$). Specifically, participants produced significantly greater normalized mean force in EF compared to IF ($P < 0.001$; ES= 1.31; CI 95% [6.3, 15.6%]), Neutral ($P = 0.028$; ES= 0.46; CI 95% [0.5, 6.3%]) and Mirror ($P = 0.017$; ES= 0.67; CI 95% [0.9, 8.9%]). When compared to IF, greater normalized force was produced in the Neutral ($P = 0.001$; ES= 0.98; CI 95% [4, 11.2%]), and Mirror conditions ($P = 0.001$; ES= 0.79; CI 95% [2.7, 9.3%]), however, no differences were observed between Neutral and Mirror conditions ($P = 0.392$; ES= 0.14; CI

95% [-2, 5.1%]) (Figure 5.1A). No significant differences were discerned between the four conditions in normalized sEMG activity of biceps brachii ($P \geq 0.972$), triceps brachii ($P \geq 0.588$), or co-contraction ratio (absolute mV activity of biceps brachii/ triceps brachii) ($P \geq 0.979$). The lack of statistical significant sEMG differences were accompanied by small effect sizes (ES≤ 0.12).

There were no significant interactions ($P = 0.445$) or main effects ($P = 0.226$) for the participants' (n=25) preferences of instructions on normalized force production (Table 2). That is, the most preferred instruction did not elicit greater force production compared to the least preferred. However, there was a moderate effect (ES= 0.32) for the greatest forces to be associated with the most preferred (EF), compared with other instruction. No differences were seen between the 2^{nd}, 3^{rd} and 4^{th} ranked instructions (ES≤ 0.01). The strength of the participants' perception of how the mirror instructions compared to IF and EF is illustrated in Figure 5.2A. It can be visually observed that although two participants strongly perceived the Mirror instruction to be IF, the majority of participants perceived the instruction to more strongly represent their interpretation of EF.

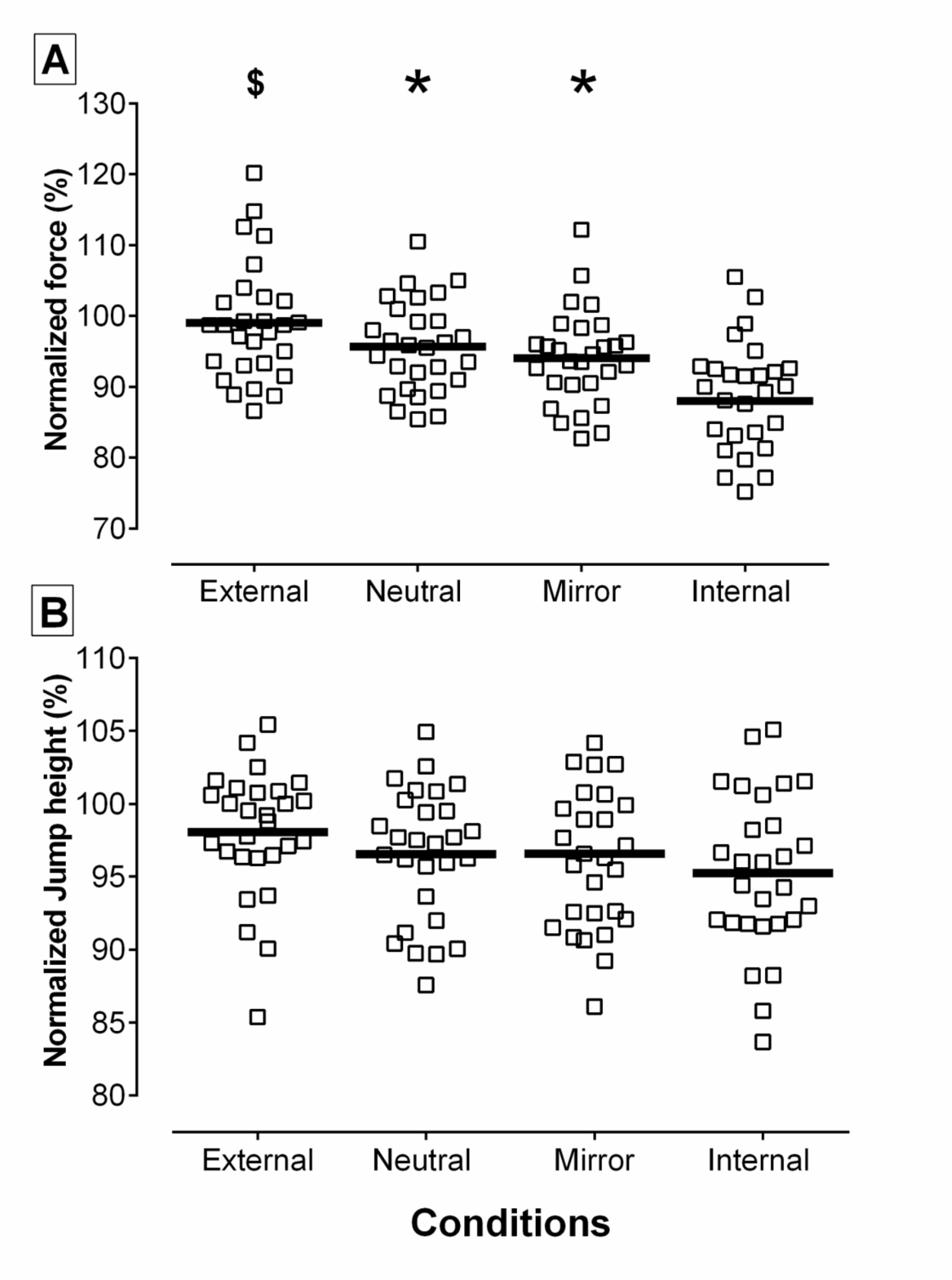

Figure 6.2 Normalized maximal voluntary isometric contraction MVIC forces in the single-joint experiment (A) and countermovement jump heights in the multi-joint experiment (B). Note: each square represents data from a single participant and the black horizontal lines represent the group average per condition.

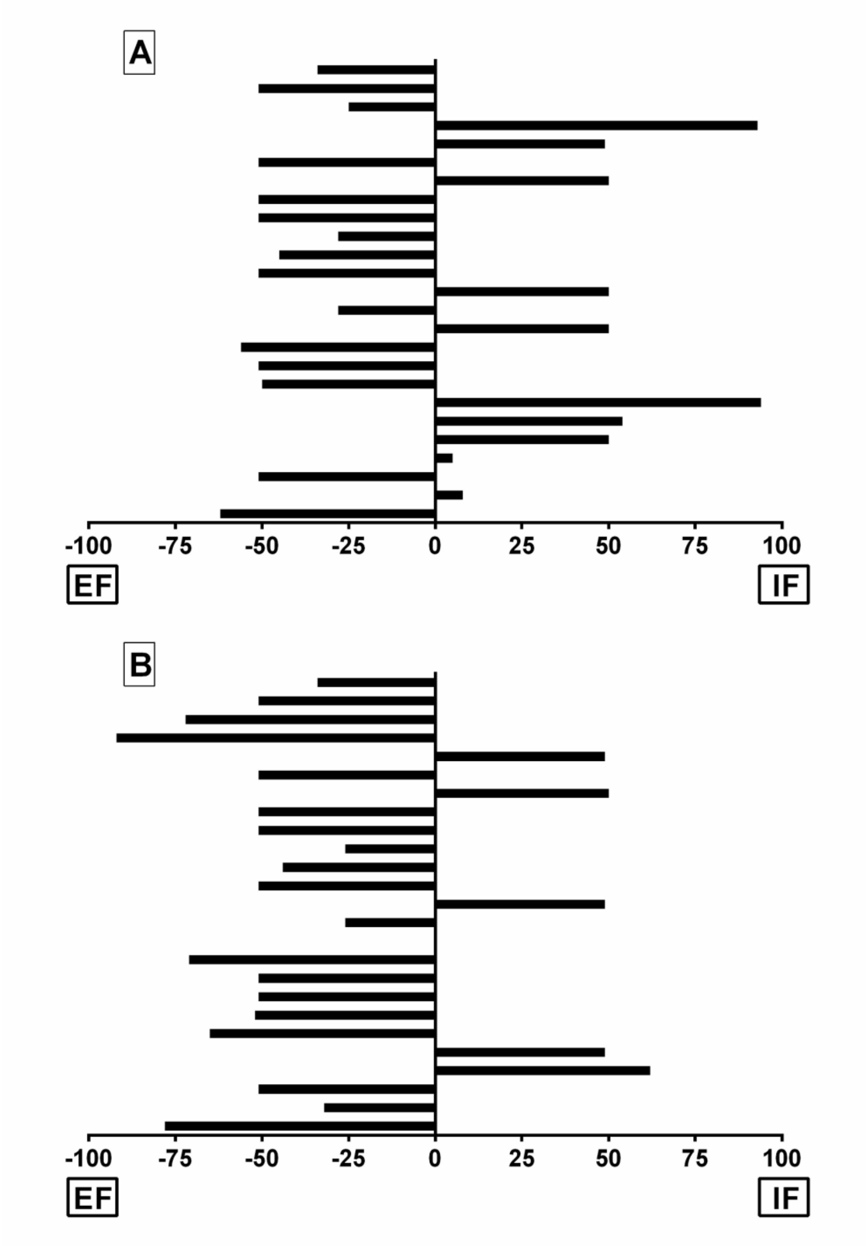

Figure 6.3 Strength of the participants' perception of how the mirror instructions compared to IF and EF in the single-joint (A) and multi-joint (B) experiments.

6.4.2 Multi-Joint Experiment

The mean (±SD) absolute jump heights for all conditions were as follows: EF (38.2±7.4 cm), Neutral (37.6±7.6 cm), Mirror (37.7±7.9 cm) and IF (37.2±7.0 cm). No significant interactions between gender and instructions (*P*= 0.346), or a main effect for instructions were identified (*P*= 0.101). However, despite the lack of statistical differences, the results of this experiment followed a similar pattern to the single-joint experiment in which EF led to greater jump height compared to IF (ES= 0.48; CI 95% [0.36, 4.3%]) and to slightly higher jump heights compared to Neutral (ES= 0.27; CI 95% [-0.41, 3.0%]) and Mirror conditions (ES= 0.26; CI 95% [0.36, 4.3%]) (Figure 5.1B). No differences were observed between Neutral and Mirror conditions (ES= 0.01; CI 95% [-1.81, 1.92%], but compared to IF, slightly greater jump heights were observed with both Neutral (ES= 0.22; CI 95% [-0.46, 2.90%]) and Mirror (ES= 0.20; CI 95% [-0.57, 3.21%]) conditions. No significant or meaningful differences were identified between the four conditions for normalized peak force (*P*≥0.402), mean force (*P*≥0.670) and mean velocity (*P*≥0.447). The lack of significant differences was accompanied by small effect sizes (ES≤ 0.19). However, peak velocity was statistically significant between conditions (*P*= 0.018) with EF resulting in greater peak velocities compared to IF (*P*= 0.01; ES= 0.19; 95% [0.015-0.108 ms^{-2}) and compared to Mirror (*P*= 0.02; ES= 0.13; 95% [0.007-0.092 ms^{-2}). The Neutral instructions lead to significantly greater peak velocities compared to Mirror (*P*= 0.014; ES= 0.12; 95% [0.010-0.085 ms^{-2}) and IF (*P*= 0.037; ES= 0.17; 95% [0.004-0.116 ms^{-2}).

There were no significant interactions (*P*= 0.680) in participant instruction preferences (n=25) (Table 2), however, a main effects for conditions (*P*= 0.038) was identified. The differences between the most and least preferred instructions were not matched for jump height performance. That is, jumping performance did not follow the rank of preferred instructions. The third most preferred instruction elicited greater jump heights compared to all other preferences. Specifically, significantly greater jump heights were found compared to the second most preferred instruction (*P*= 0.029; ES= 0.43; CI 95% [0.5, 4.2%]), the fourth (*P*= 0.028; ES= 0.52; CI 95% [0.3, 4.9%]). The visual interpretation of the participants' perception of how strongly the mirror instructions compared to EF or IF (Figure 5.2B), would support the observation that participants perceived the mirror instruction to be EF to a greater extent than IF as a representation of their interpretation.

Table 6.1 Instructions provided to each participant in the single and multi-joint experiments for the Internal Focus (IF), External Focus (EF), Neutral (N) and Mirror (M) investigation conditions.

Single-joint		
	IF	Attempt to produce as much force as you possible can while focusing on contracting your arm muscles as hard and as fast as you can
	EF	Attempt to produce as much force as you possible can while focusing on pulling the strap as hard and as fast as you can
	N	Attempt to produce as much force as you possible can
	M	Attempt to produce as much force as you possible can while looking at yourself in the mirror
Multi-joint		
	IF	Attempt to jump as high as you can while focusing on contracting your leg muscles as hard and as fast as you can
	EF	Attempt to jump as high as you can while focusing on pushing of the ground as hard and as fast as you can
	N	Attempt to jump as high as you can
	M	Attempt to jump as high as you can while looking at yourself in the mirror

Table 6.2 Participants preferences of the four instructions in both experiments.

	Preference rankings	External	Neutral	Mirror	Internal
Single-joint					
	1st	12	3	5	5
	2nd	6	5	8	6
	3rd	7	5	6	7
	4th	0	12	6	7
Multi-joint					
	1st	15	2	5	3
	2nd	3	9	3	10
	3rd	5	7	7	6
	4th	2	7	10	6

6.5 Discussion

The primary goals of the two experiments were to examine how performance of an isometric single-joint, and a dynamic multi-joint tasks would be affected by performing in front of a mirror; and compare the mirror performance results to the well investigated EF and IF instructions. As expected, elbow flexion forces and jump heights were greatest with EF and the lowest with IF. Furthermore, in both studies performance in the Mirror conditions were comparable to the Neutral condition. That is, both the Mirror and Neutral conditions were lower than EF but greater than IF. The secondary goals of these experiments were to investigate if participants' preferences of instructions match their performance; to descriptively analyse if participants perceived the mirror as EF or IF; and examine if gender effect would be observed. The stated preferences of instructions were not matched with either elbow flexion forces or with jump performance; the majority of participants perceived the mirror to elicit an external focus, although the strength of perception of the mirror differed widely between participants and experiments. Finally, no gender effect was observed in either experiment.

The differences in performance observed in this study are aligned with previous work, in which EF leads to superior performance and IF results in inferior performance (1). Furthermore, within this study the mirror condition did not result in a meaningful reduction or improvement in performance. These results support some (129, 132), but not all (127, 128), studies investigating the effect of mirrors on motor activities. Note that the majority of studies to date that have investigated the influence of a mirror on performance during a motor task have compared it solely to a Neutral condition (122, 124, 126, 129). In contrast, in the present study, the use of a mirror was also compared to EF and IF conditions which extends our understanding of how mirrors affect performance in a relation to the well-established focus conditions. Further, while previous mirror studies have investigated outcome measures such as balance (127), accuracy (128) and movement economy (125), to our knowledge no study investigated a maximal force and jumping tasks as in the present study. Investigating such tasks is important as both trained and untrained participants commonly perform resistance training exercises in front of mirrors in gym environments. While the presence of a mirror may be of value in movement tasks requiring accuracy, such as squat depth assessment (122), our study indicates that the mirror does not provide meaningful benefits in activities requiring maximal force and in jumping performance. Interestingly, sEMG of both the agonist and antagonist muscle groups did not differ between any of the conditions in the single-joint experiment which is in contrast to previous attentional focus research on the elbow flexors (45, 46). These contrasting findings may in part be due to differences in signal normalisation techniques or the use of isometric contractions in the present study whereas the two previous studies implemented dynamic contractions.

