

The effects of attentional focus and dual-tasking on conventional deadlift performance in experienced lifters

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ABSTRACT

Previous attentional focus literature suggests that adopting an external focus (EF) results in greater force production through a variety of mechanisms. The purpose of the present study was to examine the effects of attentional focus and dual-tasking when performing heavily loaded barbell movements that are specific to strength-based sports. Fifteen resistance-trained males (age = 23.3 ± 3.4 years) reported to the laboratory for three visits. The first visit consisted of a five-repetition maximum (5RM) test on the conventional deadlift. During the subsequent sessions, the participants performed a total of twelve single conventional deadlift repetitions while adopting an internal focus (IF), an external focus (EF), or while performing the cognitive task (COG). The IF and EF consisted of focusing on activating the quadriceps and maintain a straight bar path, respectively. The COG consisted of counting the total occurrence of two single-digits in a sequence of three-digit numbers, separately. Three-dimensional motion capture and force platforms were used to collect kinematic and kinetic data. No significant differences were found between the IF, the EF and the COG for lift duration, peak barbell velocity, peak vertical ground reaction force, area of 95% confidence ellipse, peak hip moments and peak hip powers. Adopting an EF significantly reduced variability of the barbell trajectory and centre of pressure (COP) in the anterior-posterior direction. Mean velocity of COP was also significantly lower for the EF. Our findings suggest that adopting an EF may lead to greater postural stability when performing heavily loaded barbell movements.

Key words: attentional focus, strength training, athletic performance, powerlifting, psychology, cognitive strategies, dual-task

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CHAPTER ONE: LITERATURE REVIEW

1.1 Attentional focus

Elite level competition in almost any discipline is often won within small margins. From implementing complex periodization models to utilizing the latest technological advancement, no stone is left unturned for athletes looking for an edge over their competition. Anecdotally, athletes have noticed that the quality and accuracy of skill execution is greatly influenced by their focus while performing a given skill. More specifically, when athletes pay attention to their own body movements, they notice substantial decreases in their ability to perform well-practiced skills (Kimble & Perlmutter, 1970; Klatzky, 1984; Masters, 1992; Schmidt, 1988). Athletes have also noticed the opposite to be true. That is, when they focus on movement outcomes (e.g. tennis ball making contact with the racket, golf ball going into the hole, a punch making contact with a target, etc.), skill execution becomes ‘smooth’ or effortless. This phenomenon has not only been documented through anecdotal evidence, but it has also been demonstrated experimentally (e.g. Wulf, Dufek, Lozano, & Pettigrew, 2001).

Literature examining attentional focus is commonly subdivided into two types of focus, internal and external. When an individual directs their focus on their own body movements during skill execution, it is said that they are adopting an internal focus (IF). Alternatively, an external focus (EF) is adopted when an individual directs their focus on the effects their body movements have on the environment (i.e. movement effects) (Wulf, Hob, & Prinz, 1998). Wulf et al. (1998) completed one of the first studies to examine the effects of instructions inducing an IF or EF on motor learning. They used a balancing task in which “participants performed slalom-type movements on a ski-simulator” to assess learning over the course of three days (i.e. two consecutive daily practice sessions followed by a retention test to assess learning on the third

session). The IF group was instructed to “exert force on the outer foot as long as the platform moved in the respective direction”, while the EF group was instructed to focus on the outer wheels rather than their feet. Participants in the EF group produced larger increases in movement amplitudes when compared to the IF and control groups during the practice sessions, which draws similarities to the expert performances completed in a previous study done by Wulf, Shea, and Matschiner (1998). The EF group also produced larger movement amplitudes during the retention test, thus strengthening the notion that this increase in performance is not transient in nature, but rather a result of more effective learning. In an effort to examine the generalizability of these findings, Wulf et al. (1998) replaced the ski-simulator with a different balancing task (i.e. balancing on a stabilometer) during a follow-up experiment. While no significant advantages were reported for the EF group during the practice sessions, the EF group yielded less root-mean-square error, indicating superior learning compared to the IF group. The findings of these two experiments would later become the start of the foundation of research focusing on attentional focus and the advantages in motor learning and performance associated with an EF.

Shortly after establishing the learning benefits associated with an EF, McNevin et al. (2003) examined the influence of focus type and distance on learning how to balance on a stabilometer. Participants of this study were instructed to focus on keeping their feet level (i.e. IF) or on markers placed at various positions on the stabilometer (i.e. EF) as they attempted to keep the platform of the stabilometer horizontal with the floor. The markers were positioned such that they were directly in front of each foot, on the lateral sides of each foot and on the medial sides of each foot. The positioning of these markers enabled McNevin et al. (2003) to study the effects of increasing the distance of an EF relative to an IF on motor learning. The

authors concluded that participants that were instructed to focus on the markers rather than their feet yielded less root-mean-square errors when trying to keep the platform of the stabilometer horizontal with ground. In other words, McNevin et al. (2003)'s findings suggest that more effective learning was demonstrated by an EF, resulting in superior balance performance during the retention test. Furthermore, more effective balance learning was found with participants instructed to focus on the distant markers (i.e. markers lateral and medial of each foot) when compared to those that were instructed to focus on markers directly in front of their feet. This second finding suggests that distancing the external focus from the body, either medially or laterally, further improves the learning effects of an EFA.

In addition to research completed by McNevin et al. (2003), many others have also arrived at a similar conclusion when comparing the effects of an EF to an IF with regards to motor learning and performance (e.g. Wulf, Shea, & Park, 2001; Totsika & Wulf, 2003; Wulf & Su, 2007; Chiviawosky, Wulf, & Avila, 2013; Kal, van der Kamp, & Houdijk, 2013, etc.). While many of these studies focus on balance and various trivial tasks, such as riding a pedalo (Totsika & Wulf, 2003), the effects of attentional focus have also been studied in a wide variety of sport specific skills (See Wulf review 2013). Examples of sports that have been studied in the attentional focus literature include golf (Kearney, 2015; Wulf & Su, 2007; Bell & Hardy, 2009; Poolton, Maxwell, Masters, & Raab, 2006), dart throwing (Lohse, Sherwood, & Healy, 2010; Marchant, Clough, & Crawshaw, 2007) and Basketball (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Zachry, Wulf, Mercer, & Bezodis, 2005), to name a few.

1.2 The Constrained action hypothesis and dual-tasking

The consistency in which an EF yields superior performances relative to an IF across a variety of sport-specific and non-sport specific tasks is commonly explained using the constrained action hypothesis. McNevin et al. (2003) proposed that consciously attending to one's movements (i.e. IF) may interfere with the automaticity of motor control processes that regulate movement, whereas focusing on movement effects (i.e. EF) may promote the automaticity of said motor control processes. Recently, Polskaia et al. (2014) extended this line of thought by comparing a cognitive task (COG) with an EF and IF during quiet standing. Participants were instructed to minimize the movement of their hips or to minimize the movement of the markers placed at their hips for the IF condition and the EF condition respectively. For the COG, participants were to 'silently count the total number of times a pre-selected digit (e.g. 0-9) was verbalized via an audio recording in a 3-digit sequence'. Polskaia et al. (2014) found that the COG showed the greatest reduction in sway amplitude and variability, and thus superior postural control compared to the attentional focus conditions. This finding is in line with previous research examining the effects of COGs on posture during quiet standing (Andersson, Hagman, Talianzedeh, Svedberg, & Larsen, 2002; Dault, Geurts, Mulder, & Duysens, 2001). Polskaia et al. (2014) suggested that the COG diverts an individual's attention away from their posture altogether and therefore leads to even less interference of the automatic processes related to posture than an EF. Furthermore, the COG was continuous in nature and prevented the participants from consciously tending to their posture (i.e. IF) for the duration of the trial. This presents an interesting advantage to using a continuous cognitive task when it comes to optimizing performance, as previous research has suggested that athletes primarily use an IF and tend to shift their focus between an IF and EF during skill execution (Porter, Nolan,

Ostrowski, & Wulf, 2010; Porter, Wu, & Partridge, 2010). Unlike attentional focus, the literature pertaining to employing a COG while simultaneously executing a sport specific skill (i.e. dual-tasking) is limited and merits further examination.

1.3 Intramuscular effects of attentional focus

Occasionally, the automaticity of movement is inferred through a variety of measures used to account for differences in outcome measures when comparing an IF and an EF. Some measures used to quantify automaticity include: regularity of movement (e.g. Roerdink, Hlavackova, & Vuillerme, 2011), fluency of movement (e.g. Shemmell, Tresilian, Riek, Barry, & Carson, 2005), secondary task loading on primary motor task performance (e.g. Abernethy, 1988; Kal, Van Der Kamp, & Houdijk, 2013), and muscle activation measured through Electromyography (EMG) (e.g. Vance, Wulf, Toellner, McNevin, & Mercer, 2004; Lohse, Sherwood, & Healy, 2011; Kal, Van Der Kamp, & Houdijk, 2013; Marchant & Greig, 2017; Snyder & Fry, 2012). It has been suggested that consciously controlled movements (i.e. IF) result in greater EMG activity compared to automatized movements, and thus a less efficient mode of control (Wulf, Dufek, Lozano, & Pettigrew, 2010). This has been made evident by several studies using EMG to measure muscle activation following instructions that direct their attention internally. Karst & Willett (2004) examined the influence of instructions emphasizing a predetermined muscle group on EMG activity during a trunk curl exercise. In this study, participants were given instructions emphasizing rectus abdominis activity, oblique abdominis activity or instructions with no specific muscular emphasis (i.e. control condition). The muscular focus was further reinforced during the execution of the trunk curl exercise, apart from the condition involving the instructions with the no specific muscular emphasis. Karst & Willett

(2004) found that participants had a greater normalized oblique:rectus EMG ratio when given the instructions emphasizing oblique abdominis activity compared to either of the other instructions (i.e. rectus abdominis focused and the no specific muscular emphasis). This suggests that individuals are able to volitionally alter relative agonistic muscular activity during the trunk curl exercise. Other studies that also looked at muscular activation of abdominal muscles have come to similar conclusions (e.g., Bressel, Willardson, Thompson, & Fontana, 2009). Additionally, these findings have also extended to other muscle groups (e.g., Bressel, Willardson, Thompson, & Fontana, 2009; Lewis, Shirley, & Sahrman, 2009; Snyder & Leech, 2009; Vance, Wulf, Toellner, McNevin, & Mercer, 2004; Marchant, Greig, & Scott, 2009), which presents the notion that an individual's attentional focus has an effect at the intramuscular level of skill execution.

1.3.1 Force production

Though the present work will not be using EMG to examine differences in muscular activation between different attentional foci, this body of literature is critical in understanding the intramuscular contributions involved in the execution of skills that heavily depend on force production (e.g. resistance based exercises). Interestingly, an increase in EMG activity associated with an IF does not necessarily result in greater force production. Marchant et al. (2009) investigated the effects of attentional focusing instructions on force production and muscle (i.e. bicep) activity during an isokinetic elbow flexion task. The participants were instructed to either 'focus upon the movement of your arm and muscles during the lift' (i.e. IF) or 'focus upon the movement of the crank hand bar during the lift' (i.e. EF) as they performed maximal single-arm elbow flexions on an isokinetic dynamometer. Marchant et al. (2009) reported less muscle activity and higher peak net joint torque in the EF condition when compared to the IF condition.

This suggests that adopting an EF is more effective and efficient in muscle fibre recruitment than an IF. However, it should be noted that Marchant et al. (2009) did not measure muscle activity of the triceps brachii (i.e. antagonist muscle group), which makes it difficult to conclude that the difference in force production between the internal and external condition is purely a result of intramuscular fibre recruitment. Alternatively, Wulf et al. (2007) suggested that a lower force output produced by an IF is the result of inefficient intermuscular coordination. That is, antagonistic muscles are activated in such a way that they impede efficient and effective activation of the agonistic muscles for a given action. With regards to the maximal isokinetic elbow flexion task, that would mean that activation of the triceps brachii (i.e. antagonist) may have been greater in the internal condition, and thus negating a larger portion of the force produced by the biceps (i.e. agonist). This explanation would be congruent with the integrated electromyography (iEMG) data reported by Vance et al. (2004), which looked at the effects of attentional focus on muscle activation of the triceps brachii and biceps brachii during free weight bicep curls. Furthermore, several other studies examining the effects of attentional focus on force production and muscle activity have also found greater EMG activity in the agonist and antagonist muscles along with a decrease in force output when participants adopted an IF rather than an EF (e.g., Wulf, Dufek, Lozano, & Prettigrew, 2010). These findings support the notion that an individual's attentional focus not only affects skill execution at an intramuscular level, but also at an intermuscular level.

1.4 Intermuscular effects of attentional focus and force production

Multi-joint resistance exercises, such as the conventional deadlift, require precise real-time coordination of several joints to efficiently and effectively execute the movement. For this

reason, in addition to the intramuscular and intermuscular effects, it is critical to examine the influence of attentional focus on the kinematic variables of a given movement. Lohse et al. (2010) were one of the first to combine motion analysis, EMG and outcome measures for a dart throwing task, in order to provide a more comprehensive analysis of motor performance as it relates to attentional focus. The participants were first instructed to ‘throw the dart as accurately and consistently as they could to the center of the board’ during the acquisition phase. Furthermore, they were instructed to restrict their movement to flexion and extension of the elbow. In the following two phases that were counterbalanced, participants were also instructed to either mentally focus on their arm (IF) or the flight of the dart (EF) (i.e. ‘Visually focus on the bulls-eye...mentally focus on the [movement of your arm/flight of the dart]. When you’re off target, think about how you can correct the mistake by changing the [motion of your arm/flight of the dart]. Each time you throw, focus on [your arm/the dart] and think about [how you are moving/how it should fly].’) The participants were reminded where to direct their focus between each block for a given phase. Lohse et al. (2010) found that adopting an EF resulted in less absolute errors and reduced EMG activity of the agonist muscle compared to an IF. These results are congruent with findings from previous research (e.g., Karst & Willett, 2004; Bressel, Willardson, Thompson, & Fontana, 2009). Moreover, variability of the shoulder movement at the moment of release during the EF condition was greater than the IF condition. Similar trends were found for throwing time (i.e. time between maximum elbow flexion and release of the dart), angular velocity during elbow extension and the joint angles of the shoulder and elbow, but none of these measures reached statistical significance. The authors suggested that the increase in shoulder movement variability can be related to “functional variability”, which is characteristic of an expert performance (Muller & Loosch, 1999). In other words, during the EF condition,

performers may have adjusted their shoulder movements in a way to compensate for changes in other parameters (e.g., throwing time, release angle, etc.) in order to gain the desired outcome (i.e. having the dart land on the bulls-eye). Conversely, there was a decrease in shoulder movement variability during the IF condition possibly due to an increase in stiffness derived from greater muscle recruitment (Lohse, Sherwood, & Healy, 2011). The stiffness about the shoulder joint reduced the degrees of freedom available to compensate for changes in other said parameters to yield the desired outcome. This notion draws parallels to Bernstein (1967)'s hypothesis, which postulates that the goal of the task is an invariant property to movement regulation while the various parameters involved in skilled execution of the task are often adjusted to yield the desired outcome. Lohse et al. (2010)'s study therefore provides preliminary evidence that adopting an EF aids in the successful adjustment of kinematic variables required to realize the desired outcome of a given task.

1.5 Attentional focus effects on multi-joint movements and force production

Perhaps one of the largest limitations of Lohse et al. (2010)'s work is instructing participants to restrict their movements to flexion and extension of the elbow during the dart throwing task. This effectively reduces the complexity of the task by restricting movement to a single joint, which imposes an unrealistic movement parameter when throwing darts or when performing multi-joint movements in general. In contrast, Wulf et al. (2007) examined the effects of attentional focus on jump-and-reach height without imposing movement parameter restrictions. Participants of this study were instructed to 'jump straight up and touch the highest rung on the Vertec they could reach with the tips of the fingers of their left hand'. They were given additional instructions based on the attentional focus condition (i.e. 'concentrate on the tips

of their fingers, reaching as high as possible during the jumps' for IF, 'concentrate on the rungs of the Vertec, reaching as high as possible' for EF, and no attentional focus instructions for the control condition). After the first experiment, Wulf et al. (2007) concluded that the EF condition yielded higher jump heights based on the rungs hit on the Vertec instrument. However, the authors suggested that it was possible that an EF may have caused the participants to alter their actions in the air (e.g. greater extension in the shoulder, elbow and wrist joints to reach a higher rung). For that reason, Wulf et al. (2007) reproduced the first experiment, but also measured vertical ground reaction forces to calculate centre of mass displacement during the vertical jumping task. It was then concluded that an EF did result in higher jump heights (i.e. greater vertical displacement of COM) and that the greater vertical jump measurements recorded by the Vertec instrument was not due to greater extension of the shoulder, elbow and wrist joints.

In a follow up study, Wulf & Dufek (2009) employed the same experimental protocol with the addition of three-dimensional motion capture (i.e. VICON) to further investigate the underlying cause of greater vertical jump heights resulting from an EF. Not only did the EF condition yield greater jump heights on the Vertec instrument and greater vertical displacement of COM, but participants adopting an EF also produced greater impulse values and lower body joint moments (i.e. ankle, knee and hip). These findings suggest that intramuscular (i.e. efficient incremental muscle fibre recruitment, hence the size principle) and/or intermuscular (i.e. effective coordination of agonist and antagonist muscle activation about the lower body joints) effects may be responsible for producing greater vertical ground reaction forces, and thus a higher jump height for the EF relative to an IF. In a second follow up study, Wulf et al. (2010) further investigated these potential intramuscular and intermuscular effects responsible for greater jump heights when adopting an EF. Once again, the same experimental protocol was

used, but this time with inclusion of EMG. Electrodes were placed on the right anterior tibialis, biceps femoris, vastus lateralis, rectus femoris and lateral gastrocnemius. EMG root mean square error and muscle onset times were derived from the raw EMG data to evaluate motor unit activation and intermuscular coordination, respectively. Wulf et al. (2010) found that the EF condition once again yielded greater jump heights (i.e. more effective outcome) and an overall reduction in EMG activity, which is congruent with previous studies examining other force production tasks (e.g., Marchant, Greig, & Scott, 2009; Zachry, Wulf, Mercer, & Bezodis, 2005). These two findings suggest that intramuscular coordination (i.e. motor unit recruitment) is more efficient and effective when adopting an EF. With regards to intermuscular coordination, Wulf et al. (2010) found no significant difference in muscle onset times between attentional focus conditions. Therefore, the difference in jump height between attentional focus conditions is not be attributed to the coordination of muscle activation timing. However, based on the figures provided by Wulf et al. (2010), it is possible to suggest that the EF condition resulted in less co-contraction between agonist and antagonistic pairs.

1.6 Attentional focus effects on multi-joint resistance exercises

Though the literature pertaining to attentional focus and force production is sufficient in making preliminary suggestions when it comes to resistance training, coaches and athletes participating in strength-based sports (e.g., Strongman, Olympic Weightlifting, Powerlifting, etc.) may be hesitant in adopting these suggestions given the lack of exercise specificity. At the time of the present work, there are few studies that have examined the influence of attentional focus on force production in multi-joint movements that are similar to events typically seen in strength-based sports (e.g., Marchant, Greig, & Scott, 2009; Snyder & Fry, 2012). Marchant et

al. (2011) were one of the first to address this limitation in the literature by investigating the effects of attentional focus on muscular endurance using three compound movements at varying difficulties (i.e. assisted bench press, bench press and free squat). It was found that the use of an EF performed significantly more repetitions before failure compared to the IF and control conditions for all three exercises. This suggests that the use of EF while executing barbell exercises fosters movement efficiency, therefore increasing the performer's ability to perform more repetitions before reaching failure. Furthermore, Marchant et al. (2011) noted that as exercise complexity increased, the difference in performance when comparing the control condition to the IF and EF conditions also increased. That is, the smallest significant differences in performance occurred when comparing the control condition with the IF and EF conditions in the assisted bench press. Conversely, the largest significant differences in performance between conditions occurred while performing the free squat exercise. This finding is in line with previous studies done outside of a weightlifting context (e.g., Wulf, Töllner, & Shea, 2007), which demonstrates that the benefits of an EF of attention becomes more pronounced as a task becomes more complex.

Another study that addresses the exercise specificity limitation present in the attentional focus literature pertaining to force production is Snyder & Fry (2012). The authors examined the effect of verbal instructions on muscle activity of agonist (i.e. pectoralis major, anterior deltoid, and triceps brachii) and antagonist (i.e. posterior deltoid and biceps brachii) muscles when performing the bench press at 50% and 80% of an individual's one repetition max. Unlike other attentional focus studies, Snyder & Fry (2012) didn't compare outcomes measures resulting from different attentional foci. Rather, they compared the EMG activity corresponding to two sets of instructions that had participant focus on either their triceps brachii or their pectoral muscles.

Snyder & Fry (2012) found that there was no significant difference in EMG activity of the antagonistic muscles between the different instruction conditions and the control group. This is incongruent with previous literature reporting increases in antagonistic muscle activity when adopting an IF (e.g., Zachry, Wulf, Mercer, & Bezodis, 2005; Vance, Wulf, Tollner, McNevin, & Mercer, 2004). Moreover, Snyder & Fry (2012) found that EMG activity of agonists increased based on the instructions given (e.g., EMG activity increased by 22% from pre-instruction activity for the pectoralis major at 50% of one repetition max), except for the triceps brachii at 80% and the anterior deltoid at 50% of one repetition max. It should be noted that previous literature controlled for speed and range of motion, both of which can affect EMG amplitudes (Brindle, Nitz, Uhl, Kifer, & Shapiro, 2006; Komi, Linnamo, Silventoinen, & Sillanpaa, 2000). Lastly, based on the data presented by Snyder & Fry (2012), the amount of muscle activity increase from pre-instruction to post-instruction for the pectoralis major and anterior deltoid across the two intensities is less for the 80% of one repetition max. This suggests that the intramuscular effects of adopting a specific attentional focus, or at least an IF, diminishes at higher intensities when performing multi-joint resistance exercises. Furthermore, Calatayud et al. (2015)'s work resulted in similar findings using a protocol that included more intensity gradations (20%, 40%, 50%, 60% and 80% of 1 repetition max) for the bench press and suggested that a threshold exists between 60 and 80% of 1 repetition max where individuals are not able to voluntarily increase agonist muscle activation relative to a control condition. Therefore, the findings of both Snyder & Fry (2012) and Calatayud et al. (2015) support the notion that invoking a specific attentional focus will not have an effect on EMG activity at the intensity being used in the present work. For this reason, EMG will not be included in the present work.