The results from both experiments indicate a lack of relationship between the preference of instruction and performance outcomes. That is, irrespective of how participants ranked their preferences for the four instructions in both studies, force and jump height remained unaffected. This supports the previous work of Wulf et al., (16), in which a balance task was completed with fewer errors with EF irrespective if participants preferred IF or EF. Other authors have reported that participants' preferences of IF and EF influence their performance to some extent in tasks requiring accuracy, such as dart throwing, billiards and basketball throws (119, 120, 136). However, within the studies investigating the relationship between attentional instructions and participants preferences, the benefits of EF persist despite situations where use of a non-preferred focus condition was imposed. That is, performance of participants who preferred EF but were asked to use their non-preferred IF suffered to a greater extent compared to those who preferred IF but were asked to use their use non-preferred EF (119, 120, 136). Thus, while preferences of focus conditions can account for some of the effects on performance, it seems as if performance is affected to a greater extent by the type of focus instruction adopted.

Similar to other studies (16, 119), participants in both experiments generally ranked EF as their most preferred focus conditions (Table A and B). The participants in the present study reported a considerable range of perceptions regarding the degree to which the Mirror condition elicited IF and EF (Figure 5.2). This observation is interesting as mirrors can be expected to either; 1) elicit a self-conscious response and thereby lead to IF, or 2) to shift participants focus away from themselves as they observe the mirror and thereby elicit an EF. We speculate that the variation of individual response may be reflective of training and life experiences. Future investigations should seek cohorts of participants that could be initially classified on sporting skill level or experience in an environment to continue to refine our understanding on the use of mirrors as an instruction focus tool.

The *constrained action hypothesis* proposed by Wulf et al. (54) provides an explanation of our observed differences in performance between EF and IF in both experiments. In this regard, it is hypothesized that EF allows participants to self-organize in an automatic manner and perform the task unconstrained by conscious control. Conversely, IF disrupts the automaticity of performance, making participants conscious of their movements. Although not overtly evident in the single joint experiment, performing an MVIC required participants to stabilise and synchronise their shoulder and trunk muscles as they performed the contraction. The requirement to synchronise and coordinate numerous body parts and muscle groups to elicit optimal performance is more evident in the multi-joint experiment. Thus, we speculate that IF leads participants to focus on a single component of a complex movement task, which reduces the contribution of other body parts and muscle groups, thereby hindering performance. In contrast, EF allows participants to organize the relevant contributors around the motor task without neglecting any one of the contributors in a more natural organisation of the motor pathway.

Our observation that the mirror condition was more neutral in the performance effect cannot be neatly explained by the *constrained action hypothesis.* However, given the inter-individual perception of the mirror condition as either IF and EF, we speculate that the *constrained action hypothesis* can account for both the negative and positive effects as a function of the mirrors perception as IF or EF. In cases in which the mirror elicits a negative effect then the use of a mirror is inducing a partial IF response, while in contrast, when participants focus on what they observe in the mirror as external to the self, a partial EF response results. Future studies should utilize specific IF and EF instructions as participants observe their movement within a mirror to enhance our understanding of the *constrained action hypothesis*.

It would be remiss if we did not consider the impact of our imposed experiment design constraints on the observed outcomes. An important consideration within this study was our decision to not counterbalance the order of the two experiments due to logistical constraints which could have led to an order effect or bias of participants' expectations. While we did seek to compare the magnitude of response between conditions, the smaller effect sizes observed in the multi-joint experiment could be related to the order in which the experiments were conducted. There is also the possibility that participants did not receive adequate familiarization with the motor tasks. Particularly, there were some inter-individual differences related to participants experience with the jumping task. These experience differences between participants could partially account for the smaller effects observed in the second experiment. Finally, the preference questionnaires for both experiments were conducted only after the completion of the multi-joint experiment. Thus, this elapsed time between the completion of the single-joint experiment and the questionnaires completion could have somewhat skewed the results. However, not doing so would have compromised the efficacy of the second experiment.

We have reported that EF leads to superior performance in both a single and multi-joint tasks compared to all conditions, and that IF leads to inferior performance in such tasks. The Mirror condition led to inferior performance compared to EF, superior performance compared to IF and was comparable to the Neutral conditions. A lack of relationship between participants' preferences of instruction type to performance outcomes was observed, as well as a wide range of responses pertaining to how the Mirror condition was perceived in relation to IF and EF. Finally, the effects were similar between males and females. We emphasised internal validity in the single-joint experiment and external and ecological validity in the multi-joint experiment. Since the results followed a similar pattern in both experiments, we consider these findings to be robust. These results are of practical relevance giving the popularity of training in front of mirrors in studios and gyms, and also expand our understanding as how focus conditions influence performance.

CHAPTER 7

CHOICES ENHANCE PUNCHING PERFORMECNE OF COMPETITVE KICKBOXERS

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Halperin I., Chapman D.W., Lewthwaite R., Martin D.T. and Wulf G. Choices enhance punching performance of competitive kickboxers. *Journal of Psychological Research* 2016 (in press). (IF= 2.7)

7.1 Abstract

While self-controlled practice has been shown to enhance motor learning with various populations and novel tasks, it remains unclear if such effects would be found with athletes completing familiar tasks. Study 1 used a single case-study design with a world-champion kickboxer. We investigated whether giving the athlete a choice over the order of punches would affect punching velocity and impact force. Separated by 1 minute of rest, the athlete completed 2 rounds of 12 single, maximal effort punches (lead straight, rear straight, lead hook & rear hook) delivered to a punching integrator in a counterbalanced order over 6 testing days. In one round the punches were delivered in a predetermined order while in the second round the order was self-selected by the athlete. In the choice condition, the world-champion punched with greater velocities (6-11%) and impact forces (5-10%). In Study 2, the same testing procedures were repeated with 13 amateur male kickboxers over 2 testing days. Similar to Study 1, the athletes punched with significantly greater velocities (6%, $P < 0.05$) and normalized impact forces (2%, $P < 0.05$) in the choice condition. These findings complement research on autonomy support in motor learning by demonstrating immediate advantages in force production and velocity with experienced athletes.

7.2 Introduction

Being able to determine one's own actions, having choices, and having control over one's environment – that is, being autonomous – is essential to well-being and quality of life (e.g., (137)). Indeed, autonomy is considered a fundamental psychological need (63, 64, 138), and even a biological necessity (25, 65). Humans (66) and other animals (67, 139) prefer to have choices, even if having choices requires greater effort than no choices. This suggests that exercising control is inherently rewarding (25, 65). Autonomy-supportive environments that provide individuals with choices – even seemingly inconsequential ones (e.g., (140)) – have been shown to increase their motivation and performance in a variety of situations.

This includes exercise behaviour (for a review, see (78)). In one recent investigation (21), participants chose the order of five calisthenics exercises to be performed (choice group), or were told they would complete the exercises in a specified order (control group). The two groups were then asked to decide on the number of sets and repetitions they would like to complete in each of the five exercises. Despite similar fitness baselines, participants who were allowed to choose the order of exercises completed 60% more repetitions overall. Thus, a simple choice increased individuals' motivation to exercise.

Having choices has also been found to facilitate motor skill learning. In the motor learning literature, numerous studies have shown enhanced learning when individuals are allowed to make decisions related to certain aspects of the practice conditions (for reviews, see (8, 56). Initial investigations reported more effective learning in participants who were allowed to choose when to receive movement-related feedback relative to yoked control groups (e.g. (60, 141). Even though both choice (so-called self-control) and control (yoked) groups in those studies received the same amount of feedback (yoked participants' feedback was matched to that of participants who chose feedback after certain trials), the choice groups consistently demonstrated more effective learning. More recently, similar learning benefits were reported when participants were allowed to choose the duration of the practice sessions (22, 59), the timing of provided verbal feedback (23, 142) and video model presentations (26, 143), when to use assistive devices, such as poles during balance tasks (61, 62), or the order of tasks to be completed (20). Interestingly, the positive effects of the self-controlled practice occurred when the choices were incidental to the completed tasks. For example, even choosing the colour of golf balls enhanced golf putting accuracy compared to a prescribed colour yoked group (11). Given the beneficial effect of practice conditions in which performers are provided choices, learner autonomy is a key variable in the OPTIMAL theory of motor learning (7).

The positive effects of choice on motor skill learning have been reported for a wide range of populations, including children (40), young (59) and older adults (22), as well as participants with motor impairments (43). An interesting and yet unexplored question is whether the benefits of providing choices would also be seen in the performance of highly skilled and trained athletes. Therefore, the present studies examined this question. Study 1 was a case study with a world-class kickboxer, and Study 2 involved amateur kickboxers. In both studies, participants were, or were not, given a choice regarding the order of different punches. We measured punching performance under each of those two conditions. The present studies differed from previous ones in various respects: 1) We tested skilled athletes rather than untrained or unskilled individuals. 2) The athletes performed a skill with which they had attained a medium to high level of mastery, rather than learning a novel motor task. Moreover, we measured 3) maximum force production and movement velocity, which could have reached a plateau through regular training, rather than movement accuracy or form for which there may be more room for change. Finally, we were interested in 4) immediate effects of choice on performance, rather than delayed effects on learning resulting from extended practice with or without choice (and measured by retention or transfer tests). If the hypothesized performance advantages of choice were found, those results might have interesting implications for the training of athletes.

7.3 Part 1 – Case Study

7.3.1 Methods

Punching velocities and impact forces are important qualities in combat sports (85, 107). These qualities are commonly improved upon by specific technical training (e.g., punching a heavy bag or pads) and non-specific training (e.g., resistance training) (144). In study 1, we investigated whether autonomy-supportive conditions would enhance punching performance of a current kickboxing world-champion. We examined whether providing him with a choice concerning the order of punches to be delivered would affect punching velocities and impact forces.

7.3.1.1 Participant

An elite male kickboxer (age: 26 years, weight: 60 kg, height: 165 cm) participated in this case study. At the time of the investigation he was the amateur K-1 league kickboxing world-champion, and the professional kickboxing world titleholder with the International Sport Kickboxing Association (ISKA) in the 57 kg division. His professional fighting record consisted of 21 wins and 10 losses. The athlete had been training competitively for the past 7 years, and regularly participated in 6 to 10 training sessions per week with total training hours per week of 8-16 h. The athlete's program varied with the schedule of upcoming competitions and was periodised for volume and intensity to achieve optimal physical adaptations. The athletes were provided with a verbal description of the study, carefully formulated so as to not compromise the study design, and then provided a written informed consent. The study was approved by the Australian Institute of Sports Ethics Committee.

7.3.1.2 Experimental Protocol

All punches were delivered to a custom built punch integrator (Figure 5), which was mounted vertically and composed of a load cell with an integrated amplifier (AST brand) bolted to a metal plate covered with a large foam pad that was wrapped by leather envelope. The load cell voltage signal was collected by Data Translation 12bit USB data acquisition module using QuickDAQ software (Australia) sampling at 1000 Hz and converted to units of force (N). Punch velocity ($m \cdot s^{-1}$) was determined by recording the time interval (Agilent oscilloscope) between activation of two phototransistor infrared LED light gates (Vishay) with one gate located 0.01 m from the striking surface and the other 0.05 m. Velocity was then calculated by dividing the distance (0.04 m) by the time interval between the two beams being broken. The punch integrator instrument reliability was previously determined to be higher than 99% for both impact forces and velocity, using a protocol that involved repeated dropping of a pendulum of known weight, and known height, on to the impact surface. High instrument reliability was maintained irrespective of the number of pendulum drops (impacts), time interval between drops, and days between tests.

Figure 7.1 Image of a participant punching the punching integrator device. The punching integrator device collects peak impact punching forces and velocity prior to impact.

The athlete completed a total of 6 testing sessions. The sessions were separated by 2 to 4 days in which the choice (A) and control (B) conditions were completed in a counterbalanced order on 6 days (AB-BA-AB-BA-AB-BA). All data collection was carried out in a quiet room by the same investigator (IH) and at approximately the same hour in each session to control for possible circadian rhythm effects. The athlete was asked to avoid heavy meals two hours prior to testing. He wore the same 16 ounces boxing gloves (Sting, Australia) and applied his own standard under-wraps during testing. The athlete was instructed to "Focus on punching the pad as fast and as forcefully as you possible can." This instruction was found to elicit the greatest impact forces and punching velocities (145) by promoting an external focus of attention (1).

On the first testing day, the athlete was familiarized with the punching protocol. He was provided with an explanation of how the test would be conducted and then performed a light, sub-maximal trial of each condition. Once understood, the athlete completed a 10-15 minute self-selected warm-up, and then performed the punching protocol in each testing session under two conditions (in an alternating order): Control and choice. In the control condition, a standard punching performance test was used (145), consisting of 12 single, maximal effort punches delivered in the following order: lead straight, rear straight, lead hook, rear hook, each of which was delivered 3 times in a row. In other words, the athletes delivered three lead straight, three rear straights, three lead hooks and three rear hooks with approximately 5-s of rest between each punch. This protocol was chosen to serve as the control condition as it has been regularly used to monitor competitive boxer's progress over time, and has been used for research purposes as well (145, 146). In the choice condition, the athlete delivered the same number and type of punches, but was able to choose the order of delivery throughout the completion of the protocol. That is, the athlete was not required to select the punch order prior to initiating of the protocol, but rather, he chose the order of punches as he was progressing through it. In cases in which the athletes were not sure on the number or type of punches left to perform, they were reminded by the investigator. One minute of rest was provided between the control and choice rounds. Due to a technical limitation of the measurement device (punch integrator), there were 5-s pauses between punches in both conditions. Finally, based on observations that athletes occasionally strike the punching integrator off centre, thereby reducing the recorded impact forces, an a priori decision was made to analyse only the 2 punches with the greatest impact forces and their associated velocities in each category.

7.3.1.3 Statistical Analysis

To determine performance differences between conditions, we implemented Kinugasa's (147) general guidelines for analysis of a single-subject case study design in elite athletes. The effects of the choice condition were investigated in regards to the 4 punch types. Cohen's *d* effect sizes (ES) (135) were calculated for the mean differences between conditions for the punch type, using the pooled standard deviation of the specific punches. Additionally, precent differences between conditions are reported. The smallest worthwhile change (smallest meaningful change) was determined for both punch force and velocity to appropriately ensure that where differences existed, they were of a meaningful magnitude (148). The smallest worthwhile change score was calculated by multiplying the overall pooled standard deviation of each dependent variable (punch force and punch velocity) across punch type and condition by 0.2. This score was then compared to the absolute difference between conditions for each day.

7.3.1 Results

Punch order in choice condition. The order of punch types chosen by the participant was different across all 6 testing days, as can be seen in Table 1.

Velocity. Greater punching velocities were found on the following punches: Lead straight (8%; ES= 1.14), rear straight (4%; ES= 0.42), lead hook (6%; ES= 0.79), and rear hook (6%; ES= 0.81) (Figure 5.1B). In all four punches the differences in favour of the choice condition were equal or greater than double the size of the calculated smallest worthwhile change.

Force. Greater punching impact forces were found on the following punches: Lead straight (8%; ES= 0.89), rear straight (6%; ES= 0.84), lead hook (5%; ES= 0.83), and rear hook (6%; ES= 0.68) (Figure 5.1A). In all 4 punches the differences in favour of the choice condition were equal or greater than double the size of the calculated smallest worthwhile change.

Table 7.1 Order of punches in the control condition, and on each of the six days in the choice condition (Study 1) for the expert athlete. LS= lead straight; RS= rear straight; LH= lead hook; RH= rear hook.

Control	**Choice Day 1**	**Choice Day 2**	**Choice Day 3**	**Choice Day 4**	**Choice Day 5**	**Choice Day 6**
LS	LH	RS	RH	LS	LH	LS
LS	RH	LH	LH	RS	RS	LS
LS	LH	RS	RS	LS	RS	RS
RS	LH	LS	LH	LS	LS	RH
RS	RH	RS	RS	RS	LS	RS
RS	RH	LS	LS	RS	LH	RS
LH	LS	LH	LH	RH	LH	LH
LH	LS	LH	LS	RH	RH	LH
LH	RS	RH	RS	LH	RH	RH
RH	LS	RH	RH	LH	RH	LH
RH	RS	RH	LS	RH	RH	RH
RH	RS	LS	RH	LH	LS	LH

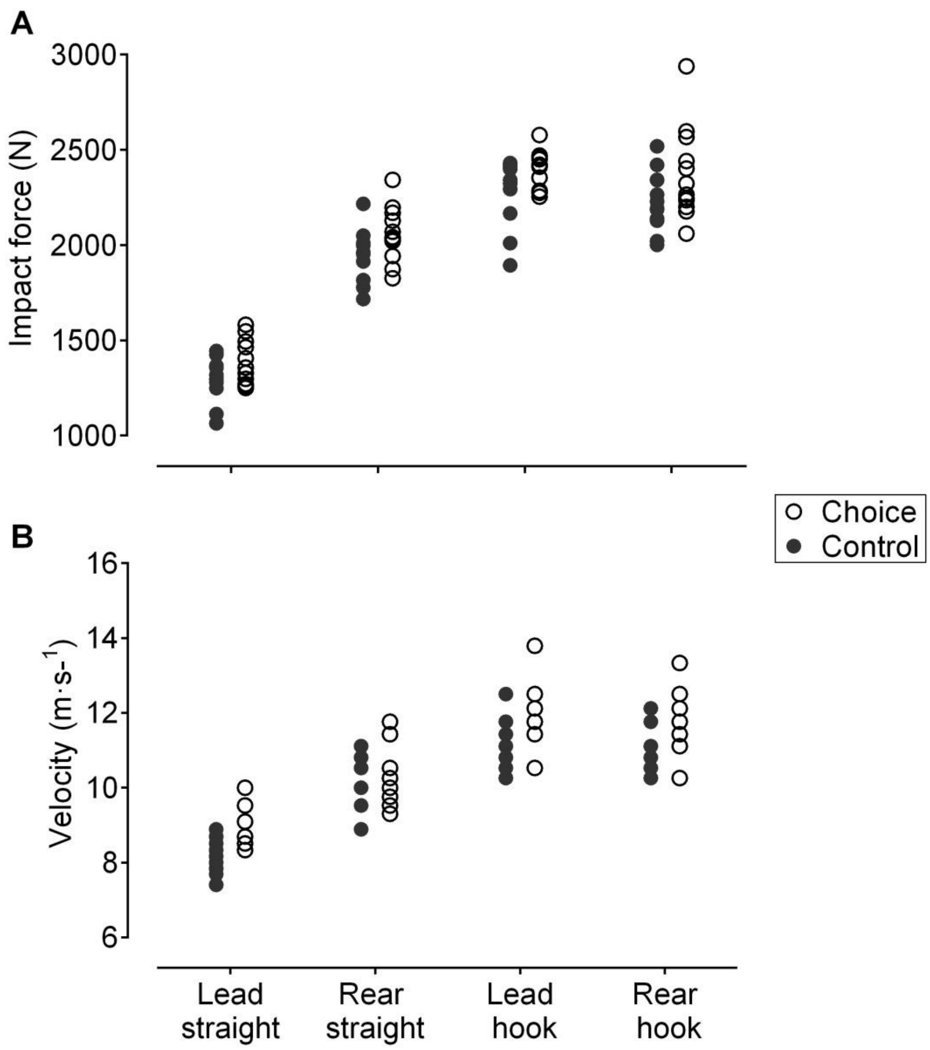

Figure 7.2. Impact force (A) and punching velocity (B) of the world-champion in the control and choice conditions. Note: Each data point represent a single punch.

7.3.1 Discussion

The results showed that the effects of choice – even relatively small ones such as the order of punches – had a meaningful positive effect on the performance of a world-class athlete who would be expected to have reached a state of mastery in his field. Indeed, it is interesting to consider the relatively large positive effect of the choice condition on the athlete, in view of the great number of maximal effort punches delivered over his training career. This finding supports the view that satisfying the need for autonomy is beneficial even for elite athletes. The finding also suggests that the simple act of providing choices can be used as additional training strategy aiming to improve not just learning, but also performance of well-established motor patterns requiring both speed and power. This is especially so considering that achieving significant improvements in punching performance is a challenging task with athletes at a world class level.

7.4 Part 2 - Group Study

7.4.1 Methods

The findings of Study 1 demonstrated a beneficial effect of autonomy support on the performance of well-practiced motor tasks in a world champion. In Study 2, we sought to provide additional evidence for this effect by using a larger sample size. We examined whether providing amateur kickboxers with a choice of punch order would have similar influences on punching velocities and impact forces.

7.4.1.1 Participants

Thirteen amateur kickboxers volunteered to participate in this study (age: 25±5 years, weight: 74±10 kg). The athletes were categorised as amateur as they had only competed in national-level events, and had participated in a minimum of 1 and a maximum of 6 competitive national-level bouts. All athletes had been training for a minimum of 1 year (range 1-3 years), at least 3 times a week, and completed between 5 to 7 weekly sessions when preparing for competition. Similar to study 1, the athletes were provided a written informed consent after provided with an explanation of the study. The study was approved by the Australian Institute of Sports Ethics Committee.

7.4.1.2 Experimental Protocol

The apparatus and task were the same as in Study 1. However, in this study the athletes completed only 2 testing sessions separated by 2 to 4 days performed in a counterbalanced order (AB-BA or BA-AB).

7.4.1.3 Statistical Analysis

Due to the large range of body weights of the athletes, the impact force values were normalized to body weight (N/kg). Normalized forces and velocity ($m \cdot s^{-1}$) were analysed in a 2 (conditions: choice, control) x 4 (type of punch: lead straight, rear straight, lead hook, rear hook) x 2 (day) x 2 (trial) repeated-measures ANOVA. Bonferroni adjustments were made for all post-hoc tests and the associated partial eta-squared effect size reported. Furthermore, when appropriate, Cohen's *d* effect sizes and percentage differences are reported.

7.4.1 Results

No athlete punched in the same order in the two testing days under the choice condition. The sequence of punches did not follow any particular order, and was dissimilar between and within the athletes as confirmed by the experimenter who recorded and compared the order of delivered punches.

Velocity. Due to a technical error, velocity measures from 1 participant were missing. Thus, the reported results are derived from 12 participants. When athletes were able to choose the order of punches, velocities were higher than they were in the control condition (see Figure 5.2B). The main effect of condition was significant, F (1, 11)= 11.69, P< .01, η_p^2 = .51. Specifically, the differences between conditions in the lead hook were minimal (0.5%; ES= 0.04), and more substantial with the rear straight (6%; ES= 0.42), lead hook (6%; ES= 0.33) and rear hook (7%; ES= 0.45). Also, as expected, velocities varied as a function of punch type, F (3, 33)= 32.21, P< .001, η_p^2 = .74. The rear hook resulted in the highest velocities, while the lead straight was associated with lowest velocities (Figure 5.2B). There were no main effects of day, F (1, 11)< 1, or trial, F (1, 11)= 1.69, P> .05, and no significant interaction effects.

Impact force. Impact forces as a function of condition are shown in Figure 5.2A. Forces were generally larger in the choice relative to the control condition. The main effect of condition was significant, F (1, 12)= 4.89, p< .05, η_p^2 = .29. Specifically, the differences between conditions in the lead hook were minimal (0.3%; ES= 0.01), and more substantial with the lead straight (2%; ES= 0.10), rear straight (2%; ES= 0.11), and rear hook (2%; ES= 0.17) (Figure 5.2A). Similar to velocities, there were also differences among punch types, F (3, 36)= 84.51, P< .001, η_p^2 = .88. The rear hook resulted in the greatest force, while the lead straight was associated with the smallest force. All punch types differed from each other (P< .001), except for the rear straight and lead hook (P> .05). On the first day of testing (36.95 N/kg), impact forces were somewhat higher than they were on the second day (35.95 N/kg). The main effect of day was significant, F (1, 12)= 5.04, P< .05, η_p^2 = .30. There were no other significant main or interaction effects.

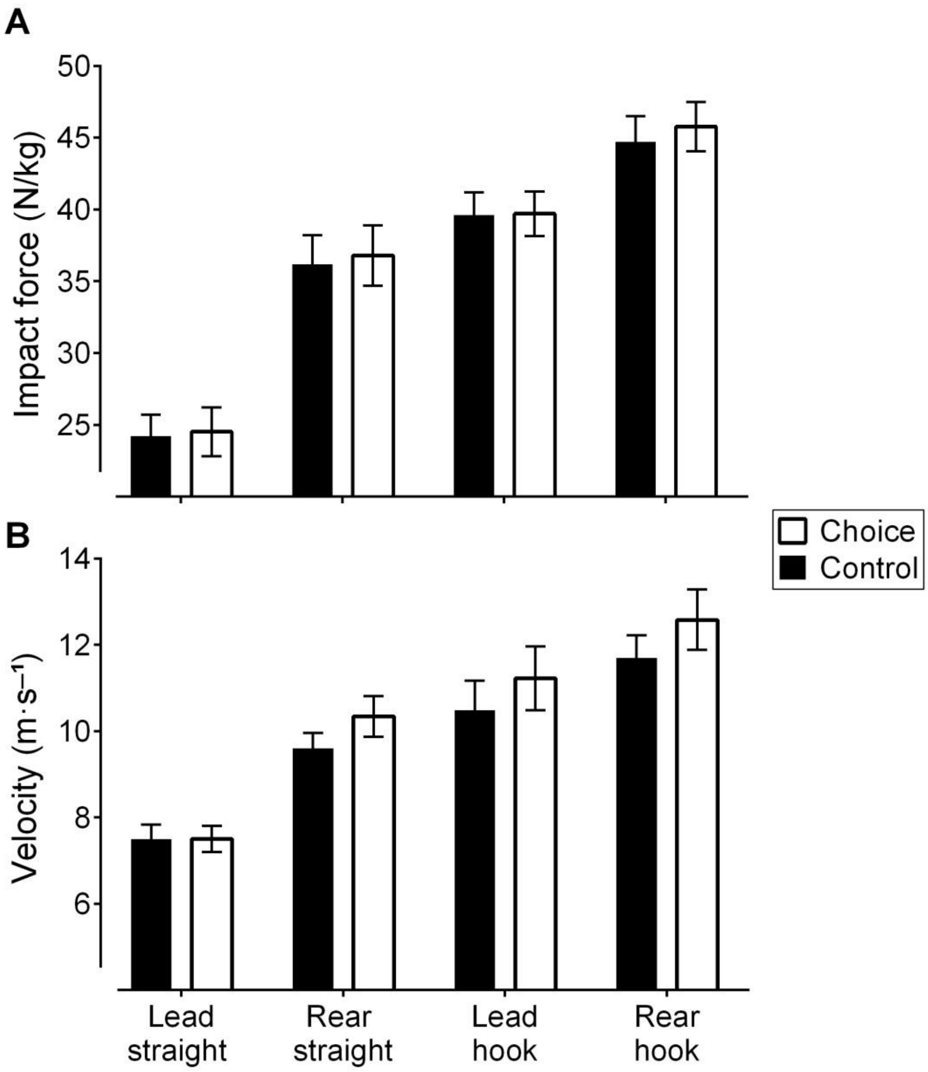

Figure 7.3 Normalized mean (± SEM) impact forces (A) and punching velocity (B) of the amateur kickboxers in the control and choice conditions.

7.4.1 Discussion

Providing amateur athletes with a choice about the order of delivered punches enhanced punching velocity and impact forces, compared to the predetermined order of punches. It is unlikely that the self-selected condition somehow led to a physiological advantage relative to the predetermined order of punches. This is because all punches were delivered as singles, and not in combinations, due to the 5-s rest interval between punches. Further, the order of delivered punches was dissimilar across the testing days. For these reasons, the possibility of a preferred order of delivered punches and muscle fatigue, which might affect performance, can be discounted. While it is possible that the novel aspect of the self-selected protocol, as well as different memory requirements between the protocols somewhat influenced the results, we speculate that the positive effect observed in the choice condition was mostly caused by an enhanced sense of autonomy and competency, which consequently improved performance.

7.5 General Discussion

The goal of these two studies was to examine if the benefits of self-selected practice programs are generalizable to amateur athletes, as well as a world-class athlete, performing a well-practiced motor task. Providing the athletes with a choice over the order of delivered punches enhanced their performance. It was found that the elite athlete punched both harder and faster with the self-selected protocol. Similarly, amateur athletes punched faster and harder when they were able to choose the order of punches. The present findings extend the literature by showing that giving performers choices enhances not only the learning of novel tasks (e.g., (20)), but can improve even the performance of both skilled and highly skilled athletes who have extensive experience in a given task.

This finding is of value to striking combat sports as fast and forceful punches have been identified as an important contributing factor to success in such sports (105, 107, 108). Improving punching performance is commonly achieved by sport-specific (e.g., punching the heavy bag) and non-specific training (e.g., strength sessions) (144, 149). However, the results of this study, together with previous work, point to opportunities for self-selected practice as another strategy to achieve this goal. The results suggest that granting athletes varying degrees of control in the training session and/or program could enhance performance, even in well-practiced motor tasks. This should be of particular interest to striking combat sports coaches who normally prescribe the order of delivered punches/kicks as a training strategy.

There are a number of possible explanations for the results. The self-selected protocol, relative to the prescribed order, may have permitted the athletes to punch in an order compatible with their optimal performance. This explanation, however, confronts difficulties. First, the sequence of punches was interrupted by 5 s of rest, thus preventing the delivery of a preferred continuous combination, which potentially could enhance punching performance. Second, the order of punches in the self-selected rounds was different across the days (see Table 1), thus excluding the possibility of an optimal sequence of punches. The control condition may have inflicted muscle fatigue due to the short (5-s) rest periods between the delivered three similar punches. This possibility is unlikely because published (86) and unpublished work from our laboratory demonstrates that the implemented protocol does not lead to fatigue. Indeed, the ICC of the control protocol are very high for all punches (0.85-0.95) (86) pointing to the non-fatiguing nature of the protocol. Further, it is not uncommon to observe that the final, third punch, of a similar set of punches, is both stronger and faster than the first. This observation illustrates that fatigue does not play a role in this protocol.