CHAPTER TWO: INTRODUCTION

2.1 Introduction

Despite overcoming the exercise specificity limitations present in much of the attentional focus literature concerning force production, Marchant et al. (2011) and Snyder & Fry (2012) examined the effects of attentional focus using sub-maximally loaded barbell exercises. Though the loading parameter was appropriate for the aims of each study (e.g., Marchant et al. (2011) used 75% of participants' one repetition max to assess muscular endurance), it has limited application within the context of competition in strength-based sports where lifting near-maximal and maximal loads are crucial for success. This presents a gap in the attentional focus literature that merits exploration. Though examining the effects of a COG and different attentional foci at one repetition maximum would yield the greatest exercise specificity to a competition lift, there exists multiple barriers in the way of doing so. First, performing a true one repetition maximum would only yield a single repetition for a given session. While it is possible to utilize multiple testing sessions to acquire numerous repetitions at a true one repetition maximum, previous research has shown that an athlete's performance capabilities can fluctuate daily due to biological readiness and recovery (Helms, Storey, Cross, Brown, Lenetsky, Ramsay, Dillen, & Zourdos, 2017; Gonzalez-Badillo & Sanchez-Medina, 2010; Jovanovic & Flanagan, 2014). Secondly, Spencer & Croiss (2015) found significantly more dangerous technical inclusions in experienced strength sport athletes performing the deadlift at 90% and 100% of their one repetition maximum when compared to their deadlift performance at 70% of their one repetition maximum (i.e., the point in which all athletes showed no dangerous technical inclusions). This presents a safety issue if participants are performing multiple single deadlift repetitions at an intensity equal to or above 90% of their one repetition max. Therefore, in the interest of

preserving the applicability of the present work to deadlifts being performed in strength-based sports, reducing the influence of confounding factors in performance and ensuring the safety of our participants, an intensity of 87% of one repetition max was used.

Moreover, there is evidence in the postural control literature suggesting that performing a concurrent COG during quiet standing results in greater postural stability when compared to adopting an IF or EF (Polskaia, Richer, Dionne, & Lajoie, 2014; Richer, Saunders, Polskaia, & Lajoie, 2017). To the present author's best knowledge, the comparison between the effects of a concurrent COG and attentional focus on posture when executing a sport-specific task has yet to be examined. Given the large disparity in movement parameters between quiet standing and sport specific tasks, further research is required to determine if the postural stability benefits associated with performing a concurrent COG during quiet standing would also occur in sport specific settings. Thus, the present work aims to also compare the effects of a concurrent COG and attentional focus on posture when performing conventional deadlifts at near maximal loads.

Findings from the present work will provide valuable insight on how the performance benefits associated with performing a concurrent cognitive task compares to those associated with an EF in a sporting context. Additionally, the findings obtained through three-dimensional motion capture will improve our current understanding of how lifting mechanics change based on the use of an IF, EF or COG. Recommendations on where to direct one's focus during strength-based endeavors can then be given to athletes and coaches looking to optimize athletic performance.

2.2 Hypotheses

1. The COG condition will yield the most efficient (i.e. smaller standard deviation in barbell position for the anterior-posterior direction) and effective (i.e. greater peak barbell velocity for the inferior-superior direction, greater vertical peak ground reaction force, a shorter lift duration, greater hip extensor power) conventional deadlift performance, followed by the EF condition and then the IF condition. At the time of this writing, there has yet to be research comparing the effects of a COG to an attentional focus condition on a sport-specific skill. However, the effects of a COG have been shown to be superior from a postural stability perspective when compared to attentional focus conditions (Polskaia et al. 2014). Furthermore, previous attentional focus literature has demonstrated a motor performance advantage being associated with an EF of attention as opposed to an IF of attention (e.g. Wulf, 2013).
2. Based on the findings of Polskaia et al. (2014) and Richer et al. (2017), we anticipate greater postural stability (i.e. smaller COP area, smaller COP standard deviation and greater COP velocity in the anterior-posterior direction) for the COG, followed by the EF condition and then the IF condition.

CHAPTER THREE: MANUSCRIPT

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ABSTRACT

Previous attentional focus literature suggests that adopting an external focus (EF) results in greater force production through a variety of mechanisms. The purpose of the present study was to examine the effects of attentional focus and dual-tasking when performing heavily loaded barbell movements that are specific to strength-based sports. Fifteen resistance-trained males (age = 23.3 ± 3.4 years) reported to the laboratory for three visits. The first visit consisted of a five-repetition maximum (5RM) test on the conventional deadlift. During the subsequent sessions, the participants performed a total of twelve single conventional deadlift repetitions while adopting an internal focus (IF), an external focus (EF), or while performing the cognitive task (COG). The IF and EF consisted of focusing on activating the quadriceps and maintain a straight bar path, respectively. The COG consisted of counting the total occurrence of two single-digits in a sequence of three-digit numbers, separately. Three-dimensional motion capture and force platforms were used to collect kinematic and kinetic data. No significant differences were found between the IF, the EF and the COG for lift duration, peak barbell velocity, peak vertical ground reaction force, area of 95% confidence ellipse, peak hip moments and peak hip powers. Adopting an EF significantly reduced variability of the barbell trajectory and centre of pressure (COP) in the anterior-posterior direction. Mean velocity of COP was also significantly lower for the EF. Our findings suggest that adopting an EF may lead to greater postural stability when performing heavily loaded barbell movements.

Key words: attentional focus, strength training, high performance, powerlifting, psychology, cognitive strategies

INTRODUCTION

Elite level competition in almost any discipline is often won within small margins. From implementing complex periodization strategies to utilizing the latest equipment, athletes are always looking for an edge over their competition. Over the past two decades, the attentional focus literature has shown that where an individual directs their attention during goal-directed action can affect motor learning and performance (28). More specifically, directing one's focus on movement effects (i.e. external focus) as opposed to one's own body movement (i.e. internal focus) yields superior motor learning and performance (29). This phenomenon has been well studied in a wide variety of sport specific skills (28). Examples of sports that have been studied in the attentional focus literature include golf (3, 10, 19, 32), dart throwing (12, 14) and Basketball (1), to name a few.

The consistency in which an EF yields superior performances relative to an IF across a variety of sport specific and non-sport specific tasks is commonly explained using the constrained action hypothesis. McNevin et al. (17) proposed that consciously attending to one's movements (i.e. IF) may interfere with the automaticity of motor control processes that regulate movement, whereas focusing on movement effects (i.e. EF) may promote the automaticity of said motor control processes. Polskaia et al. (18) extended this line of thought by comparing the effects of a continuous cognitive task with an EF and IF during quiet standing. The continuous cognitive task showed the greatest reduction in sway amplitude and variability, and thus superior postural control compared to the attentional focus conditions. This finding was attributed to the continuous cognitive task diverting one's attention away from their posture altogether, leading to even less interference of the automatic processes related to posture than an EF. Furthermore, the continuous nature of the cognitive task may provide a unique advantage regarding sport

performance as previous research suggests that athletes primarily use an IF and tend to shift their focus between IF and EF during skill execution (20, 21). Though the effects of different attentional focuses are well studied, research examining the effects of a continuous cognitive task while simultaneously executing a sport-specific skill is limited and merits further examination.

Though the literature pertaining to attentional focus and force production is sufficient in making preliminary suggestions when it comes to resistance training, coaches and athletes participating in strength-based sports (e.g., Strongman, Olympic Weightlifting, Powerlifting, etc.) may be hesitant in adopting these suggestions given the lack of exercise specificity. At the time of the present work, there are few studies that have examined the influence of attentional focus on force production that are similar to events typically seen in strength-based sports (e.g. 16, 25). For example, Marchant et al. (16) reported greater peak net joint torque for the EF condition relative to an IF condition during an isokinetic elbow flexion task. Though the task was performed at similar intensity to what is typically seen in strength-based sports, the task only involved the coordination of a single joint. Moreover, while the series of vertical jump studies completed by Wulf and Colleagues (29, 30, 33) showed greater vertical jump heights derived from larger vertical ground reaction forces resulting from an EF, the task lacked any manipulation of an external load (e.g. barbell, dumbbell, atlas stone, etc.). Previous studies that used exercise specific tasks to examine the effects of attentional focus were completed without the context of sport performance. Consequently, these attentional focus studies used intensity loads that were much lower than what is typically done in competition (e.g. Marchant et al. (15) used 75% of one repetition maximum to assess muscular endurance, Catalayud et al. (4) used between 20-80% of one repetition maximum and Snyder & Fry (25) used 20-80% of one repetition maximum to assess changes in muscle activation).

The purpose of this project was to examine the effects of attentional focus and a continuous cognitive task on heavily loaded conventional deadlift performance in experienced lifters. It was hypothesized that subjects simultaneously performing the COG would exhibit the greatest conventional deadlift performance (i.e. Smaller standard deviation in barbell position for the anterior-posterior direction, greater peak barbell velocity for the inferior-superior direction, greater peak vertical ground reaction force (pVGRF), a shorter lift duration and a greater hip extensor power) when compared to an EF followed by an IF. Similarly, it was also hypothesized that subjects performing the COG would exhibit the greatest postural stability (i.e. Smaller COP area, smaller COP standard deviation and greater COP velocity in the anterior-posterior direction) (18, 22) leading to greater force production (6) when compared to an EF followed by an IF.

Methods

Experimental Approach to the Problem

Participants visited the laboratory once per week for a total of 3 visits. During the first visit, participants completed a repetition maximum of 5 repetition or lower. Using Baechle et al. (2)'s one repetition maximum table, an estimated 1 repetition maximum was calculated and used to establish the appropriate relative intensity (i.e. 87% of 1 repetition maximum) for the experimental trials. This first visit allowed the investigators to more accurately gauge the current strength of the participants.

During the subsequent visits, participants performed twelve single repetitions at 87% of their 1 repetition maximum after hearing the general task instructions and the instructions

specific to a given experimental condition. Kinetic and kinematic data were collected for the lower body joints and the barbell using three-dimensional motion capture. The second and third sessions were identical apart from the randomized condition order. The sessions were performed one week apart from each other, all participants were asked to avoid vigorous exercise over the three-week period and to specifically refrain from exercises involving the lower back and lower body 24hrs prior to each session.

Subjects

Fifteen young adult males between the ages of 18 and 30 ($n = 15$, body mass = 89.4 ± 13.1 kg, age = 23.3 ± 3.4 years) were recruited for this study. All participants were required to have a conventional deadlift 1 repetition maximum of at least twice their current bodyweight and have a minimum of two years of conventional deadlift experience. Additionally, participants were in good general health and did not experience any musculoskeletal injuries at least 6 months prior to data collection. Lastly, all participants provided written informed consent at the start of the first session. This study was approved by the University of Ottawa Research Ethic Board.

* Table 1 *

Procedure

Repetition Maximum

Prior to performing the repetition maximum protocol, participants were allotted an optional 10-minute period to perform a self-directed warm-up (e.g. Myofascial release using a foam roller, dynamic stretching, etc.). Using the estimated conventional DL 1RM provided by the participant on the athletic history questionnaire, the investigator calculated the appropriate load for the following relative intensities: 72%, 77%, 82%, 87%. Participants were then instructed to warm-up to 70% of their 1RM for three repetitions, then 75% of their 1RM for two repetitions and lastly 80% for a single repetition. The first attempt at a 5-repetition maximum was performed at 87% of their 1RM. If the attempt was successful, with the aid of the participant's feedback, the investigator increased the load by up to 5% on the subsequent attempt. If the attempt was unsuccessful, the participant was offered an opportunity to reattempt the same load. If the participant declined the offer, the investigator used the attempt with the highest load to calculate the estimated 1RM using Baechle et al. (2)'s one repetition maximum chart. Participants were given up to 5 minutes of rest between all sets, and all lifts were performed in accordance with USAPL rules and regulations (27).

Equipment and Apparatus

Upon entering the lab for the second and third session, participants were outfitted with reflective markers on the: upper back (T2, left and right acromioclavicular joint) ; Lower back (left and right aspect of L5, pelvis cluster over S1, left and right posterior superior iliac spines) ; left and right thigh (medial aspect of the epicondyles of the knee, cluster placed posteriorly mid-thigh); left and right shank (cluster placed posteriorly mid-shank) ; and left and right foot (medial malleolus, lateral malleolus, superior aspect of the first metatarsal, superior aspect of the fifth metatarsal, calcaneus). An additional set of reflective markers were used solely for calibration

and were removed prior to starting the warm-ups sets leading into the twelve trials. A total of forty-three 14 mm reflective markers were placed on the participant (37 positional markers and 6 calibration-only markers) and three additional 14 mm reflective markers were placed on the barbell (1 at each end of the barbell and 1 on top of a weight plate loaded onto the barbell).

Centre of pressure, ground reaction forces and moments were collected at a sampling rate of 1000 Hz by having participants stand with one foot on each of the two force platforms (OR6-6-1000, Watertown, MA, USA; OR6-7-1000, Watertown, MA, USA). Marker position data were collected at a frequency of 100 Hz using a 3-dimensional motion capture system consisting of thirteen reflective infrared cameras (Oxford Metrics, Tustin, CA, USA). Force platform data and marker position data were synchronized both temporally and spatially using Nexus software (Vicon, Centennial, CO, USA).

Participants performed all lifts without shoes (i.e. barefoot, socks), but were permitted to use chalk. The use of a lifting belt was mandatory during the repetition maximum protocol and for all experimental trials. Only lifting belts that were 10 mm in thickness and in accordance with USAPL rules (27) were permitted. Furthermore, all participants used a 20 kg Ohio Power Bar (Rogue, Ohio, USA) that is typically used in competition.

* Figure 1 *

Attentional Focus and the Cognitive Task

Using the estimated 1RM acquired from the repetition maximum protocol, the investigator recalculated the relative intensities used in the first session (i.e. 72%, 77%, 82%, 87%). Participants were once again allotted the optional 10-minute period to perform a self-directed warm-up and were given the same instructions for the submaximal deadlift warm-up. Prior to performing each trial, the investigator gave the participant the following general instructions: “Once you are given the start signal, you are to step onto the platform and perform one conventional deadlift repetition as though you were attempting a new 1RM.”

The appropriate focus instructions or cognitive task instructions were given after the general instructions. For the internal focus condition, participants were instructed: “For this trial, just focus on activating your quadriceps to drive the barbell off the floor.”. For the external focus condition, participants were instructed: “For this trial, just focus on moving the barbell in a straight and vertical bar path.”. After completing the attentional focus trials, participants were asked for a subjective rating (i.e. 0-100%) of how much of their attention was directed at the focus instructions during the trial. Trials with ratings of 50% or less were removed from the dataset.

For the cognitive task, participants were instructed to silently count the frequency of two pre-selected digit (i.e. 0-9), which was verbalized in a pre-recorded 3-digit number sequence, separately. The numbers were presented every two seconds and the duration of the number sequence matched that of the trial length (i.e. the number sequence started when the participant stepped onto the force platforms and ended once the bar returned to the starting position). Three different number sequences were used to prevent participants from memorizing the sequences. The use of counting aids (e.g. fingers, toes, etc.) was prohibited. After completing the cognitive task trials, participants were asked for the frequency at which the two pre-selected digits were

presented. Given that the total number of errors was 6 or greater, the trial was removed from the data set.

Biomechanical Analysis

Visual3D software (Version 4, C-motion, Inc., Germantown, MD, USA) was used to create an inverse dynamical linked-segment model based on both standing calibration trials and anatomical landmarks. The model was constructed using the default segment geometry available in Visual3D along with anthropometric data provided by Dempster (8). More specifically, conical frustrums were used for the feet, shanks and thighs of the model. Whereas the pelvis and thorax were modelled using cylinders. This inverse dynamical linked-segment model was then applied to each motion trial. Motion trials were then trimmed such that only the concentric phase of each lift was included for analysis. The start of a lift was defined by the instance in which the barbell's upward velocity was greater than 0. The end of the lift was when the barbell reached an upward velocity equal to 0 and reached its maximum vertical position. From the inverse dynamical linked-segment model, lower body (i.e. ankles, knees and hips) joint angular velocity, net joint moments, net joint powers and barbell kinematics (i.e. position & velocity) were extracted after the raw data were filtered. Marker position data and kinetic data were filtered using a digital lowpass Butterworth filter at 6 Hz and 10 Hz, respectively (23). Given the small contribution of the ankle and knee joints (see figure 2, 3 & 4), kinetic and kinematic measures about the ankle and knee joints were excluded from further analysis. The remaining dependent variables (i.e. kinetic measures about the hip & barbell kinematics) were then extracted for statistical analysis. Force platform data were exported to Matlab (The Mathworks, Natick, MA, USA) to extract variables concerning centre of pressure.

* Figure 2 *

* Figure 3 *

* Figure 4 *

Statistical Analyses

Due to the lack of visibility of marker clusters located on the posterior side of the right leg, data were discarded for one participant resulting in these statistical analyses to be conducted on 14 participants. First, a two-way analysis of variance (ANOVA) was used to determine if there were significant differences between sessions for each condition. Once it was confirmed that there were no significant differences between sessions ($p > 0.05$), a separate repeated measures ANOVA on condition (i.e. Internal focus, External focus, Cognitive Task) was used for each of the dependent variables (see results). Fischer's least significant difference post-hoc analysis was used to determine the location of significance. Statistical significance was set at $p < 0.05$. Mauchly's test of sphericity was performed and, when necessary, Greenhouse-Geisser corrections were reported. A total of 13 statistical tests were performed (i.e. one for each dependent variable).

Results

Lift Duration

Only the concentric portion of the lifts were considered for lift duration. The separate repeated measures ANOVA revealed no main effect of condition for lift duration ($F(2,56) = 2.78$, $p > 0.05$, $\eta^2 = 0.355$, Fig. 3). However, a trend for a faster lift duration for COG when compared to EF was observed ($p = 0.071$).

* Figure 5*

Peak Barbell Velocity

The separate repeated measures ANOVA revealed no main effect of condition for peak barbell velocity in the inferior-superior direction ($F(2,56) = 1.08$, $p = 0.345$).

Standard Deviation of the Barbell Position

There was a main effect of condition for the standard deviation of the barbell position in the anterior-posterior direction ($F(2,56) = 4.40$, $p < 0.017$, $\eta^2 = 0.928$, Fig. 4). Post-hoc analysis revealed greater standard deviation of the barbell position in the AP direction for IF and COG when compared to the EF ($p < 0.05$). No significant differences were found between the SD of the barbell in the AP direction when comparing IF with COG ($p > 0.05$).

* Figure 6 *

Peak Vertical Ground Reaction Force

There was no main effect of condition for pVGRF ($F(2,56) = 2.46$, $p > 0.05$, $\eta^2 = 0.338$).

However, a trend for a smaller pVGRF for EF when compared to IF and COG was observed ($p = 0.095$).

Area of 95% confidence ellipse

There was no main effect of condition for Area ($F(2,56) = 2.73$, $p > 0.05$, $\eta^2 = 0.689$). However, a trend for a less sway amplitude was observed for EF condition when compared to IF and COG ($p = 0.074$).

Mean velocity of centre of pressure

There was no main effect of condition for mean velocity of centre of pressure in the medial-lateral direction ($F(2,56) = 1.980$, $p = 0.148$). However, there was a main effect of condition for the mean velocity of centre of pressure in the anterior-posterior direction ($F(2,56) = 3.54$, $p = 0.036$, $\eta^2 = 0.885$). Post-hoc analysis revealed greater velocity for the COG condition when compared to EF condition ($p > 0.05$).

Standard deviation of centre of pressure

There was no main effect of condition for SD of COP in the medial-lateral direction ($F(2,56) = 0.030$, $p = 0.971$). However, there was a main effect of condition for SD of COP in the anterior-posterior direction ($F(2,56) = 5.47$, $p = 0.007$, $\eta^2 = 0.917$). Post-hoc analysis revealed less sway

variability for the EF condition when compared to IF and COG ($p < 0.05$). There was no significant difference observed between IF and COG ($p > 0.05$).

Peak Hip Moment

There was no main effect of condition for left peak hip moment ($F(2,56) = 1.45, p = 0.242$, Fig. 5). There was also no main effect of condition for the right peak hip moment ($F(2,56) = 1.28, p = 0.285$, Fig. 6).

* Figure 7 *

* Figure 8 *

Peak Hip Power

There was no main effect of condition for left peak hip power ($F(2,56) = 0.996, p = 0.376$). There was also no main effect of condition for the right peak hip power ($F(2,56) = 1.045, p = 0.358$).

* Table 2 *

DISCUSSION

The purpose of the present work was to examine the effects of attentional focus and dual-tasking, using a COG, on conventional deadlift performance in experienced lifters. It was hypothesized that utilizing a COG would yield the most efficient (i.e. smaller standard deviation in barbell position for the anterior-posterior direction) and effective (i.e. greater peak barbell velocity for the inferior-superior direction, greater pVGRF, a shorter lift duration, greater hip extensor power) conventional deadlift performance followed by an EF and then an IF. Similarly, we hypothesized that utilizing a COG would also result in the greatest postural stability (i.e. smaller COP area, smaller COP standard deviation and greater COP velocity in the anterior-posterior direction) when performing the conventional deadlift followed by an EF and then an IF.

In contrast to our first hypothesis, the findings of the present work revealed no significant differences between adopting an EF, IF, or utilizing a cognitive task with regards to the effectiveness of conventional deadlift performances at high intensity loads (i.e. 87% of 1RM). Despite a large body of literature (e.g. 5, 9, 26, 28, 31, 32, etc.) indicating a robust performance advantage associated with adopting an EF relative to an IF in other sporting domains, the results of the present work show no significant differences between an EF and an IF for lift duration ($p > 0.05$) and peak barbell velocity in the inferior-superior direction ($p > 0.05$). These findings suggest that attentional focus effects diminish at higher loading intensities, which is congruent with previous studies (4, 25) that investigated the effects of IF instructions on muscle activity during multi-joint resistance exercises. Snyder & Fry (25) and Calatayud et al. (4)'s findings both indicate a threshold between 60 to 80% of 1RM exists where adopting an IF no longer results in greater muscle activation relative to neutral instructions. However, as indicated by other attentional focus studies pertaining to force production tasks, greater muscle activation

does not directly result in greater force production (16, 33). Rather, Wulf et al. (16) suggests that a decrease in agonist muscle activity paired with greater force production derived from an EF is the result of a reduction in agonist-antagonist co-activation. Though the present work did not measure muscle activity, pVGRF ($p > 0.05$), peak hip moments ($p > 0.05$) and peak hip powers ($p > 0.05$) indicated no significant differences between any of the conditions which further reinforces the notion that attentional focus effects diminish at high intensity loads.