It is possible that the novel aspect of the self-selected condition can account for some of the results. This is because the elite athlete in study 1, and four athletes in study 2 were familiar with the control condition. However, despite the familiarity of the elite athlete with the control condition, in all six testing days punching performance was superior with the self-selected condition. It can be argued that if novelty played a key role in the results then the effects should have saturated over the testing days, yet this was not the case. Additionally, while the four participants in study 2 previously completed the control condition, they performed it approximately 5 months prior to the present study. Five months is a long wash out period which would nullify the possibility that the self-selected condition led to greater motivation to perform due to the novel aspects of it. Nevertheless, this possibility exists and should be more carefully accounted for in future work. Finally, while in the control condition the athletes had to recall the number and sequence of punches, in the self-selected condition the athletes were occasionally reminded or asked for the number and/or type of punches left for them to complete. As such, these differences in the memory requirements may also partly explain the results. Alternatively, the athlete's perception of choice may have increased their sense of autonomy and competence, and subsequently enhanced performance. Though a sense of autonomy and competence were not assessed here, this last hypothesis is supported by a recent study indicating that providing even incidental choices can enhance motor learning (11).

Underlying neuromodulatory mechanisms may be consistent with, and explain the potentiating effect of autonomy support on motor performance (7). Leotti and Delgado (25) reported that the anticipation of choice was associated with greater activity in the brain regions involved in affective and motivational processes. Lee and Reeve (150) found that imagery of self-determined task engagement, including the notion of acting autonomously, was related to activation in a brain region (anterior insula) associated with a sense of agency, a state associated with dopamine release (68). Further, kinematic and kinetic advantages in rapid force production movements have been found in Parkinson disease when dopamine agonists are administered (151).

The present study is not without limitations. First, while punching velocity and impact forces are important in combat sports, they are commonly delivered in combinations rather than single punches as delivered in this study. This limitation was enforced due to technical limitation of the punch integrator, which only allows for single punches to be recorded. Accordingly, it would be of interest to further investigate this topic with punching combinations to better illustrate how punches are mostly delivered in combat sports. Second, the sample size of these studies was relativity small. In an attempt to overcome the sample size limitation, the study included a relatively large number of data points, reflecting 560 analysed punches between the two studies (280 per condition). Additionally, in Study 1 we tested the athlete over 6 testing sessions to insure that the effects, if present, are consistent across days. Finally, special attention was given to eliminate confounding variables, such as the type and number of instructions, number and gender of observers, as well as the time of testing and the intensity of the warm up (118).

In summary, to our knowledge this is the first study to investigate the effects of choice conditions on competitive athletes performing a familiar motor task, including a world-champion athlete. The results are in line with previous research demonstrating a positive effect on motor performance when participants are able to make choices about various aspects of practice conditions, even if the choices are relatively small. Given the observed effects and their consistency, we believe that the results are meaningful. Future studies utilizing larger sample sizes and other outcome measures would be a fruitful endeavour given the potential practical implications of the findings for the training of athletes.

CHAPTER 8

FALSE-PERFORMANCE FEEDBACK DOES NOT AFFECT PUNCHING FORCE AND PACING OF ELITE BOXERS

This chapter was submitted in 2017 as follows:

Halperin I., Chapman D.W, Thompson K.G and Abbiss C.R. False-performance feedback does not affect punching forces and pacing of elite boxers. *Frontiers (submitted)* (IF= 3.2)

8.1 Abstract

Prior research indicates that providing participants with positive augmented feedback tends to enhance motor learning and performance, whereas the opposite occurs with negative feedback. However, the majority of studies were conducted with untrained participants performing unfamiliar motor tasks and so it remains unclear if elite athletes completing familiar tasks respond in a similar fashion. Thus, this study investigated the effects of three different versions of false-performance feedback on punching force (N), pacing (force over time) and ratings of perceived exertion (RPE) in 15 elite amateur male boxers. Athletes completed a simulated boxing bout consisting of three rounds with 84 maximal effort punches delivered to a punching integrator on four separate days. Day one was a familiarisation session in which no feedback was provided. In the following three days athletes randomly received false-positive, false-negative and false-neutral feedback on their punching performance between each round. No statistical or meaningful differences were observed in punching forces, pacing or RPE between conditions (*P*> 0.05; ≤ 2%). These null results, which differ from previous literature, could stem from the elite status of the athletes involved; indicating that task proficiency might mitigate against changes in performance and pacing variability when feedback is manipulated.

8.2 Introduction

Amateur boxing is an Olympic sport in which athletes attempt to score points, or knock their opponents down/out, using punches delivered in a tactical and strategic manner (85). Depending on gender, amateur boxing bouts consist of 3-4 rounds lasting 2-3 minutes with 1 minute of rest between rounds (85). Amateur boxing has specific physiologic demands, including the ability to strike hard, fast and repeatedly (85, 107, 108, 152, 153) For example, Smith et al., (107) found that elite boxers punch with more force compared to non-elite and novice boxers. Likewise, the average punching forces measured during professional boxing bouts was higher among winners, compared with losers (108). Such findings indicate that enhancing punching performance is of significant importance to boxers, which is commonly achieved by technical training (154) and strength and conditioning sessions (109).

Augmented feedback is an alternative strategy that can be used to enhance punching performance. In two recent studies by our group, it was observed that providing specific types of feedback enhanced punching forces and velocities of competitive combat athletes (boxers and kickboxers). Halperin et al. (86) investigated the effects of providing external, internal and neutral focused verbal instructions on punching forces of a single, maximal effort punch in a cohort of combat athletes. External instructions resulted in harder (2-4%) and faster (3-5%) punches, compared with the two other conditions. Further to this, Halperin et al. (87) compared the effects of order choice on single, maximal effort punches among competitive combat athletes with athletes punching harder (~5%) and faster (~6%) when freely choosing the order of delivered punches.

A commonly implemented feedback strategy (9), which has been shown to influence motor learning and performance (7), is feedback describing one's performance in a positive or negative manner (also known as feedback valence). Compared with negative and/or control feedback, providing participants with positive performance feedback enhanced balance (28), accuracy (29), and has allowed participants to endure longer durations in a continuous submaximal force production task (27). Positive feedback has also been shown to improve running economy of trained runners, compared with a control group who received no feedback (33). The provision of false or negative feedback (e.g., 5% slower or 5% faster) throughout an exercise task has also been shown to influence pacing (i.e., the distribution of energy expenditure throughout the task) in various ways (4, 30-32). However, To date, the effects of positive and negative feedback have not been investigated in relation to punching performance, despite such feedback being frequently given by boxing coaches (9).

Halperin et al. (9) reported that coaches in both winning and losing bouts delivered a comparable amount of negative feedback (13.7% vs. 12.5%), but coaches of winning bouts provided double the amount of positive feedback (36% vs. 18.6%). It is not possible to draw any causal conclusions since positive feedback could have enhanced the boxer's performance and led them to victory, or alternatively, the boxers' successful performance led the coaches to provide the athletes with more positive feedback. Accordingly, the purpose of this study is to experimentally manipulate three sets of feedback (positive, negative and neutral) and examine the effects on punching impact forces (N), punch pacing (forces over time), and ratings of perceived exertion among elite level amateur boxers, using a specific punching protocol.

8.3 Methods

8.3.1 Participants

Fifteen elite male amateur boxers (age: 21±4 y [range:17-29 y]; body mass: 71±11 kg, [57-96 kg]; number of bouts 50±21, [30-100]) volunteered to participate in this study. All athletes regularly competed at a national level and had participated in at least one international level event. They were considered by the national boxing coaches as the best amateur boxers in Australia. Athletes were provided with a verbal description of the study, which was carefully presented so as to not compromise the study design (description below), after which each athlete provided written informed consent. The study was approved by the Australian Institute of Sport and Edith Cowan University Ethics Committees.

8.3.2 Experimental Design

Athletes were asked to attend the laboratory on five separate occasions. On the first day they were provided with an inaccurate explanation about the purpose of the study. That is, they were instructed that the goal was to examine the reliability of the new punching protocol over four testing days and their performance in each testing day would be compared to their first testing day. This explanation was provided to reduce possible suspicions of the true purpose of the study. Thereafter, an overview of the protocol was provided, followed by a short practice session of the protocol on a punching bag (described below). Finally, an explanation of the Borg rating of perceived exertion (RPE) scale was provided (155). Athletes were asked to report their RPE for each round. An explanation was delivered concerning the anchor points provided with the RPE scale (i.e. light, somewhat hard, maximal exertion). During the second session the athletes performed a familiarisation session during which they were asked to punch the punching integrator (Figure 6) as fast and as forcefully as possibly, while making sure it would simulate a punch thrown in training or competition. Over the next three sessions participants performed the same punching protocol during which they received false-positive, false-negative and false-neutral feedback between rounds in a blocked-randomized fashion (described below).

Prior to completing the punching protocol on all days, athletes performed a warm up consisting of a series of 3 min activities completed in the following order: jumping rope, self-selected dynamic stretching, shadow boxing and punching the bag. Before beginning the protocol, athletes punched the punching integrator with increasing intensity for 30 s. The punching protocol consisted of three rounds lasting 2 min, with a 1 min break between rounds. Each round consisted of 84 maximal effort punches delivered in a set order. Every 5 s a loud beep sound was given indicating that the athletes were required to deliver a specific combination within a 5 sec period. Specifically, four straight punches (alternating between a lead straight and rear straight) were delivered within the first beep, three lead hooks within the second beep, and three rear hooks within the third beep. This sequence was repeated continuously for 2 min, resulting in 84 punches. Apart from the familiarisation day, the athletes received false performance feedback on their performance and were then asked to report their RPE at the completion of each round (2-5 s after the last punch combination).

The false feedback consisted of a performance statement about the round, followed by a precent decrement or improvement relative to the baseline/familiarisation day (described below). To reduce the possibility of the athletes developing suspicions of the true purpose of the study, the precent differences provided to the athletes ranged between 6-9% and were randomized between rounds and between conditions. That is, a given round could have been 6%, 7%, 8%, or 9% lower or higher compared to the baseline round. Further, to avoid possible confounders, the average score between the positive and negative rounds was the same. For example, if in the positive feedback condition a participant was told that, compared with his baseline round, his performance was 6%, 8% and 9% greater in round 1, 2 and 3 respectively. Likewise, in the negative feedback day he was told that compared to his baseline round, his performance were lower by 7%, 7% and 9% in round 1, 2 and 3 respectively. Thus, the average score was similar (8%) between conditions. The 6-9% range was chosen based on consultation with a number of coaches, a further pilot study with four amateur athletes, and based on similar values that have been previously used in the literature

(27). We considered this range to be large enough to have an effect on the athletes, but not too large to elicit suspicion.

The feedback on the positive day was “Good round, your performance is 6-9% higher compared to your baseline round”, on the negative day it was “This is not a very good round, your performance is 6-9% lower compared to your baseline round”, and in the neutral day it was “Your performance in this round is the same as your baseline round”. Note, however, that performance and pacing measures were calculated differently to what the athletes were told for the sake of deception (see statistical analysis). Apart from the single feedback statement provided by the same investigator (IH) in a noise sensitive room, no other encouragement, verbal or visual feedback was provided and a similar tone of delivery was used in all occasions. All subjects wore the same 16 ounces boxing gloves (Sting, Australia) during testing and their own hand wraps. Athletes were asked to avoid a large meal two hours prior to testing, any strenuous exercise on the day of testing, and were tested on the same time on all days.

Figure 8.1 The punching integrator device collects peak impact punching forces and velocity prior to impact.

Punching forces. All punches were delivered to a custom built punching integrator (Figure 6), which is mounted vertically and composed of a load cell with an integrated amplifier (AST brand) bolted to a metal plate which is covered with a large foam pad wrapped by leather envelope. The load cell voltage signal is collected by Data Translation 12bit USB data acquisition module using QuickDAQ software (Australia) sampling at 1000 Hz and converted to units of force (N). The punching integrator instrument reliability has previously been determined as less than 1% for impact forces, using a protocol of dropping a pendulum of known weight, and known height, on to the impact surface, on numerous occasions over several months. The high instrument reliability was maintained irrespective of the number of pendulum drops (impacts), time interval between drops, and days between tests.

8.3.3 Statistical Analysis

In order to reduce the sample of punches, the average impact forces of 14 punches delivered every 20 s (four alternating straights, three lead hooks and three rear hooks) were averaged and treated as a data bin. Hence, each round consisted of six bins. First, a two way ANOVA with repeated measures (conditions [4] x bins [6]) was conducted to compare differences between performance in only the first round across the four conditions. This examined if the punching protocol performance was consistent prior to the study's manipulation taking place in each of the feedback intervention conditions. Second, a three way ANOVA with repeated measures (conditions [3] x rounds [3] x bins [6]) was used to compare the intervention effects on punching performance. Third, to fully explore how the feedback statements affected performance, absolute differences between round two and one, and between round three and one, were calculated per each bin for each participant and compared using a three way ANOVA with repeated measures (conditions [3] x round differences [2] x bins [6]). Finally, a two way ANOVA with repeated measures (conditions [3] x rounds [3]) was conducted to examine if differences in RPE occurred between conditions and rounds. If the assumption of Sphericity was violated, the Greenhouse–Geisser correction was performed. A Bonferroni post-hoc test was used if a main effect was identified, and paired *t*-tests with Holms-Bonferroni corrections were used if an interaction was found. Significance was accepted as $P < 0.05$. Furthermore, absolute values and differences, as well as Cohen *d* effect sizes (ES) are reported when appropriate. The magnitudes of these ES were classified as trivial (0–0.19), small (0.20–0.49), medium (0.50–0.79) and large (0.80 and greater) using the scale advocated by Cohen (135).

8.4 Results

After data collection was completed, athletes were informed about the true purpose of the investigation, with no athlete admitting to being suspicious of the intent. No significant interaction or main effects were observed in punching forces over the six bins of the first round for each condition ($P \geq 0.272$; ES≤ 0.23) (Figure 6.1). No significant interactions were observed in punching forces between the experimental conditions, all rounds, and bins ($P \geq 0.135$). A main effect was observed for rounds ($P = 0.047$), however post hoc testing did not reveal any statistical differences between rounds 1, 2 or 3 across the three experimental conditions (2081±273 N, 2119±290 N, 2141±326 N, respectively; $P \geq 0.071$, ES≤ 0.19) (S1 file). There were no significant main effect between the three experimental conditions ($P \geq 0.283$, ES≤ 0.11) in terms of the average force production across the three rounds for each of the three feedback conditions, [Positive: 2129±305 N; Negative: 2093± 281 N; Neutral: 2120± 290 N (Figure 6.1)]. No significant interactions or main effects ($P \geq 0.131$; ES≤ 0.12) were observed in absolute differences between round 2 and 1, and between round 3 and 1, when compared across the three conditions and the six bins (Figure 6.2).