Contrary to these findings, Wulf & Dufek (29) reported greater lower extremity joint moments and less EMG activity (30) when comparing an EF to an IF during vertical jumps. Furthermore, Marchant et al. (16) reported greater peak net joint torque for an EF relative to an IF during a maximal isokinetic elbow flexion task. Collectively, these studies indicate that there is a profound attentional focus effect at play during tasks that require maximal force production. However, these studies draw large distinct differences from the conventional deadlift (e.g. lack of object manipulation, different force-velocity profiles, the use of a single joint versus multiple joints etc.), which creates difficulty when attempting to compare findings. Nevertheless, a possible reason for the lack of differences between attentional foci for the previously mentioned variables could be from the sheer intensity of the motor task. De Luca & Kline (7) reported motor unit recruitment thresholds and rate coding vary amongst different muscle groups, which may occur below 100% of maximum isometric voluntary contractions. This would suggest a possible 'ceiling effect' may be present in reducing the neuromuscular benefits associated with an EF for maximal force production tasks. More specifically, at high intensity loads, the efficiency of motor unit recruitment and firing are likely already maximized in experienced populations. From an intermuscular perspective, the co-activation of agonist and antagonist

muscles acting on the hip are also likely minimized at loads nearing an individual's 1RM, thus maximizing one's efforts in completing the lift.

Interestingly, adopting an EF still resulted in less barbell position variability in the AP direction ($p < 0.05$), suggesting a more consistent deadlift performance than adopting the IF or performing the COG. While Lohse et al. (12) have previously suggested that movement variability can be related to "functional variability", we presume that this may be due to the EF yielding superior postural stability as evidenced by a significantly lower mean velocity ($p < 0.05$) and SD of COP ($p < 0.05$) in the AP direction, along with a trend for less sway amplitude ($p = 0.074$). Though an increase in movement variability may be related to "functional variability" for a dart throwing task, the same rationale should be applied with caution when considering heavily loaded conventional deadlifts. Lohse et al. (12) noted that an increase in muscle recruitment resulting from an IF may have reduced the degrees of freedom available at the shoulder joint that could have otherwise compensated for changes in other movement parameters during dart throws. This would effectively reduce an individual's ability to use "functional variability" to yield the desired outcome (i.e. the dart landing on the bullseye). As previously mentioned, when performing heavily loaded conventional deadlifts, motor unit recruitment and muscle activation are likely maximized. Similar to the IF condition in Lohse et al. (12)'s study, this would limit the influence of "functional variability" by restricting the degrees of freedom about each joint. Rather, the reduction in barbell position variability in the AP direction during an EF may be the by product of greater postural stability derived from greater automaticity. This rationale is more consistent with previous findings made by Polskaia et al. (18), Richer et al. (22), and the constrained action hypothesis. According to this hypothesis, consciously attending to one's movements (i.e. IF) may interfere with the automaticity of motor control processes that regulate

movement, whereas focusing on movement effects (i.e. EF) may promote the automaticity of said motor control processes (17). However, without EMG, Polskaia et al. (18) were unable to determine if the greater postural stability from the EF was from an increase in automaticity, or if it was due to an ankle stiffening strategy. Richer et al. (22)'s findings provided evidence (i.e. increase in MPF with no increases in muscle activity about the ankle joint) that the increase in postural stability measures were the result greater automaticity. Drawing from this chain of logic, we rationalize the decrease in barbell position variability in the AP direction is the result of greater automaticity as suggested by the constrained action hypothesis. However, without the addition of EMG data, our rationale remains speculative.

The findings of the present study revealed the COG yielded similar results to the attentional focus conditions with regards to barbell kinematics and force production. That is, no significant differences were found when comparing the COG with the attentional focus conditions for lift duration, peak barbell velocity in the inferior-superior direction, pVGRF, peak hip moments, and peak hip powers. Given that the same loading intensity was used across all conditions, the same rationale for the lack of difference between attentional focus conditions can be applied here (i.e. near maximal motor unit recruitment and muscle activation may cause a potential 'ceiling effect' that reduces an individual's ability to express the neuromuscular effects of attentional focus). Moreover, the results of the present study suggest that performing the COG yielded a less posturally stable performance relative to an EF as evidenced by a greater SD of COP ($p < 0.05$), a greater mean velocity ($p < 0.05$) and a trend for larger sway amplitude ($p = 0.074$) in the AP direction. This is inconsistent with previous postural control studies (18, 22) that found greater postural stability to be associated with a COG when compared to an IF or EF. The difference between these studies and the present work may be due to the difference in

cognitive demand resulting from the motor task. The limited attentional capacity sharing model for explaining dual-task interference would suggest that a competition for information processing resources would occur between the COG and the motor task (13). Given that information processing resources are finite, and the summation of information processing demands exceeds the capacity of the individual, the performance of one or both tasks would be compromised (13). More specifically, the information processing demands of performing a COG during quiet standing are likely within one's information processing capacity, whereas performing a heavily loaded conventional deadlift in conjunction with the COG may exceed one's information processing capacity. Since COG trials that exceeded the error count threshold were removed from the data set, only the trials where the participants placed greater information processing capacity on the COG remained. Therefore, the decrease in postural stability when performing the COG and the conventional deadlift simultaneously may be the result of cognitive resource competition between tasks. Alternatively, the bottleneck model suggests that critical tasks are processed sequentially (13) and presents an equally viable rationale for the present findings. During the experimental testing sessions, several participants verbalized that they performed the COG and motor task sequentially. Given the short duration of the motor task and the rate at which the number sequence is presented, participants adopting this strategy would be able to score below the error threshold. Furthermore, the lack of significant differences between the COG and the IF for all the variables in the present study suggests that the participants may have opted for an IF when performing the conventional deadlift during the COG trials. This potential phenomenon would be congruent with previous literature suggesting that athletes primarily adopt an IF and may switch between an IF and an EF during skill execution (20, 21).

It is critical to note several limitations that exist within the present study. First, without EMG data about the lower body joints, we are only able to speculate that muscle activation and motor unit recruitment were nearly maximized due to the loading intensity. Including EMG would not only enable the future studies to examine the magnitude of muscle activation, but also the timing of those activations. EMG data about the muscles of the ankle joints (i.e. dorsiflexors and plantar flexors) and the knee joints (i.e. knee extensors and knee flexors) may provide valuable information regarding the differences in postural control between conditions for the present study. Despite the variety of logistical barriers that may prevent the use of EMG (e.g. electrodes on the anterior side of the body inhibiting regular AP barbell trajectory, cost, etc.), future studies examining the effects of any manipulation on heavily loaded conventional deadlifts should consider including EMG. Second, the difficulty of the COG used in the present study erred on the difficult side in the efforts to prevent participants from allocating any attentional resources to the motor task. While with respect to the constrained action hypothesis this would induce greater automaticity, the difficulty seems to have been set too high and may have resulted in a large amount of dual-task interference which ultimately overwhelmed the participants. Future studies comparing attentional focus to a COG should consider scaling the difficulty of the cognitive task such that it does not overwhelm the participant, but still fully engages their attentional resources. Lastly, the present study only included a single set of instructions for each attentional focus type. Given that there are numerous coaching cues that can be used to evoke an IF or an EF, future studies should also include multiple sets of instructions that compare the effects of different coaching cues within the same sub division of attentional focus.

In summary, the results of the present work indicate that the effects of attentional focus diminish when conventional deadlifts are performed at loading intensities that are close to an individual's one repetition maximum, which is consistent with previous literature attentional focus effects on muscle activation (4, 25). This was shown by the lack of significant differences between attentional foci for lift duration, peak barbell velocity and the kinetic measures (i.e. pVGRF, peak hip moments and peak hip powers). Furthermore, performing the COG resulted in no significant differences when compared to the attentional foci for the aforementioned variables suggesting that the intensity of the motor task may be causing a 'ceiling effect'. Moreover, adopting an EF appears to improve the consistency of barbell positioning in the AP direction (i.e. lower SD of barbell position in the AP direction) and improve postural stability (i.e. Smaller SD of COP in the AP direction, slower mean velocity in the AP direction, and a trend for less sway amplitude), which may be due to greater automaticity. Conversely, performing the COG increased variability in barbell positioning in the AP direction and resulted in less postural stability relative to the EF. This was attributed to the large amount of cognitive-motor interference derived from the information processing demand required to perform both tasks simultaneously, exceeding the lifter's processing capabilities. Collectively, these findings suggest that adopting an EF may have limited impact on postural stability when performing heavily loaded barbell exercises typically seen in some strength-based sports.

PRACTICAL APPLICATIONS

Novel and sport specific recommendations can be made based off the findings of the present work and the current state of the literature. First, athletes performing heavily loaded barbell movements in competition (e.g. powerlifters, strongman, weightlifters etc.) should

consider using EF cues to acquire the postural stability benefits when performing heavy repetitions. This is true whether the athlete is attempting to improve the quality of their repetitions in training or trying to maximize their performance in competition. Perhaps the only period when experienced strength athletes should consider using an IF rather than an EF would be when attempting to maximize muscle hypertrophy during the off-season. Schoenfeld et al. (23) found that using an IF over time yields greater muscle hypertrophy relative to an EF. Given that postural stability demands are likely not the limiting factor in performing resistance exercises at the moderate intensities typically used when training for muscular hypertrophy, adopting an IF would be the superior option. Lastly, until further research is completed on the use of a cognitive task on sport performance, athletes and coaches should avoid using it in their training and competition performances.

Acknowledgements

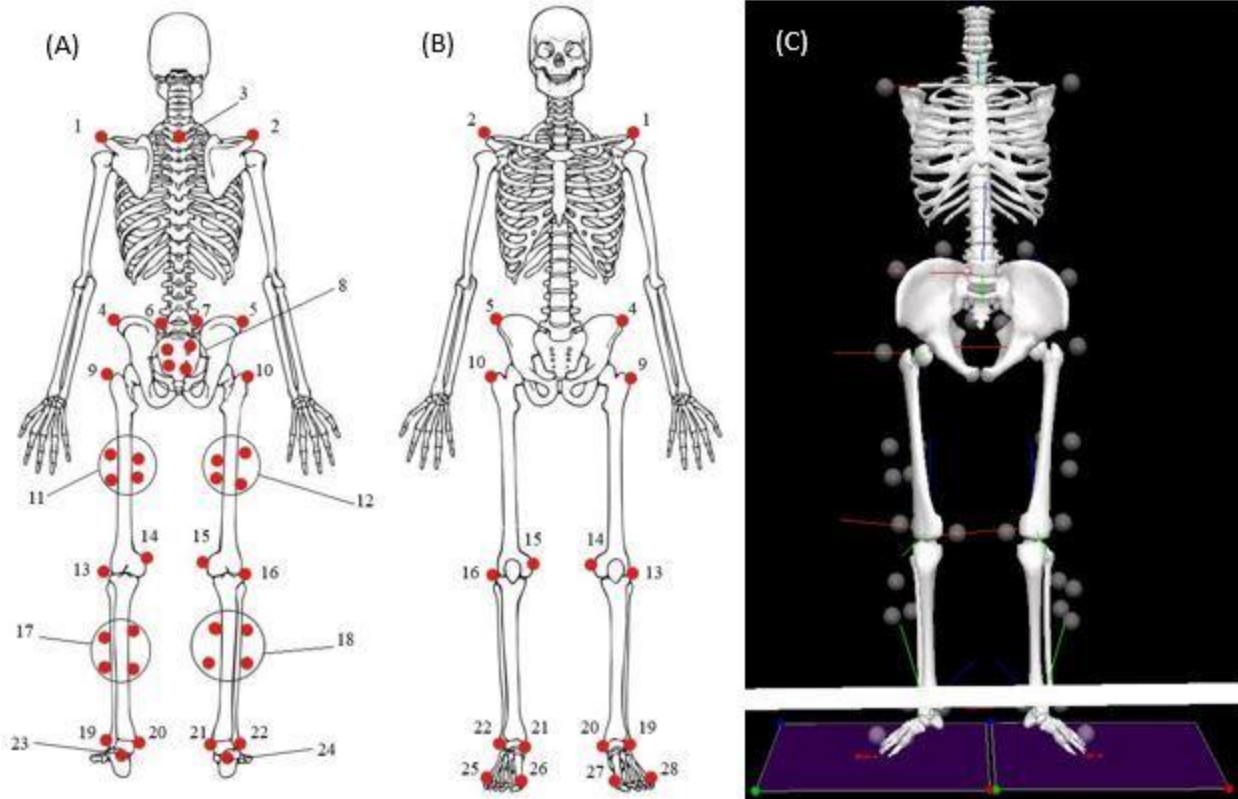
The authors report no conflicts of interest.