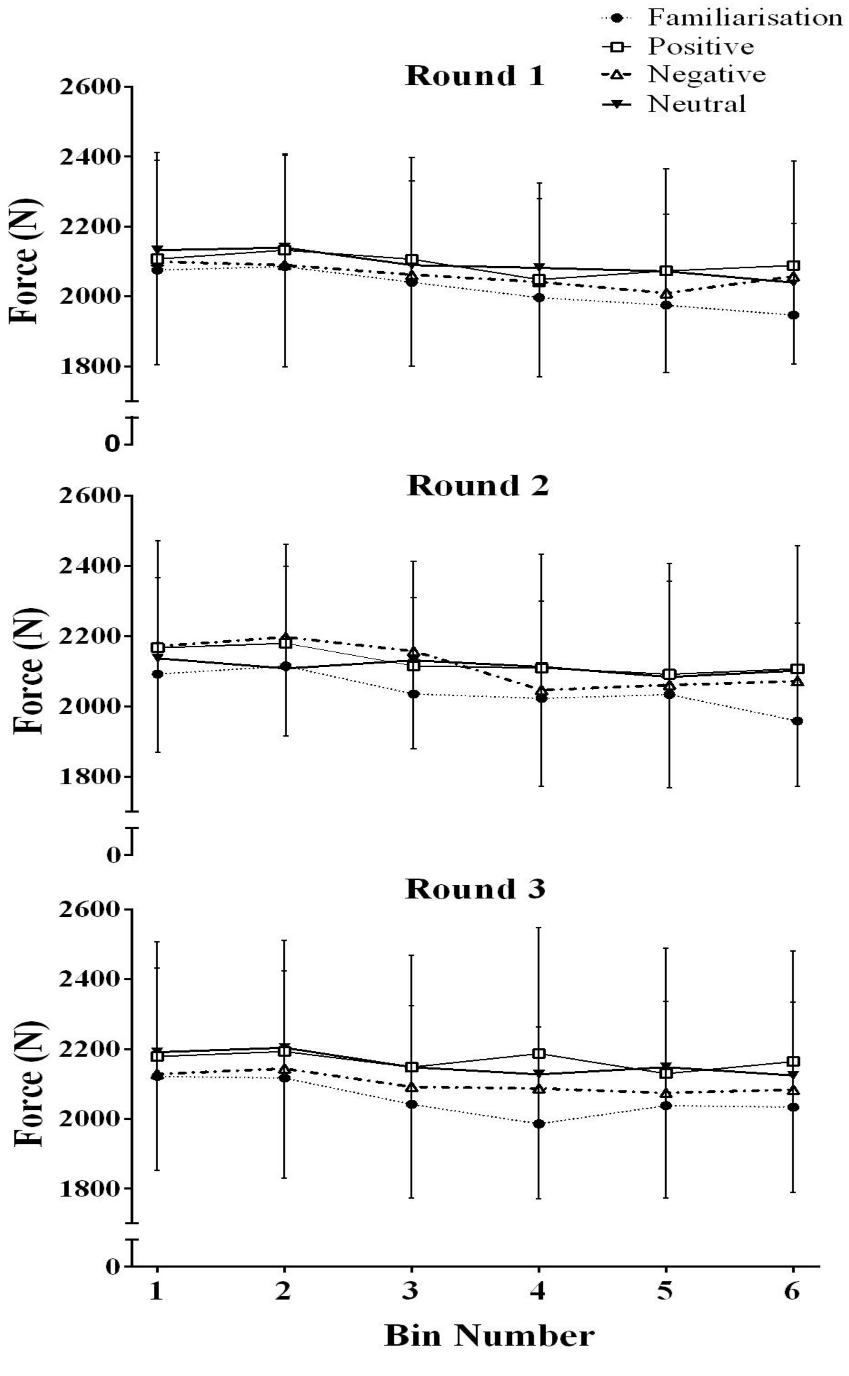

Figure 8.2 The mean (SD) forces in the four conditions delivered over each round and distributed in six bins.

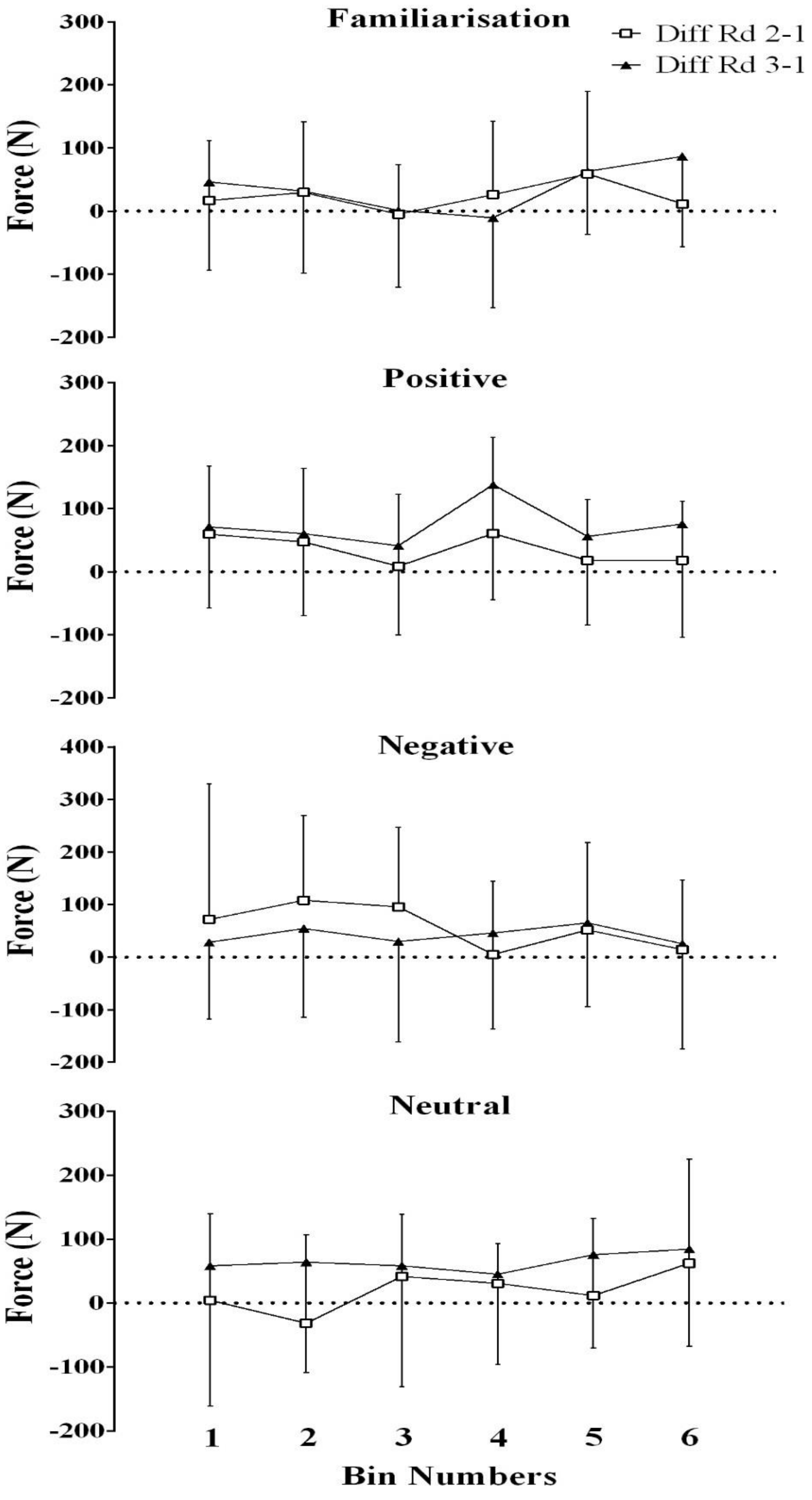

Figure 8.3 The mean (SD) differences between round two and one, and round three and one, across the four conditions in six bins.

No significant interaction between conditions and rounds in RPE was observed (P= 0.600; ES≤ 0.18), nor a main effect for conditions (P= 0.055; ES≤ 0.18) (Fig 6.3). However, a significant main effect was observed for RPE across rounds (P< 0.001; ES≥ 1.0) with RPE increasing with each round (round 1: 13.8±1.4; round 2: 15.6±1.4; round 3: 17.0±1.4).

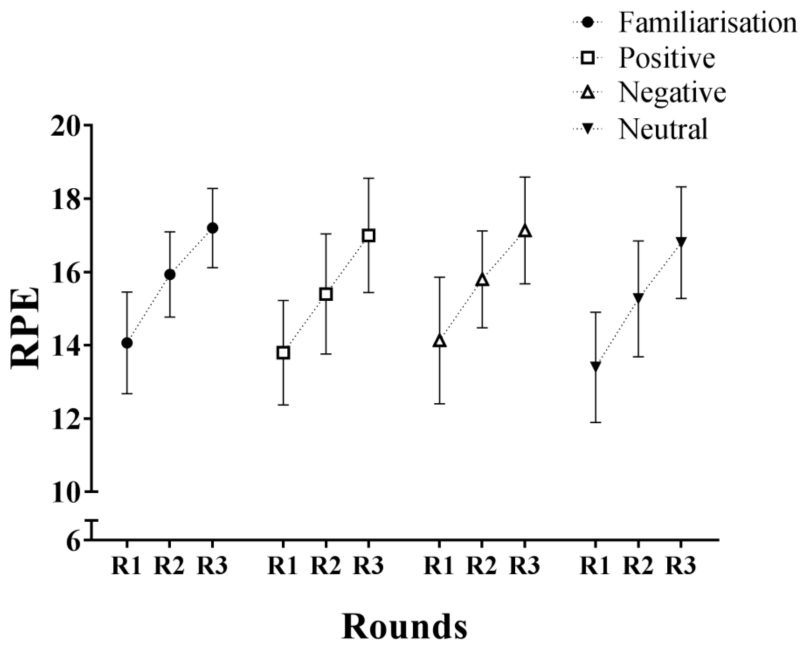

Figure 8.4 The mean (SD) RPE scores in the four conditions across the three rounds.

8.5 Discussion

The purpose of this research was to investigate how false positive, negative and neutral performance feedback affects punching forces, pacing, and RPE in elite male amateur boxers. No statistical or meaningful differences were observed in punching forces and RPE between conditions with punching forces remaining relatively constant throughout a given round, between rounds, and conditions. These observations indicate that elite level boxers may not be susceptible to positive and negative feedback, at least when measured with activities that require maximal efforts over time. The lack of differences in the force data from the bins between each of the conditions demonstrate that the athletes were able to adopt an “even” pacing strategy irrespective of the feedback being provided (156). This would suggest that they did not fatigue to any greater or lesser extent or alter their pace in any of the conditions. As RPE increased across rounds the participants did perceive a greater level of exertion between rounds however this did not correspond with a reduction in the force measures.

The lack of performance and perceptual differences between positive, neutral and negative feedback observed in this study are in agreement with the findings of some (4, 30-32), but not all investigations (28, 29, 34). Specifically, studies within motor learning typically demonstrate that positive feedback leads to superior learning, compared with negative feedback and/or a control condition (e.g., (28, 29, 34)). The different results observed in the present study and those within previous studies emphasising motor learning may be explained in a number of ways. First, in motor learning studies participants commonly complete a novel simple task in which they have little or no experience with. In contrast, the current study used a cohort of athletes completing a complex task they have vast experience with. Participants completing a task they are familiar with may be less susceptible to influence by specific types of feedback, such as positive and negative. Second, the main outcome measure in the present study was maximal punching forces, which could have reached a plateau through regular training. In contrast, common outcome measures in motor learning studies include task accuracy (i.e., throwing and golf putting, etc.) and balance (i.e., reducing centre of gravity sway), which could be effected more easily. Motor learning studies commonly examine learning by utilizing delayed retention and transfer tests, whereas in the present study only immediate performance was measured. Indeed, in a larger number of studies, the experimental interventions did not influence immediate performance, but various effects were identified in the delayed retention and transfer tests (29, 157, 158). Hence, it is possible that effects were not present in the current study only because immediate performance was measured. Further studies investigating both learning in addition to performance could help shed light on this topic. Another reason for the null results in this study is the point of references for the feedback. Whereas in the current study participants were compared to their own baseline, in other studies which found an effect for positive and negative feedback participant's performance were compared to a peer group (27, 33, 34). Studies comparing the effects of different feedback as it pertains to the two references point are required to answer this question.

It is also plausible that the lack of effect observed in the present study is because the performance of athletes is less affected by positive and negative feedback, compared with non-athletes. Indeed, a number of studies which have not found an effect for positive and negative performance feedback have examined moderately to highly trained athletes (4, 30-32). Supporting this, athletes have greater levels of mental toughness compared to non-athletes (159), and demonstrate superior inhibitory control and mental fatigue resistance compared to recreational athletes (160). The study of psychological resilience, which seeks to understand why some individuals are able to respond in a positive manner to setbacks, obstacles and failures (161), offers possible insights in explaining the results of the current study. Elite athletes report encountering a wide range of sport and non-sport related stressors and failures which they believe were essential for their success (162). A number of psychological factors, such as the ability to stay focused and maintain high levels of motivation, have been proposed to protect elite level athletes against the various sport and non-sport related stressors and failures (163). The cohort of participants in the present study included expert boxers with extensive competition experience. Hence, they may have developed the ability to block out negative stressors, such as the negative feedback, and may have followed our request to punch as hard as they possibly could with every punch leaving little possibility for improvement with the positive feedback. Finally, the lack of effect in the current study may also stem from the athletes' familiarising with the three types of feedback. Indeed, Halperin et al. (9) have previously reported that the distribution of neutral, positive and negative feedback provided between rounds of competitions were 58%, 13% and 29%, respectively, across all bouts. It can also be expected that such feedback is implemented during regular training sessions as well. It is a possibility that familiarity with specific types of feedback nullifies its effects to some extent.

A limited degree of muscle fatigue induced by the current protocol may also partly account for the null results observed in this study. In the pacing literature, a gradual reduction in power output or force is typically observed, followed by an increase in force or power as athletes approach the end of the exercise task (164, 165). However, in present study, punching force over the entire protocol was remarkably consistent and unexpected based on pacing observed within the majority of literature (156). Despite the gradual increments in RPE in each round, performance and pacing remained unaffected. Hence, it could be that positive and negative feedback has a much greater effect on performance in more fatigue conditions, in which reductions in performance are evident. Yet, it should be noted that deceptive performance feedback has been reported to effect learning and performance in non-fatiguing conditions within the motor learning literature. Regardless, such discrepancies can be accounted for by the differences between the research fields discussed above and warrants further investigation.

The results of this study suggest that elite athletes completing a familiar motor task, in which they have attained a high degree of mastery, may not be effected by negative and positive performance feedback during repeated bouts of maximal efforts of the investigated task. However, it is unclear how such feedback would influence athletes completing tasks which they are less familiar with, or those that require different physical and/or cognitive qualities. For example, the pace of learning and implementing a new technical and/or tactical move, as observed in various motor leaning studies. Further investigations on this topic are warranted, especially those comparing the effects of negative and positive feedback on athletes and non-athletes, as well as on familiar and non-familiar outcome measures and under fatigued and non- fatigued conditions. Such studies would clarify whether the lack of effect observed in this study was due to the investigated sample, the outcome measure, state of fatigue, and an interaction between the three.

CHAPTER 9

SUMMARY, CONCLUSIONS & RECOMMENDATIONS

9.1 Thesis Summary

This thesis examined the frequency and distribution of three types of feedback provided by boxing coaches to their athletes between rounds in competition. It then examined in controlled laboratory experiments how these three types of feedback (attentional feedback, autonomy-supportive, and positive and negative feedback) influence athletic and combat specific performance of resistance trained participants, and combat athletes. Several of these studies involved a unique population of elite, competitive athletes which have not been thoroughly studied before. Indeed, despite the growing popularity of combat sports, there is currently limited research on this population, particularly in regards to the influence of feedback on performance. The findings from this thesis contribute to and expand the body of knowledge pertaining to feedback and its effects of performance and pacing. The findings also have direct practical application for athletes, coaches and sport scientists. Outcomes detailed within this thesis can aid coaches and sports scientists in order to improve their feedback delivery to athletes or manipulate the feedback given to athletes, with the aim of improving overall performance. A discussion of the three different types of feedback investigated within this thesis are discussed in detail below.

9.2 Frequency and type of feedback

The purpose of the first study in this thesis (Chapter 3) was to examine the types and frequencies of verbal feedback national level boxing coaches provided to their athletes between rounds of boxing competition. There was no hypothesis as to what the results may be prior to conducting this study as no known research had previously examined this topic in a natural setting. Indeed, while a large number of studies have examined the influence of different types of feedback on motor learning and performance in controlled experiments (1, 20, 21, 45, 47), only a handful of studies investigated what types of feedback coaches, or any other movement practitioners, naturally use in practice/training environments (10, 166). This is an important investigation question as it can assist in matching and comparing the results derived from controlled laboratory experiments with the occurrence that takes place in real life scenarios. Knowing what types of feedback exercise professionals use in their natural environments could also provide valuable information to scientists concerning the most important relevant research questions to be addressed. The findings from Chapter 3 were used to guide the feedback and research questions of subsequent experiments within the thesis.

Within Chapter 3 it was found that, for the most part, coaches underutilised feedback strategies that have been shown to be effective and over utilised feedback strategies that have been shown to hinder performance. Specifically, while external focus has been shown to be an effective feedback strategy in enhancing physical performance of a wide range of populations across a wide range of outcomes (1, 44), coaches in this study rarely used such feedback/instructions. Across all bouts, only 6% of communication with athletes were regarded as external instructions. Conversely, coaches implemented roughly double (15%) that amount of feedback to provide internal focus instructions, which has repeatedly shown to negatively influence performance. Likewise, coaches in this study predominately used controlling feedback (53%) and very little of supportive feedback (4%). Supportive feedback, which allows the participant/athlete to make a choice, and provides him or her with a sense of control, has been shown to positively influence performance and motor learning (8, 58). Conversely, controlling feedback deprives the athlete of a choice and of a sense of control over the situation and typically negatively effects performance. It should be noted however that coaches did use more positive (29%), compared with negative (12%) feedback in this study. Positive feedback is associated with superior motor learning and performance compared to negative feedback (28). Therefore, based on the findings of Chapter 3, and current research, it appears that the feedback provided by the coaches of elite combat athletes could be improved upon with two out of the three investigated feedback themes if superior performance is desired. Importantly, it should be noted that in winning bouts of the present study, coaches provided different feedback compared with bouts that were lost. A causal relationship cannot be ascertained from the results of this study, since it is plausible that both the feedback provided by the coach influences the boxer’s performance and that the performance influences the feedback style the coach provides. Nevertheless, this is an interesting finding that warrants further research.

9.3 Attentional focus

Within this thesis three studies were conducted which investigated the effects of external, internal, neutral, and a mirror condition (only in one study) on resistance type activities and punching performance. Within these studies it was observed that explosive maximal performance of trained individuals was improved with external conditions compared with internal and neutral conditions. First, the effects of external, internal and neutral instructions on isometric maximal force production among well-resistance trained participants were examined (Chapter 4). The results were consist with the literature in which force production was largest with external instructions, followed by neutral and internal instructions. This study examined a commonly implemented physical test in both research and practice – the isometric mid-thigh pull (90, 92, 95). Given the size of the identified effect, these findings are of importance to practitioners and scientists as they highlight the need to provide consistent feedback when conducting this test. The isometric-mid-thigh pull is regularly used to assess function and performance in a range of sports and populations yet the specific instructions provided to individuals when conducting this test within the literature are very rarely described. This could lead to a number of shortcomings such as reducing the test-retest reliability and/or hinder performance of athletes due to the inferior internal instructions. Accordingly, it is hoped that both practitioners and scientists who use this test will be mindful of the instructions and feedback they provide as otherwise they may confound the results.

Second, based on the results of Chapter 3, Chapter 5 aimed to examine the effects of external the effects of external, internal and neutral instructions on punching forces and velocities among intermediate and elite level striking combat athletes. It was found that external focus instructions led to superior punching forces and velocities compared to both neutral and internal instructions. These results are of practical importance to combat sport coaches as the instructions they provide in training and competitions environments can increase or decrease punching performance of their athletes. It is interesting consider the results of this study, in which punching performance was effected by the feedback, in view of the results from Chapter 3 in which coaches in winning bouts provided less internal instructions compared those from losing bouts. Collectively, these results are intriguing and do suggest that coaches should pay close attention to how they instruct their athletes in training and in competition.

In Chapter 6, I included a new feedback condition to those most commonly compared between external, internal and neutral, which was a mirror condition. Whereas many studies compared the three feedback conditions, to date no study compared them to a mirror condition. This is of interest for two main reasons. Firstly it is unclear if mirrors direct one to focus on the muscles or body parts being observed in the mirror, and thus elicit an internal focus which negatively influences performance. Conversely, it may be that focusing on the mirror directs one to focus on an object that is external to the self, even if the person is observing their own muscles and body parts. Hence, it was useful to investigate the mirror condition in relation to the other feedback conditions, rather than just a control group/condition, absent of a focus condition, as is commonly done (126, 132, 134). Second, given the popularity of mirrors in gyms, dancing and martial arts studios, few studies have examined how performing in front of mirrors actually influence performance, and more specifically, tasks that require force and power.

In line with the first hypothesis of this study, it was found that external instructions led to superior performance compared to neutral and internal instructions in both the single (isometric elbow flexion forces) and multi-joint (jump height) exercises. These results are not surprising, as a number of studies already examined the effects of attentional focus instructors on both of these tasks and reported comparable results. However, the two mirror conditions elicited interesting results that were not expected given the lack of any hypothesis to this aspect of the study. The effects that the mirrors had on performance were similar to those of the neutral conditions. That is, inferior to external instructions and superior the internal instructions. These results shed light for the first time on how use of mirror may confound the attentional instruction provided and should have practical importance. Mainly, it is of value to know that at least acutely, mirrors do not enhance or hinder resistance training exercises performance. Given that to the best of my knowledge no other study to date has investigated this question before, it would be of value to conduct more research on this topic.

9.4 Autonomy-Support

Chapter 7 examined if providing combat athletes with a choice concerning the order of the punches to be delivered would enhance their punching performance, when compared with punches in a pre-determined order. It was found that athletes punched harder and faster when they received the possibility of choosing the order of the delivered punches, compared to when they were not provided with a choice. These results are consisted with the existing literature (8, 20, 21), and add a number of important and novel components. Whereas most studies that investigated the effects of choice used untrained participants, the present study used competitive combat athletes. Second, most studies implemented a novel motor task to the participants, or they had had minimum exposure to, in the present study all participants were experienced with the task, and have been practicing it for years. Finally, whereas most studies used outcome measures that relay on balance and accuracy, in this study the outcome measure was maximal force and velocity. Hence, this study extends the boundaries of our understanding of this phenomenon, and allows for careful extrapolation to other situations and populations. From a practical point of view, these results are of importance because they indicate that performance of very well-trained athletes can be improved through the provision of choice.

The results of this study are in line with findings from Chapter 3 where by coaches provided less controlling feedback in winning compared to losing bouts, and in the current study controlling feedback led to inferior punching performance. Yet, while it is not possible to draw any causal relationships between the provided feedback and the match outcome, the results of Chapter 3 and the current chapter propose that supportive feedback is an effective coaching strategy in training and in competition. Allowing athletes some freedom as to what to do in competition, especially in a dynamic, decision making based sports, such as combat sports is a good coaching strategy. This freedom may enhance force delivery, movement velocities, and other important physical qualities, and also because constraining the athletes to a particular plan may lead them to lose sight of important opportunities that may appear during the event. Future research examining the effects of choices on performance during actual competition and training is warranted.

9.5 Positive and negative feedback

The results from the final study, Chapter 8, did not support the initial study hypotheses, and the majority of literature on this topic (28, 33, 34). It was hypothesised that positive feedback would enhance punching forces compared to negative feedback, and alter an athlete's pacing strategy, however no evidence for such an effect was observed. These findings are interesting, especially considering what was observed in Chapter 3, whereby coaches in losing bouts provided half the amount of positive feedback as coaches in the winning bouts. Hence, it is plausible that the superior performance of the athletes observed in Chapter 3 may have resulted in coaches providing them with greater positive feedback, rather than performance being directly influenced by feedback.

The findings from this study indicate that, unlike the majority of research in untrained individuals (11, 33, 34, 58), the provision of false negative feedback appears to have had little influence on performance in these athletes. Whether such results were due to the level of the individuals or the specific exercise task remains unclear. The participants in this study were elite, international calibre athletes. This status could be associated with the ability to deal effectively with various types of feedback without letting it effect performance to a large extent (159, 162). Indeed, it would be interesting to examine if athletes of a lower competitive status would respond in a comparable fashion. It may be that different types of positive and negative feedback lead to dissimilar results. Furthermore, in the present study the reference point of the feedback was the baseline measure. Athletes were told that their performance was better/worst compared to themselves. It may be that changing the reference point to others, rather than oneself, could lead to a stronger response. Indeed, most studies implemented a feedback which compared participant's performance to a peer group rather than their own baseline (27, 33, 34). Studies comparing the effects of different feedback as it pertains to the two references point are required to answer this question.

Finally, the pacing of the punching activity observed over the three rounds, and the three testing days, was an even profile (156). That is, the athletes maintained similar punching forces across a given round, over subsequent rounds, and testing days. This finding, to the best of my knowledge, is novel and thought-provoking. It is not clear what led the athletes to implement this pacing, as fatigue was expected to have a greater impact on their performance. Delivering a large amount of maximal effort punches in a short duration was expected to induce fatigue thus reducing their impact forces. The punching protocol does not fully mimic the boxing activity that commonly takes places in a boxing round/match in which submaximal punches maximal effort punches are delivered interchangeably (104, 105). For these two reasons, a negative pacing strategy was expected to have been implemented, in which the forces decrease over time, within a round, and perhaps between rounds (156). It may be that athletes attempted to spread their efforts evenly across the rounds and within each round to maintain consist performance, which is perhaps associated with better performance in competitions. Indeed, an "aggressive" pace, in which an athlete applies maximal efforts, may lead to premature fatigue early in the bout thereby risking losing the subsequent rounds. Conversely, we could expect athletes to apply higher punching forces early in the task. Whether similar pacing is observed in actual competition is not known but may be unique to the combat athlete and their competition environment reflecting a true self-preservation strategy. In the majority of pacing literature an increase in power/force is commonly observed in running and cycling exercises (156, 165, 167). Accordingly, it is somewhat surprising that an increase in punching forces towards the end of the exercise task was not observed. Rather, punching forces in the present study were maintained throughout the punching task. Clearly, more research is warranted investigating pacing in combat sports, a topic that is currently mostly investigated in sports such as swimming running and cycling.

9.6 Limitations

There are a number of limitations to the studies conducted in this thesis worthy of discussion. Mainly, in all studies other than study 4 (Chapter 6) the sample sizes were relatively small which limits both the internal and external validity. The reason for the small samples is that the amount of competitive athletes is limited, and they are not always able or willing to participate in such studies. Various research designs were implemented to overcome this shortcoming, such as repeated measures, a large number of data points, as well as tight control over possible cofounding variables. Nevertheless, is important to note and acknowledge this limitation.

Study 1 (Chapter 3) was limited to boxing coaches of a national calibre. Hence, the external validity of the results is limited in scope. The results cannot be extrapolated to other sports or situations. Further, only feedback provided between rounds was analysed and not feedback provided during the bout. It may be that the feedback provided during the bout is different than feedback provided between rounds. Additionally, only three types of feedback were analysed. It could be that other types of feedback that were not included in the analysis also influence performance. Study 3 (Chapter 5) tested impact forces and velocities of combat athletes using a protocol that includes only a number of features that are part of a competitive environment. As such, it is difficult to extrapolate the results to more realistic, combat specific situation that require quick decision making and reaction times which is why future research may wish to examine how feedback influences other aspects of combat performance. Part 1 of Study 5 (Chapter 7) involved a case-study, which has a number of clear limitations. In study 6, due to technical limitations, velocity was not collected. Given that in all other studies velocity was sensitive and reactive to the various types of feedback, this is a significant shortcoming as it may be possible that the positive and/or negative feedback influenced this outcome.

9.7 Conclusions

In summary, this thesis examined what type of coaching feedbacks are commonly provided during boxing competitions, and how these types of feedback influence physical performance as measured with competitive combat athletes and resistance trained participants. This thesis concludes the following:

1. For the most part, national level boxing coaches do not take advantage of optimal feedback and instructions in competition. They underutilize feedback that was repeatedly found to enhance motor learning and performance, and over utilize feedback that was shown to negatively affect performance. Further, differences were identified between the frequencies of feedback types provided in bouts that were won, compared to those that were lost. Coaches in winning bouts provided feedback that is consider more optimal than those in the losing bouts.
2. External focus led resistance trained participants to apply greater peak forces in the Isometric Mid-Thigh Pull compared to internal focus and neutral instructors.
3. External focus led intermediate and elite level combat athletes to punch harder and faster compared to internal focus and neutral instructors.
4. Performing single and multi-joint resistance training like exercises in front of mirror does not seem to have a positive or a negative effect. Performance in front of the mirror was inferior compared to external focus instructions, superior compared to internal focus instructions, and comparable with neutral instructions.
5. Providing competitive combat athletes with a choice concerning the order of the to-be-delivered punches enhanced punching forces and velocities compared to a no-choice condition. This was confirmed in a case-study of a world champion kickboxers, as well as with a cohort of amateur competitive boxers.

6. False positive, negative and neutral performance feedback did not influence punching forces or pacing (distribution of forces over time) of elite amateur boxers during a repeated punching protocol. The pacing profile observed was an even pace, in which forces remained relatively unchanged within a round, and between rounds.

10 REFERENCES

1. Wulf G. Attentional focus and motor learning: a review of 15 years. International Review of Sport and Exercise Psychology. 2013;6(1):77-104.

2. Jones HS, Williams EL, Bridge CA, Marchant D, Midgley AW, Micklewright D, et al. Physiological and psychological effects of deception on pacing strategy and performance: a Review. Sports Medicine. 2013;43(12):1243-57.