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Markers

- | | |
|---|--|
| 1. Left Acromioclavicular Joint (C&T) | 15. Right Medial Femoral Epicondyle (C&T) |
| 2. Right Acromioclavicular Joint (C&T) | 16. Right Lateral Femoral Epicondyle (C&T) |
| 3. T2 (C&T) | 17. Left Shank Cluster (C&T) |
| 4. Left Iliac Crest (C) | 18. Right Shank Cluster (C&T) |
| 5. Right Iliac Crest (C) | 19. Left Lateral Malleolus (C&T) |
| 6. Left Lateral Aspect of L5 (C&T) | 20. Left Medial Malleolus (C&T) |
| 7. Right Lateral Aspect of L5 (C&T) | 21. Right Medial Malleolus (C&T) |
| 8. Pelvis Cluster (C&T) | 22. Right Lateral Malleolus (C&T) |
| 9. Left Greater Trochanter (C) | 23. Left Calcaneus (C&T) |
| 10. Right Greater Trochanter (C) | 24. Right Calcaneus (C&T) |
| 11. Left Thigh Cluster (C&T) | 25. Right Fifth Metatarsal (C&T) |
| 12. Right Thigh Cluster (C&T) | 26. Right First Metatarsal (C&T) |
| 13. Left Lateral Femoral Epicondyle (C) | 27. Left First Metatarsal (C&T) |
| 14. Left Medial Femoral Epicondyle (C) | 28. Left Fifth Metatarsal (C&T) |

Figure 1. (A) Posterior and (B) anterior view of a skeletal model with both calibration (C) and tracking (T) markers. (C) Anterior view of the Visual3D model.

ATTENTIONAL FOCUS AND DUAL-TASKING ON CONVENTIONAL DEADLIFT PERFORMANCE

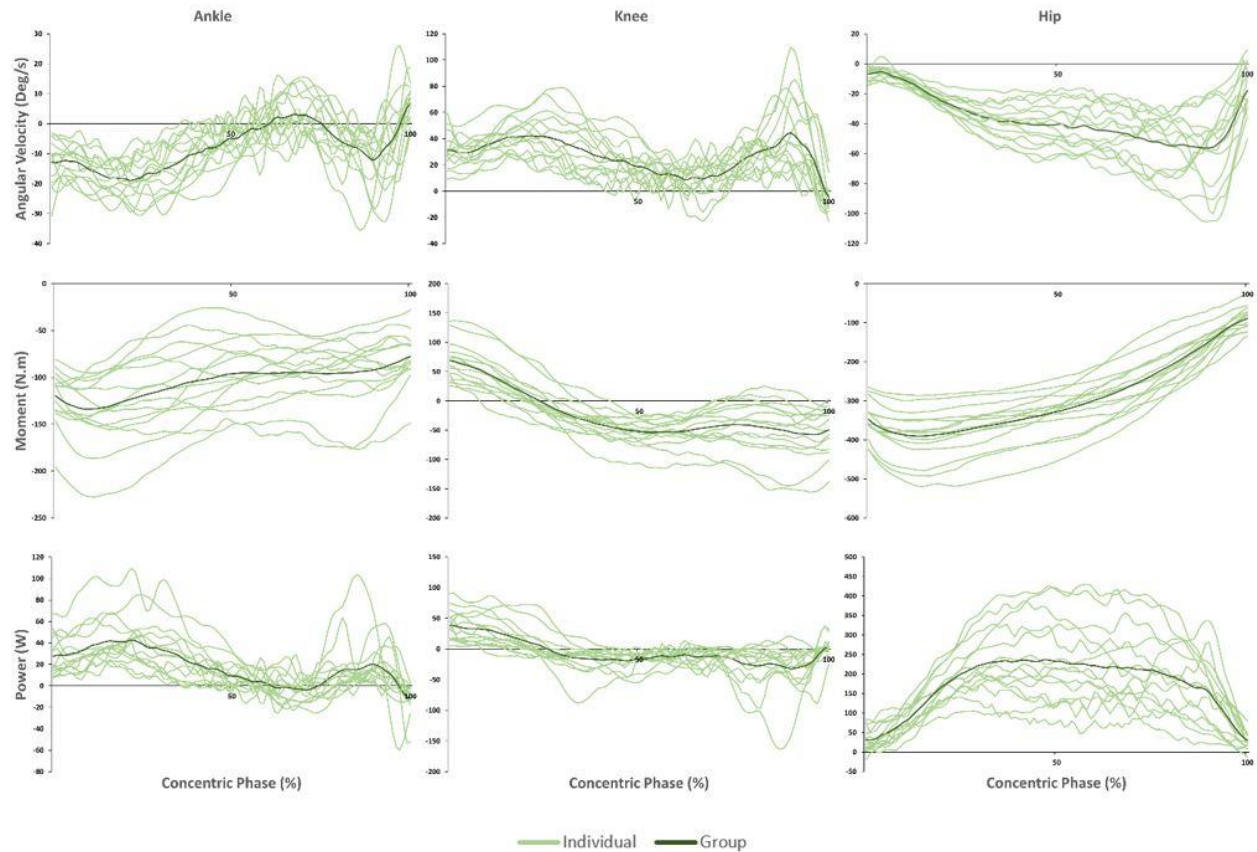


Figure 2. Individual participant mean and group mean data ($n = 14$) during both experimental sessions for the internal focus condition. Angular velocities, net joint moments and powers are displayed as a function of the concentric phase of the conventional deadlift for the first, second and third row, respectively. Each column corresponds to a different lower body joint on the left side (i.e. Ankle joint for the left column, Knee joint for the middle column and Hip joint for the right column). Positive moments at the hip are flexor; positive moments at the knee are extensor; positive moments at the ankle are dorsiflexor.

ATTENTIONAL FOCUS AND DUAL-TASKING ON CONVENTIONAL DEADLIFT PERFORMANCE

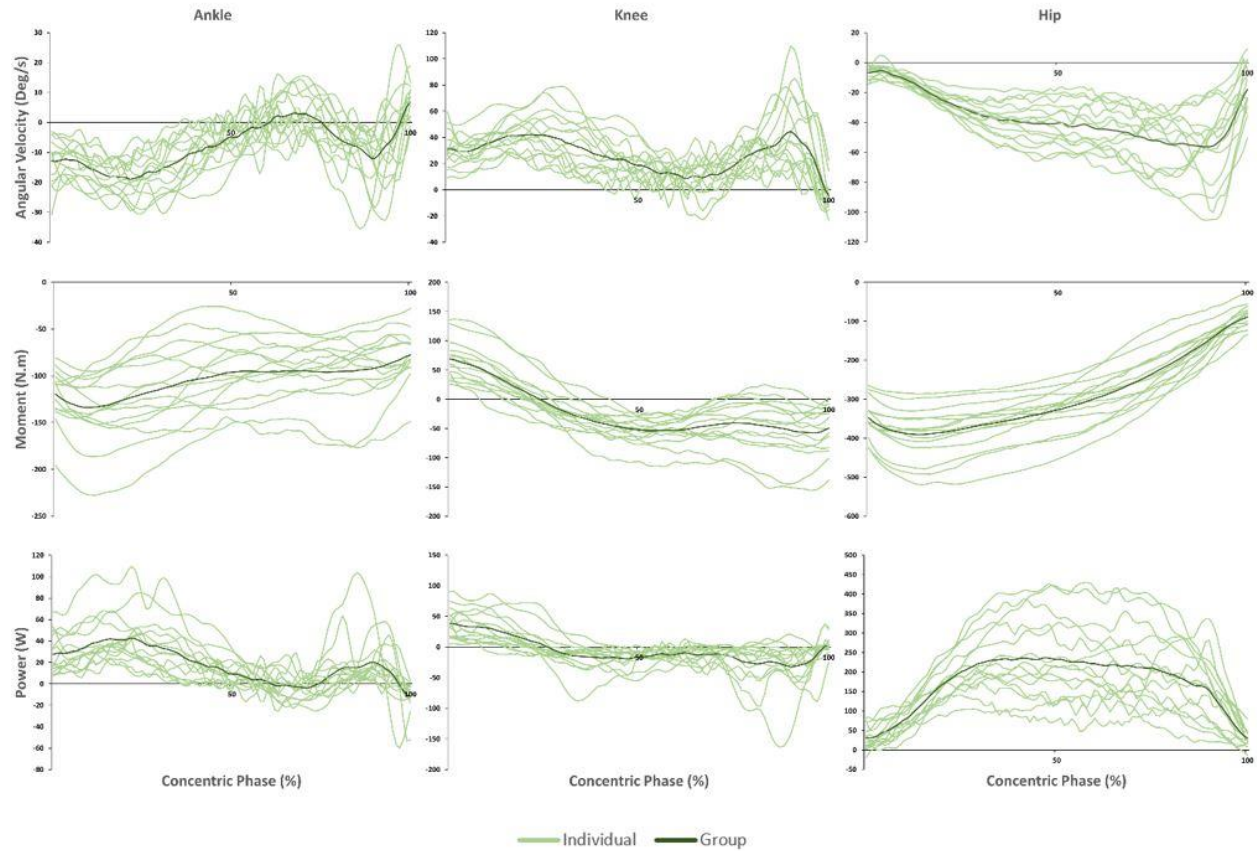


Figure 3. Individual participant mean and group mean data ($n = 14$) during both experimental sessions for the external focus condition. Angular velocities, net joint moments and powers are displayed as a function of the concentric phase of the conventional deadlift for the first, second and third row, respectively. Each column corresponds to a different lower body joint on the left side (i.e. Ankle joint for the left column, Knee joint for the middle column and Hip joint for the right column). Positive moments at the hip are flexor; positive moments at the knee are extensor; positive moments at the ankle are dorsiflexor.