3. Lauber B, Keller M. Improving motor performance: Selected aspects of augmented feedback in exercise and health. European Journal of Sport Science. 2014;14(1):36-43.

4. Faulkner J, Arnold T, Eston R. Effect of accurate and inaccurate distance feedback on performance markers and pacing strategies during running. Scandinavian Journal of Medicine and Science in Sports. 2011;21(6):176-83.

5. Mauger AR, Jones AM, Williams CA. Influence of feedback and prior experience on pacing during a 4-km cycle time trial. Medicine and Science in Sports and Exercise. 2009;41(2):451-8.

6. Skorski S, Abbiss CR. The Manipulation of Pace within Endurance Sport. Frontiers in Physiology. 2017;8(102):1-8.

7. Wulf G, Lewthwaite R. Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. Psychonomic Bulletin and Review. 2016;23(5):1-33.

8. Wulf G. Self-controlled practice enhances motor learning: implications for physiotherapy. Physiotherapy. 2007;93(2):96-101.

9. Halperin I, Chapman DW, Martin DT, Abbiss C, Wulf G. Coaching cues in amateur boxing: An analysis of ringside feedback provided between rounds of competition. Psychology of Sport and Exercise. 2016;25:44-50.

10. Porter J, Wu W, Partridge J. Focus of attention and verbal instructions: Strategies of elite track and field coaches and athletes. Sport Science Review. 2010;19(3-4):77-89.

11. Lewthwaite R, Chiviacowsky S, Drews R, Wulf G. Choose to move: The motivational impact of autonomy support on motor learning. Psychonomic Bulletin and Review. 2015;22(5):1-6.

12. Makaruk H, Porter JM. Focus of Attention for Strength and Conditioning Training. Strength and Conditioning Journal. 2014;36(1):16-22.

13. Zachry T, Wulf G, Mercer J, Bezodis N. Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. Brain Research Bulletin. 2005;67(4):304-9.

14. Marchant DC, Greig M, Bullough J, Hitchen D. Instructions to Adopt an External Focus Enhance Muscular Endurance. Research Quarterly for Exercise and Sport. 2011;82(3):466-73.

15. Porter JM, Anton PM, Wikoff NM, Ostrowski JB. Instructing skilled athletes to focus their attention externally at greater distances enhances jumping performance. The Journal of Strength and Conditioning Research. 2013;27(8):2073-8.

16. Wulf G, Shea C, Park J-H. Attention and motor performance: Preferences for and advantages of an external focus. Research Quarterly for Exercise and Sport. 2001;72(4):335-44.

17. Stoate I, Wulf G. Does the attentional focus adopted by swimmers affect their performance? International Journal of Sports Science and Coaching. 2011;6(1):99-108.

18. Wulf G. Attentional focus effects in balance acrobats. Research Quarterly for Exercise and Sport. 2008;79(3):319-25.

19. Porter J, Nolan R, Ostrowski E, Wulf G. Directing attention externally enhances agility performance: a qualitative and quantitative analysis of the efficacy of using verbal instructions to focus attention. Frontiers in Psychology. 2010;1(216):1-7.

20. Wulf G, Adams N. Small choices can enhance balance learning. Human Movement Science. 2014;38:235-40.

21. Wulf G, Freitas HE, Tandy RD. Choosing to exercise more: Small choices increase exercise engagement. Psychology of Sport and Exercise. 2014;15(3):268-71.

22. Lessa HT, Chiviacowsky S. Self-controlled practice benefits motor learning in older adults. Human Movement Science. 2015;40:372-80.

23. Lim S, Ali A, Kim W, Kim J, Choi S, Radlo SJ. Influence of Self-Controlled Feedback on Learning a Serial Motor Skill. Perceptual and Motor Skills. 2015;120(2):462-74.

24. Chiviacowsky S. Self-controlled practice: Autonomy protects perceptions of competence and enhances motor learning. Psychology of Sport and Exercise. 2014;15(5):505-10.

25. Leotti LA, Delgado MR. The inherent reward of choice. Psychological Science. 2011;22(10):1-8.

26. Wulf G, Raupach M, Pfeiffer F. Self-controlled observational practice enhances learning. Research Quarterly for Exercise and Sport. 2005;76(1):107-11.

27. Hutchinson JC, Sherman T, Martinovic N, Tenenbaum G. The effect of manipulated self-efficacy on perceived and sustained effort. Journal of Applied Sport Psychology. 2008;20(4):457-72.

28. Lewthwaite R, Wulf G. Social-comparative feedback affects motor skill learning. The Quarterly journal of experimental psychology A, Human experimental psychology. 2010;63(4):738-49.

29. Chiviacowsky S, Wulf G. Feedback after good trials enhances learning. Research Quarterly for Exercise and Sport. 2007;78(2):40-7.

30. Wilson MG, Lane AM, Beedie CJ, Farooq A. Influence of accurate and inaccurate 'split-time'feedback upon 10-mile time trial cycling performance. European Journal of Applied Physiology. 2012;112(1):231-6.

31. Micklewright D, Papadopoulou E, Swart J, Noakes T. Previous experience influences pacing during 20 km time trial cycling. British Journal of Sports Medicine. 2010;44(13):952-60.

32. Parry D, Chinnasamy C, Micklewright DP. Optic flow influences perceived exertion during cycling. Journal of Sport and Exercise Psychology. 2012;34(4):444-56.

33. Stoate I, Wulf G, Lewthwaite R. Enhanced expectancies improve movement efficiency in runners. Journal of sports sciences. 2012;30(8):815-23.

34. McKay B, Lewthwaite R, Wulf G. Enhanced expectancies improve performance under pressure. Frontiers in Psychology. 2012;3(8):1-5.

35. Palmer K, Chiviacowsky S, Wulf G. Enhanced expectancies facilitate golf putting. Psychology of Sport and Exercise. 2016;22:229-32.

36. Pascua LA, Wulf G, Lewthwaite R. Additive benefits of external focus and enhanced performance expectancy for motor learning. Journal of sports sciences. 2015;33(1):58-66.

37. Hodges N, Williams MA. Skill acquisition in sport: Research, theory and practice: Routledge; 2012.

38. Wulf G, Weigelt M, Poulter D, McNevin N. Attentional focus on suprapostural tasks affects balance learning. The Quarterly journal of experimental psychology A, Human experimental psychology. 2003;56(7):1191-211.

39. Wulf G, Su J. An external focus of attention enhances golf shot accuracy in beginners and experts. Research Quarterly for Exercise and Sport. 2007;78(4):384-9.

40. Chiviacowsky S, Wulf G, de Medeiros FL, Kaefer A, Tani G. Learning benefits of self-controlled knowledge of results in 10-year-old children. Research Quarterly for Exercise and Sport. 2008;79(3):405-10.

41. Badami R, VaezMousavi M, Wulf G, Namazizadeh M. Feedback about more accurate versus less accurate trials: Differential effects on self-confidence and activation. Research Quarterly for Exercise and Sport. 2012;83(2):196-203.

42. Rotem-Lehrer N, Laufer Y. Effect of focus of attention on transfer of a postural control task following an ankle sprain. Journal of Orthopaedic and Sports Physical Therapy. 2007;37(9):564-9.

43. Chiviacowsky S, Wulf G, Lewthwaite R, Campos T. Motor learning benefits of self-controlled practice in persons with Parkinson's disease. Gait and Posture. 2012;35(4):601-5.

44. Marchant DC. Attentional focusing instructions and force production. Movement Science and Sport Psychology. 2011;1:1-9.

45. Marchant DC, Greig M, Scott C. Attentional focusing instructions influence force production and muscular activity during isokinetic elbow flexions. Journal of Strength and Conditioning Research. 2009;23(8):2358-66.

46. Greig M, Marchant D. Speed dependant influence of attentional focusing instructions on force production and muscular activity during isokinetic elbow flexions. Human Movement Science. 2014;33:135-48.

47. Porter JM, Anton PM, Wu WF. Increasing the distance of an external focus of attention enhances standing long jump performance. The Journal of Strength and Conditioning Research. 2012;26(9):2389-93.

48. Zarghami M, Saemi E, Fathi I. External focus of attention enhances discus throwing performance. Kinesiology. 2012;44(1):47-51.

49. Ille A, Selin I, Do M-C, Thon B. Attentional focus effects on sprint start performance as a function of skill level. Journal of sports sciences. 2013;31(15):1705-12.

50. Wu WFW, Porter JM, Brown LE. Effect of attentional focus strategies on peak force and performance in the standing long jump. The Journal of Strength and Conditioning Research. 2012;26(5):1226-31.

51. Porter JM, Sims B. Altering focus of attention influences elite athletes sprinting performance. International Journal of Coaching Science. 2013;7(2):41-51.

52. Bartholomew B. Attentional focus does not impact agility performance amongst division I women collegiate Tennis players. (Unpublished master's thesis) Southern Illinois University, Carbondale, USA. 2012.

53. Wulf G, Mercer J, McNevin N, Guadagnoli MA. Reciprocal influences of attentional focus on postural and suprapostural task performance. Journal of Motor Behavior. 2004;36(2):189-99.

54. Wulf G, McNevin N, Shea CH. The automaticity of complex motor skill learning as a function of attentional focus. The Quarterly journal of experimental psychology A, Human experimental psychology. 2001;54(4):1143-54.

55. Wulf G, Dufek JS, Lozano L, Pettigrew C. Increased jump height and reduced EMG activity with an external focus. Human Movement Science. 2010;29(3):440-8.

56. Sanli E, Patterson J, Bray S. Understanding self-controlled motor learning protocols through the selfdetermination theory. Frontiers in Movement Science and Sport Psychology. 2013;3:1-17.

57. McKay B, Lewthwaite R, Wulf G. Enhanced expectancies improve performance under pressure. Frontiers in Psychology. 2012;3:1-5.

58. Hooyman A, Wulf G, Lewthwaite R. Impacts of autonomy-supportive versus controlling instructional language on motor learning. Human Movement Science. 2014;36:190-8.

59. Post PG, Fairbrother JT, Barros JA. Self-controlled amount of practice benefits learning of a motor skill. Research Quarterly for Exercise and Sport. 2011;82(3):474-81.

60. Janelle CM, Kim J, Singer RN. Subject-controlled performance feedback and learning of a closed motor skill. Perceptual and Motor Skills. 1995;81(2):627-34.

61. Hartman JM. Self-controlled use of a perceived physical assistance device during a balancing task. Perceptual and Motor Skills. 2007;104(3):1005-16.

62. Wulf G, Toole T. Physical assistance devices in complex motor skill learning: Benefits of a self-controlled practice schedule. Research Quarterly for Exercise and Sport. 1999;70(3):265-72.

63. Deci EL, Ryan RM. The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior. Psychological Inquiry. 2000;11(4):227-68.

64. Deci EL, Ryan R. Overview of self-determination theory: An organismic dialectical perspective. Handbook of self-determination research, University Rochester Press. 2002:3-33.

65. Leotti LA, Iyengar SS, Ochsner KN. Born to choose: The origins and value of the need for control. Trends in Cognitive Sciences. 2010;14(10):457-63.

66. Tiger JH, Hanley GP, Hernandez E. An evaluation of the value of choice with preschool children. Journal of Applied Behavior Analysis. 2006;39(1):1.

67. Catania AC. Freedom and knowledge: an experimental analysis of preference in pigeons. Journal of the Experimental Analysis of Behavior. 1975;24(1):89-106.

68. Aarts H, Bijleveld E, Custers R, Dogge M, Deelder M, Schutter D, et al. Positive priming and intentional binding: Eye-blink rate predicts reward information effects on the sense of agency. Social Neuroscience. 2012;7(1):105-12.

69. Allen MS, Greenlees I, Jones M. An investigation of the five-factor model of personality and coping behaviour in sport. Journal of sports sciences. 2011;29(8):841-50.

70. Saemi E, Porter JM, Ghotbi-Varzaneh A, Zarghami M, Maleki F. Knowledge of results after relatively good trials enhances self-efficacy and motor learning. Psychology of Sport and Exercise. 2012;13(4):378-82.

71. Maurer H, Munzert J. Influence of attentional focus on skilled motor performance: Performance decrement under unfamiliar focus conditions. Human Movement Science. 2013;32(4):730-40.

72. Lohse KR, Sherwood DE, Healy AF. How changing the focus of attention affects performance, kinematics, and electromyography in dart throwing. Human Movement Science. 2010;29(4):542-55.

73. Marchant DC, Clough PJ, Crawshaw M. The effects of attentional focusing strategies on novice dart throwing performance and Their task experiences. International Journal of Sport and Exercise Psychology. 2007;5(3):291-303.

74. Halperin I, Williams K, Martin DT, Chapman DW. The effects of attentional focusing instructions on force production during the isometric mid-thigh pull. The Journal of Strength and Conditioning Research. 2015;30(4):919-23.

75. Kal E, Van Der Kamp J, Houdijk H. External attentional focus enhances movement automatization: A comprehensive test of the constrained action hypothesis. Human Movement Science. 2013;32(4):527-39.

76. McNevin NH, Shea CH, Wulf G. Increasing the distance of an external focus of attention enhances learning. Psychological Research. 2003;67(1):22-9.

77. Lohse KR. The influence of attention on learning and performance: Pre-movement time and accuracy in an isometric force production task. Human Movement Science. 2012;31(1):12-25.

78. Teixeira PJ, Carraça EV, Markland D, Silva MN, Ryan RM. Exercise, physical activity, and self-determination theory: a systematic review. International Journal of Behavioral Nutrition and Physical Activity. 2012;9(1):1-30.

79. Trempe M, Sabourin M, Proteau L. Success modulates consolidation of a visuomotor adaptation task. Journal of Experimental Psychology: Learning, Memory, and Cognition. 2012;38(1):52-60.

80. Lewthwaite R, Wulf G. 10 Motor learning through a motivational lens. 2nd ed. Skill acquisition in sport: research, theory and practice: Taylor and Francis; 2012. 300 p.

81. McKay B, Wulf G, Lewthwaite R, Nordin A. The self: Your own worst enemy? A test of the self-invoking trigger hypothesis. The Quarterly journal of experimental psychology A, Human experimental psychology. 2015;68(9):1910-9.

82. Wulf G, Chiviacowsky S, Cardozo PL. Additive benefits of autonomy support and enhanced expectancies for motor learning. Human Movement Science. 2014;37(2):12-20.

83. Wulf G, Chiviacowsky S, Drews R. External focus and autonomy support: Two important factors in motor learning have additive benefits. Human Movement Science. 2015;40(2):176-84.

84. Wulf G, Lewthwaite R, Cardozo P, Chiviacowsky S. Triple play: Additive contributions of enhanced expectancies, autonomy support, and external attentional focus to motor learning. The Quarterly journal of experimental psychology A, Human experimental psychology. 2017(in-press):1-22.

85. Chaabène H, Tabben M, Mkaouer B, Franchini E, Negra Y, Hammami M, et al. Amateur boxing: physical and physiological attributes. Sports Medicine. 2014;45(3):337-52.

86. Halperin I, Chapman DW, Martin DT, Abbiss C. The effects of attentional focus instructions on punching velocity and impact forces among trained combat athletes. Journal of sports sciences. 2016;35(5):1-8.