ATTENTIONAL FOCUS AND DUAL-TASKING ON CONVENTIONAL DEADLIFT PERFORMANCE

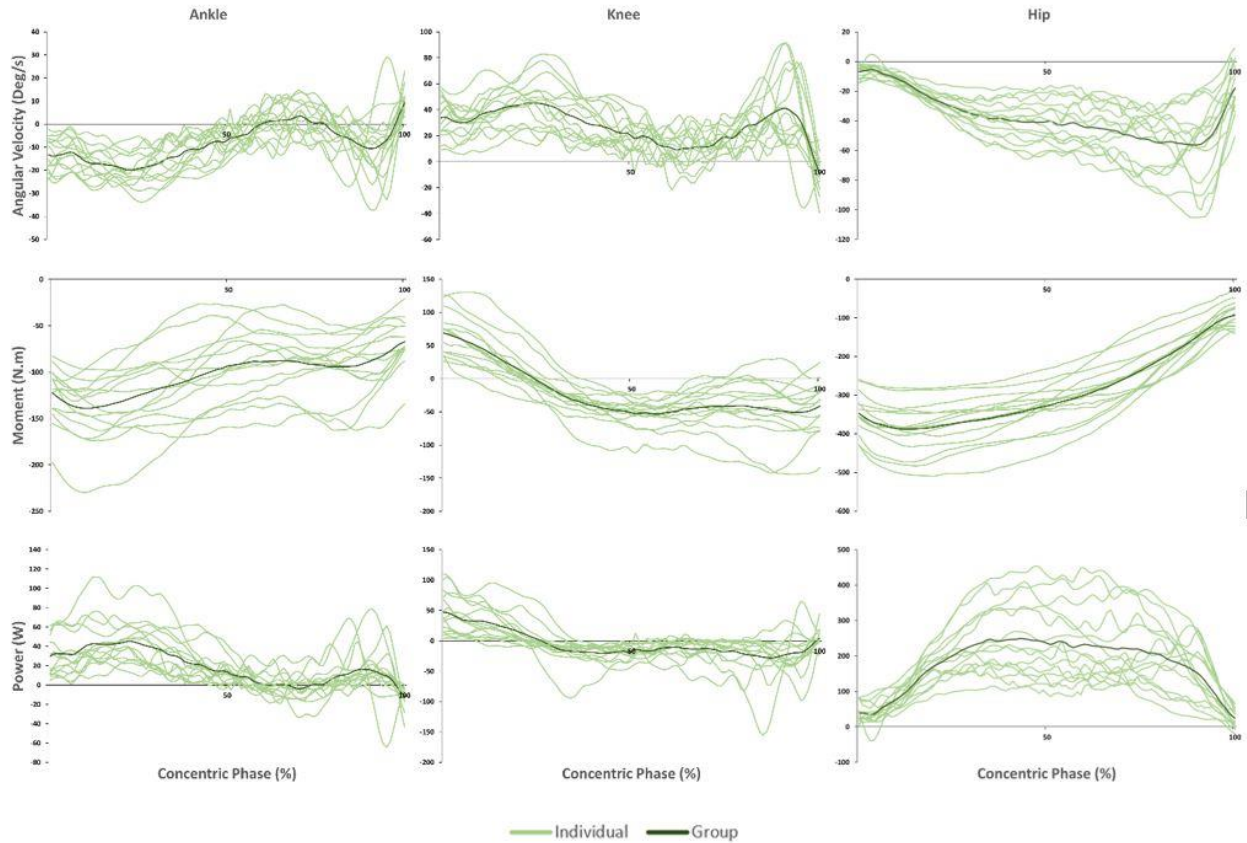


Figure 4. Individual participant mean and group mean data ($n = 14$) during both experimental sessions for the cognitive task condition. Angular velocities, net joint moments and powers are displayed as a function of the concentric phase of the conventional deadlift for the first, second and third row, respectively. Each column corresponds to a different lower body joint on the left side (i.e. Ankle joint for the left column, Knee joint for the middle column and Hip joint for the right column). Positive moments at the hip are flexor; positive moments at the knee are extensor; positive moments at the ankle are dorsiflexor.

ATTENTIONAL FOCUS AND DUAL-TASKING ON CONVENTIONAL DEADLIFT PERFORMANCE

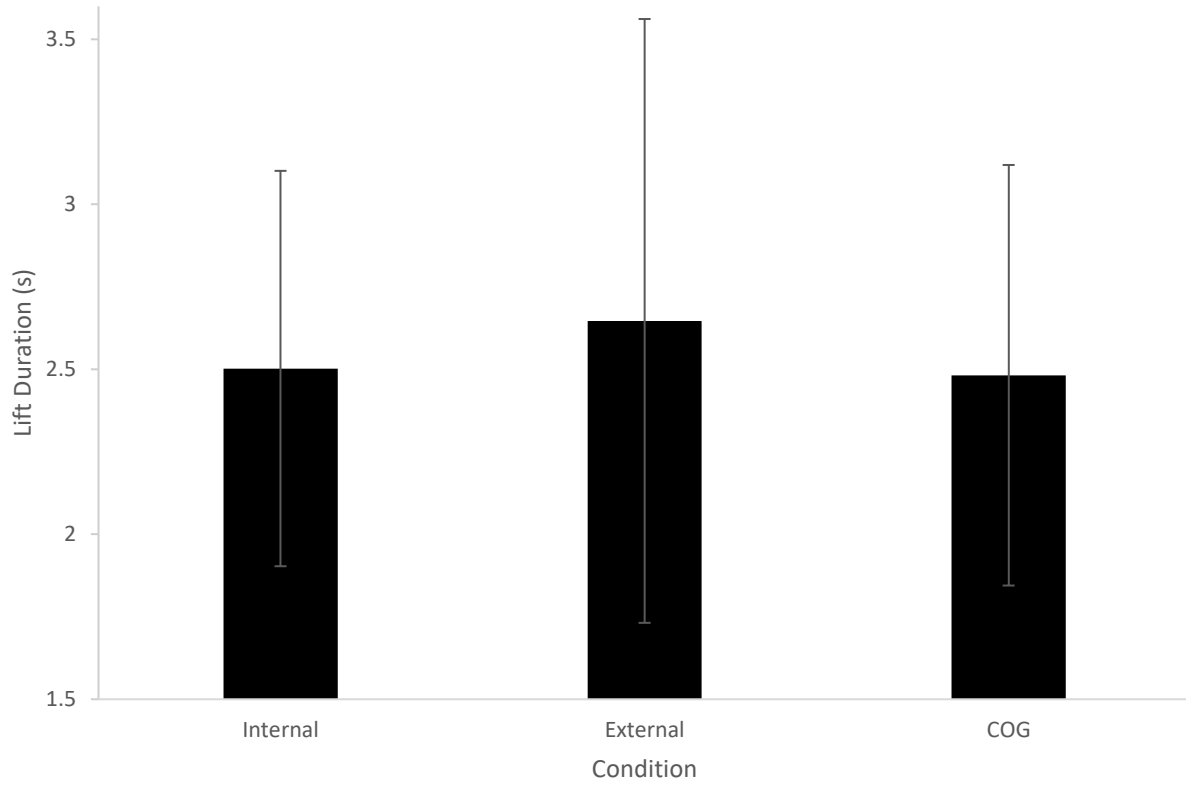


Figure 5. Lift duration as a function of experimental conditions.

ATTENTIONAL FOCUS AND DUAL-TASKING ON CONVENTIONAL DEADLIFT PERFORMANCE

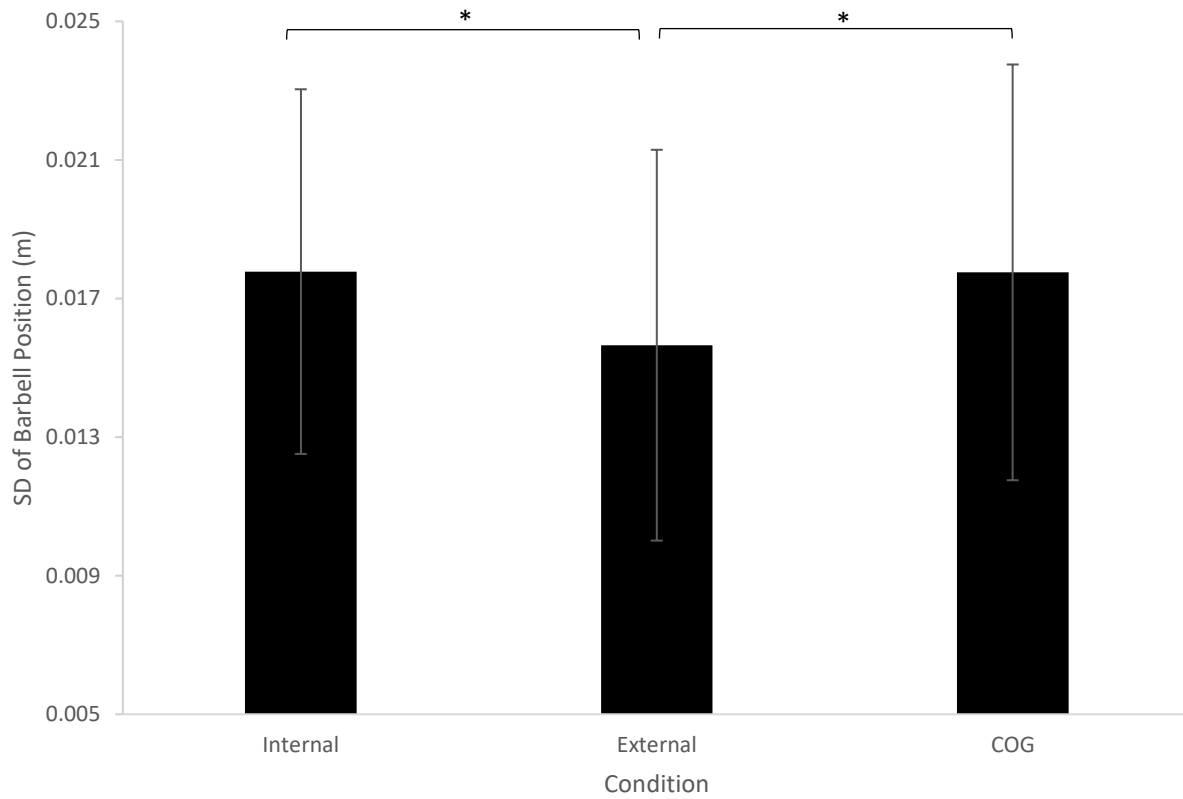


Figure 6. Standard deviation (SD) of the barbell position in the anterior-posterior direction (AP) as a function of experimental conditions. Significant difference between conditions = *.