87. Halperin I, Chapman DW, Martin DT, Lewthwaite R, Wulf G. Choices enhance punching performance of competitive kickboxers. Psychological Research. 2016;In-press:1-8.

88. Wulf G, Lewthwaite R, Hooyman A. Can Ability Conceptualizations Alter the Impact of Social Comparison in Motor Learning? Journal of Motor Learning and Development. 2013;1(1):20-30.

89. Makaruk H, Porter JM, Makaruk B. Acute effects of attentional focus on shot put performance in elite athletes. Kineziologija. 2013;45(1):55-62.

90. Comfort P, Jones PA, McMahon JJ, Newton R. Effect of knee and trunk angle on knetic variables during the isometric mid-thigh pull: test-retest reliability. International Journal of Sports Physiology and Performance. 2014;10(1):58-63.

91. Sheppard J, Chapman D, Taylor K-L. An evaluation of a strength qualities assessment method for the lower body. Journal of Australian Strength and Conditioning. 2011;19(2):4-10.

92. Beckham G, Mizuguchi S, Carter C, Sato K, Ramsey M, Lamont H, et al. Relationships of isometric mid-thigh pull variables to weightlifting performance. The Journal of Sports Medicine and Physical Fitness. 2013;53(5):573-81.

93. Haff GG, Carlock MJ, Hartman JM, Kilgore JL, Kawamori N, Jackson RJ, et al. Force--time curve characteristics of dynamic and isometric muscle actions of elite women olympic weightlifters. The Journal of Strength and Conditioning Research. 2005;19(4):741-8.

94. West DJ, Owen NJ, Jones MR, Bracken RM, Cook CJ, Cunningham DJ, et al. Relationships between force–time characteristics of the isometric midthigh pull and dynamic

performance in professional rugby league players. The Journal of Strength and Conditioning Research. 2011;25(11):3070-5.

95. Kawamori N, Rossi SJ, Justice BD, Haff EE, Pistilli EE, O'bryant HS, et al. Peak force and rate of force development during isometric and dynamic mid-thigh clean pulls performed at various intensities. The Journal of Strength and Conditioning Research. 2006;20(3):483-91.

96. Nuzzo JL, McBride JM, Cormie P, McCaulley GO. Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. The Journal of Strength and Conditioning Research. 2008;22(3):699-707.

97. Bemben MG, Clasey JL, Massey BH. The effect of the rate of muscle contraction on the force-time curve parameters of male and female subjects. Research Quarterly for Exercise and Sport. 1990;61(1):96-9.

98. Christ CB, Boileau RA, Slaughter MH, Stillman RJ, Cameron J. The effect of test protocol instructions on the measurement of muscle function in adult women. Journal of Orthopaedic and Sports Physical Therapy. 1993;18(3):502-10.

99. Sahaly R, Vandewalle H, Driss T, Monod H. Maximal voluntary force and rate of force development in humans–importance of instruction. European Journal of Applied Physiology. 2001;85(3-4):345-50.

100. Miller T. NSCA's Guide to Tests and Assessments. Association NSC, editor: Human Kinetics; 2012. 178-9 p.

101. Rhea MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. The Journal of Strength and Conditioning Research. 2004;18(4):918-20.

102. Cappai I, Pierantozzi E, Tam E, Tocco F, Angius L, Milia R, et al. Physiological responses and match analysis of Muay Thai fighting. International Journal of Performance Analysis in Sport. 2012;12(3):507-16.

103. Franchini E, Tabben M, Chaabene H. Physiological responses during taekwondo training and competition: review article. International SportMed Journal. 2014;15(4):500-15.

104. Davis P, Leithäuser RM, Beneke R. The Energetics of Semi-Contact 3 x 2 min Amateur Boxing. International Journal of Sports Physiology and Performance. 2014;9(2):233-9.

105. Davis P, Benson PR, Pitty JD, Connorton AJ, Waldock R. The activity profile of elite male amateur boxing. International Journal of Sports Physiology and Performance. 2015;10(1):53-7.

106. Silva JJR, Del Vecchio FB, Picanço LM, Takito MY, Franchini E. Time-motion analysis in Muay-Thai and kick-boxing amateur matches. Journal of Human Sport and Exercise. 2011;6(3):490-6.

107. Smith M, Dyson R, Hale T, Janaway L. Development of a boxing dynamometer and its punch force discrimination efficacy. Journal of sports sciences. 2000;18(6):445-50.

108. Pierce JD, Reinbold KA, Lyngard BC, Goldman RJ, Pastore CM. Direct measurement of punch force during six professional boxing matches. Journal of Quantitative Analysis in Sports. 2006;2(2):1-4.

109. Lenetsky S, Harris N, Brughelli M. Assessment and contributors of punching forces in combat sports athletes: Implications for strength and conditioning. Strength and Conditioning Journal. 2013;35(2):1-7.

110. Turner AN. Strength and conditioning for Muay Thai athletes. Strength and Conditioning Journal. 2009;31(6):78-92.

111. Wulf G, Lauterbach B, Toole T. The learning advantages of an external focus of attention in golf. Research Quarterly for Exercise and Sport. 1999;70(2):120-6.

112. Hodges NJ, Ford P. Wulf on attentional focus and motor learning [Target article]. Skillful attending, looking and thinking. E-Journal Bewegung und Training. 2007;1:23-4.

113. Freudenheim AM, Wulf G, Madureira F, Pasetto SC, Corrêa UC. An external focus of attention results in greater swimming speed. International Journal of Sports Science and Coaching. 2010;5(4):533-42.

114. Obminski Z BL, Sikorski W. The shot put performanceas a marker of explosive strength in polish amateur boxers. Archives of Budo. 2011;7(3):173-7.

115. Loturco I, Nakamura FY, Artioli GG, Kobal R, Kitamura K, Cal Abad CC, et al. Strength and power qualities are highly associated with punching impact in elte boxers Journal of strength and conditioning research / National Strength & Conditioning Association. 2015;30(4):109-16.

116. Schücker L, Knopf C, Strauss B, Hagemann N. An internal focus of attention is not always as bad as its reputation: How specific aspects of internally focused attention do not hinder running efficiency. Journal of Sport and Exercise Psychology. 2014;36(3):233-43.

117. Lohse KR, Sherwood DE. Defining the focus of attention: effects of attention on perceived exertion and fatigue. Frontiers in Psychology. 2011;2:1-10.

118. Halperin I, Pyne DB, Martin DT. Threats to internal validity in exercise science: A review of overlooked confounding variables. International Journal of Sports Physiology and Performance. 2015;10(7):823-9.

119. Marchant DC, Clough PJ, Crawshaw M, Levy A. Novice motor skill performance and task experience is influenced by attentional focusing instructions and instruction preferences. International Journal of Sport and Exercise Psychology. 2009;7(4):488-502.

120. Ehrlenspiel F, Lieske J, Rübner A. Interaction between preference and instructions for a focus of attention in billiards. Perceptual and Motor Skills. 2004;99(1):127-30.

121. Sewall LP, Reeve TG, Day RA. Effect of concurrent visual feedback on acquisition of a weightlifting skill. Perceptual and Motor Skills. 1988;67(3):715-8.

122. Bennett S, Davids K. The manipulation of vision during the powerlift squat: Exploring the boundaries of the specificity of learning hypothesis. Research Quarterly for Exercise and Sport. 1995;66(3):210-8.

123. Dearborn K, Ross R. Dance learning and the mirror: comparison study of dance phrase learning with and without mirrors. Journal of Dance Education. 2006;6(4):109-15.

124. Radell SA, Adame DD, Cole SP. Effect of teaching with mirrors on ballet dance performance. Perceptual and Motor Skills. 2003;97(3):960-4.

125. Eaves DL, Hodges NJ, Williams AM. Energetic costs of incidental visual coupling during treadmill running. Medicine and Science in Sports and Exercise. 2008;40(8):1506-14.

126. Rougier P, editor [How mirror feedback improves undisturbed upright stance control]. Annales de readaptation et de medecine physique: revue scientifique de la Societe francaise de reeducation fonctionnelle de readaptation et de medecine physique; 2002.

127. Vaillant J, Vuillerme N, Janvy A, Louis F, Juvin R, Nougier V. Mirror versus stationary cross feedback in controlling the center of foot pressure displacement in quiet standing in elderly subjects. Archives of Physical Medicine and Rehabilitation. 2004;85(12):1962-5.

128. Lynch JA, Chalmers GR, Knutzen KM, Martin LT. Effect on performance of learning a Pilates skill with or without a mirror. Journal of Bodywork and Movement Therapies. 2009;13(3):283-90.

129. Notarnicola A, Maccagnano G, Pesce V, Di Pierro S, Tafuri S, Moretti B. Effect of teaching with or without mirror on balance in young female ballet students. BMC research notes. 2014;7(1):426-31.

130. Katula JA, McAuley E. The mirror does not lie: Acute exercise and self-efficacy. International Journal of Behavioral Medicine. 2001;8(4):319-26.

131. Lamarche L, Gammage KL, Strong HA. The effect of mirrored environments on self-presentational efficacy and social anxiety in women in a step aerobics class. Psychology of Sport and Exercise. 2009;10(1):67-71.

132. Radell SA, Adame DD, Cole SP. Effect of teaching with mirrors on body image and locus of control in women college ballet dancers. Perceptual and Motor Skills. 2002;95(3):1239-47.

133. Ginis KAM, Jung ME, Gauvin L. To see or not to see: Effects of exercising in mirrored environments on sedentary women's feeling states and self-efficacy. Health Psychology. 2003;22(4):354-62.

134. Radell SA, Keneman ML, Adame DD, Cole SP. My body and its reflection: a case study of eight dance students and the mirror in the ballet classroom. Research in Dance Education. 2014;15(2):161-78.

135. Cohen J. A power primer. Psychological Bulletin. 1992;112(1):155-9.

136. Weiss SM, Reber AS, Owen DR. The locus of focus: The effect of switching from a preferred to a non-preferred focus of attention. Journal of sports sciences. 2008;26(10):1049-57.

137. Rodin J, Langer EJ. Long-term effects of a control-relevant intervention with the institutionalized aged. Journal of Personality and Social Psychology. 1977;35(12):897-906.

138. White RW. Motivation reconsidered: the concept of competence. Psychological Review. 1959;66(5):297-333.

139. Voss S, Homzie M. Choice as a value. Psychological Reports. 1970;26(3):912-4.

140. Tafarodi RW, Milne AB, Smith AJ. The confidence of choice: Evidence for an augmentation effect on self-perceived performance. Personality and Social Psychology Bulletin. 1999;25(11):1405-16.

141. Janelle CM, Barba DA, Frehlich SG, Tennant LK, Cauraugh JH. Maximizing performance feedback effectiveness through videotape replay and a self-controlled learning environment. Research Quarterly for Exercise and Sport. 1997;68(4):269-79.

142. Ali A, Fawver B, Kim J, Fairbrother J, Janelle CM. Too much of a good thing: random practice scheduling and self-control of feedback lead to unique but not additive learning benefits. Frontiers in Psychology. 2012;3:1-10.

143. Aiken CA, Fairbrother JT, Post PG. The effects of self-controlled video feedback on the learning of the basketball set shot. Frontiers in Psychology. 2012;3:1-10.

144. Turner A, Baker E, Miller S. Increasing the impact force of the rear hand punch. Strength and Conditioning Journal. 2011;33(6):2-9.

145. Halperin I, Chapman D, Martin DA, C. The effects of attentional feedback instructions on punching velocity and impact forces among trained combat athletes Journal of Sports Science 2015;35(5):1-7.

146. Halperin I, Hughes S, Chapman DW. Physiological profile of a professional boxer preparing for Title Bout: a case study. Journal of sports sciences. 2016;34(20):1949-56.

147. Kinugasa T. The application of single-case research designs to study elite athletes' conditioning: An update. Journal of Applied Sport Psychology. 2013;25(1):157-66.

148. Hopkins WG. How to interpret changes in an athletic performance test. Sportscience. 2004;8:1-7.

149. Cordes K. Boxing: Reasons to strength train for amateur boxing. Strength and Conditioning Journal. 1991;13(5):18-21.

150. Lee W, Reeve J. Self-determined, but not non-self-determined, motivation predicts activations in the anterior insular cortex: an fMRI study of personal agency. Social Cognitive and Affective Neuroscience. 2012;8(5): 538-45.

151. Foreman KB, Singer ML, Addison O, Marcus RL, LaStayo PC, Dibble LE. Effects of dopamine replacement therapy on lower extremity kinetics and kinematics during a rapid force production task in persons with Parkinson disease. Gait and Posture. 2014;39(1):638-40.

152. Smith M. Physiological profile of senior and junior England international amateur boxers. Journal of Sports Science and Medicine. 2006;5:74-89.

153. Ashker SE. Technical and tactical aspects that differentiate winning and losing performances in boxing. International Journal of Performance Analysis in Sport. 2011;11(2):356-64.

154. Blower G. Boxing: Training, Skills and Techniques: Crowood; 2012.

155. Borg GA. Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise 1982;14(5):377-81.

156. Abbiss CR, Laursen PB. Describing and understanding pacing strategies during athletic competition. Sports Medicine. 2008;38(3):239-52.

157. Kantak SS, Winstein CJ. Learning–performance distinction and memory processes for motor skills: A focused review and perspective. Behavioural Brain Research. 2012;228(1):219-31.

158. Wulf G, Chiviacowsky S, Lewthwaite R. Normative feedback effects on learning a timing task. Research Quarterly for Exercise and Sport. 2010;81(4):425-31.

159. Guillén F, Laborde S. Higher-order structure of mental toughness and the analysis of latent mean differences between athletes from 34 disciplines and non-athletes. Personality and Individual Differences. 2014;60:30-5.

160. Martin K, Staiano W, Menaspà P, Hennessey T, Marcora S, Keegan R, et al. Superior inhibitory control and resistance to mental fatigue in professional road cyclists. PloS One. 2016;11(7):e0159907.

161. Galli N, Gonzalez SP. Psychological resilience in sport: A review of the literature and implications for research and practice. International Journal of Sport and Exercise Psychology. 2015;13(3):243-57.

162. Sarkar M, Fletcher D, Brown DJ. What doesn't kill me…: Adversity-related experiences are vital in the development of superior Olympic performance. Journal of Science and Medicine in Sport. 2015;18(4):475-9.

163. Fletcher D, Sarkar M. A grounded theory of psychological resilience in Olympic champions. Psychology of Sport and Exercise. 2012;13(5):669-78.

164. Halperin I, Aboodarda S, Basset F, Byrne J, Behm D. Pacing strategies during repeated maximal voluntary contractions. European Journal of Applied Physiology. 2014;14(7):1413-20.

165. Billaut F, Bishop DJ, Schaerz S, Noakes TD. Influence of knowledge of sprint number on pacing during repeated-sprint exercise. Medicine and Science in Sports and Exercise. 2011;43(4):665-72.

166. Diekfuss JA, Raisbeck LD. Focus of Attention and Instructional Feedback From NCAA Division 1 Collegiate Coaches. Journal of Motor Learning and Development. 2016;4(2):262-73.

167. De Koning JJ, Foster C, Bakkum A, Kloppenburg S, Thiel C, Joseph T, et al. Regulation of pacing strategy during athletic competition. PloS One. 2011;6(1):e15863.