ATTENTIONAL FOCUS AND DUAL-TASKING ON CONVENTIONAL DEADLIFT PERFORMANCE

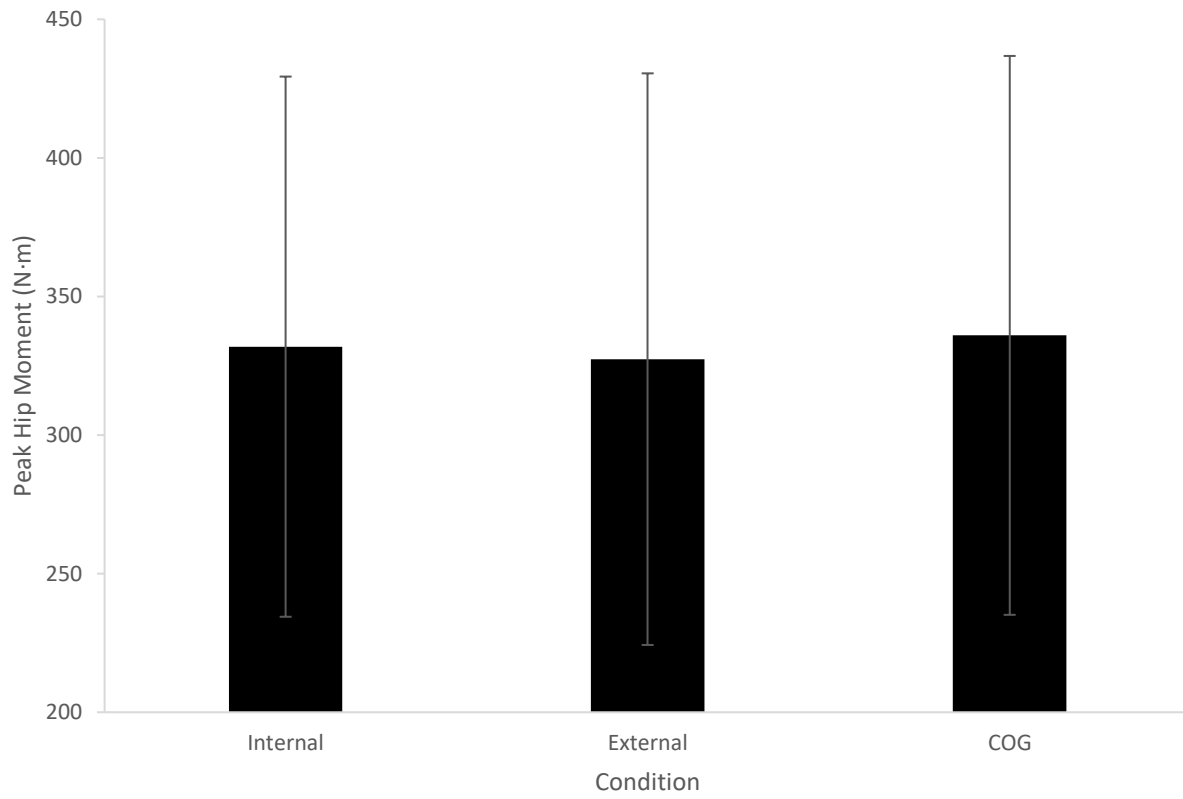


Figure 7. Left peak hip moment means as a function of experimental conditions.

ATTENTIONAL FOCUS AND DUAL-TASKING ON CONVENTIONAL DEADLIFT PERFORMANCE

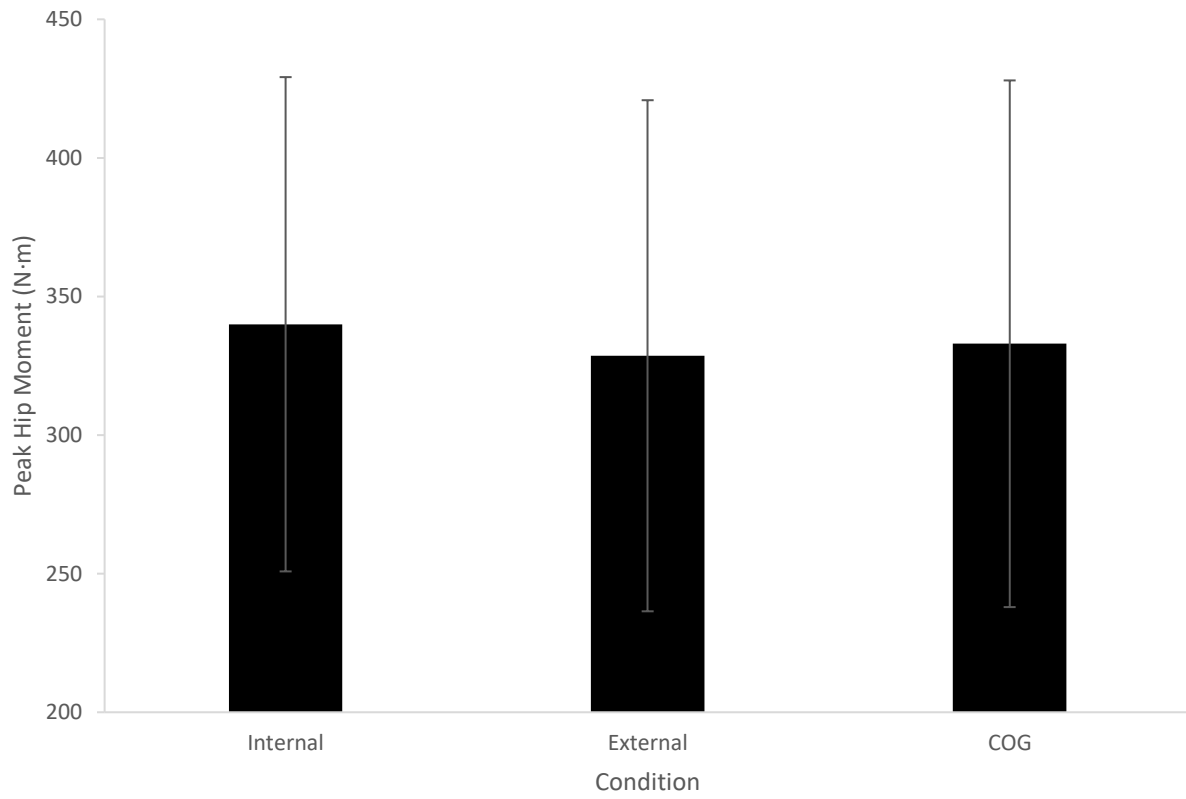


Figure 8. Right peak hip moment means as a function of experimental condition.

Table 1. Descriptive characteristics of participants

Characteristics	Participants (n = 15)
Body-mass (kg)	89.4 ± 13.1
Height (m)	1.8 ± 0.07
BMI (kg/m ²)	27.6 ± 2.6
Age (y)	23.3 ± 3.4
Resistance Training Experience (y)	5.9 ± 4.1
Experience with Conventional Deadlift (y)	4.2 ± 2.2
Estimated 1RM (kg)*	215.1 ± 27.2

*Estimated 1RM were based on the 1RM protocol performed during the first session

Values are mean ± standard deviation (SD). BMI = body mass index.

Table 2. Mean and standard deviation (SD) of each condition across all outcome measures

Outcome Measure	Internal	External	COG
Lift Duration (s)	2.50 ± 0.60	2.65 ± 0.91	2.48 ± 0.64
Peak Barbell Velocity z (m/s)	0.39 ± 0.11	0.37 ± 0.11	0.38 ± 0.11
SD of Barbell Position y (cm)	1.78 ± 0.53	1.57 ± 0.56	1.78 ± 0.60
Vertical Peak Ground Reaction Force (N)	2876 ± 371	2869 ± 371	2875 ± 377
Area (cm ²)	36.61 ± 12.23	32.43 ± 11.61	37.20 ± 14.03
Mean Velocity COPx (cm/s)	7.38 ± 3.33	7.27 ± 3.16	7.06 ± 2.56
Mean Velocity COPy (cm/s)	7.51 ± 1.97	7.26 ± 1.84	7.68 ± 2.01
SD of COPx (cm)	1.09 ± 0.32	1.08 ± 0.24	1.09 ± 0.31
SD of COPy (cm)	2.10 ± 0.52	1.86 ± 0.57	2.11 ± 0.63
Left Peak Hip Moment (N·m)	-395 ± 69	-393 ± 71	-392 ± 69
Right Peak Hip Moment (N·m)	-393 ± 71	-392 ± 66	-391 ± 69
Left Peak Hip Power (N·m)	332 ± 97	327 ± 103	336 ± 101
Right Peak Hip Power (N·m)	340 ± 89	329 ± 92	333 ± 95

Values are mean ± standard deviation (SD). z = inferior-superior direction. y = anterior-posterior direction. COP = centre of pressure. COG = cognitive task.

CHAPTER IV: GENERAL DISCUSSION

The purpose of the present work was to examine the effects of attentional focus and dual-tasking, using a cognitive task, on conventional deadlift performance in experienced lifters. It was hypothesized that utilizing a cognitive task would yield the most efficient (i.e. smaller standard deviation in barbell position for the anterior-posterior direction) and effective (i.e. greater peak barbell velocity for the inferior-superior direction, greater pVGRF, a shorter lift duration, greater hip extensor power) conventional deadlift performance followed by an external focus and then an internal focus. Similarly, we hypothesized that utilizing a cognitive task would also result in the greatest postural stability (i.e. smaller COP area, smaller COP standard deviation and greater COP velocity in the anterior-posterior direction) when performing the conventional deadlift followed by an external focus and then an internal focus.

4.1 Attentional focus effects on conventional deadlift performance

In contrast to our first hypothesis, the findings of the present work revealed no significant differences between adopting an EF, IF, or utilizing a cognitive task with regards to the effectiveness of conventional deadlift performances at high intensity loads (i.e. 87% of 1RM). Despite a large body of literature (e.g. Wulf, Shea, & Park, 2001; Totsika & Wulf, 2003; Wulf & Su, 2007; Chiviacowsky, Wulf, & Avila, 2013; Kal, van der Kamp, & Houdijk, 2013; Totsika & Wulf, 2003; Wulf, 2013 etc.) indicating a robust performance advantage associated with adopting an EF relative to an IF in other sporting domains, the results of the present work show no significant differences between an EF and an IF for lift duration ($p > 0.05$) and peak barbell velocity in the inferior-superior direction ($p > 0.05$). These findings suggest that attentional focus effects diminish at higher loading intensities, which is congruent with previous studies (Snyder & Fry, 2012; Calatayud et al., (2016) that investigated the effects of IF instructions on muscle

activity during multi-joint resistance exercises. Snyder & Fry (2012) and Calatayud et al. (2016)'s findings both indicate a threshold between 60 to 80% of 1RM exists where adopting an IF no longer results in greater muscle activation relative to neutral instructions. However, as indicated by other attentional focus studies pertaining to force production tasks, greater muscle activation does not directly result in greater force production (Wulf et al., 2007; Marchant et al., 2009). Rather, Wulf et al. (2007) suggests that a decrease in agonist muscle activity paired with greater force production derived from an EF is the result of a reduction in agonist-antagonist co-activation. Though the present work did not measure muscle activity, pVGRF ($p > 0.05$) into the ground, peak hip moments ($p > 0.05$) and peak hip powers ($p > 0.05$) indicated no significant differences between any of the conditions which further reinforces the notion that attentional focus effects diminish at high intensity loads.

Contrary to these findings, Wulf & Dufek (2009) reported greater lower extremity joint moments and less EMG activity (Wulf et al., 2010) when comparing an EF to an IF during vertical jumps. Furthermore, Marchant et al. (2009) reported greater peak net joint torque for an EF relative to an IF during a maximal isokinetic elbow flexion task. Collectively, these studies indicate that there is a profound attentional focus effect at play during tasks that require maximal force production. However, these studies draw large distinct differences from the conventional deadlift (e.g. lack of object manipulation, different force-velocity profiles, the use of a single joint versus multi joint etc.), which creates difficulty when attempting to compare findings. Nevertheless, a possible reason for the lack of differences between attentional foci for the previously mentioned variables could be from the sheer intensity of the motor task. De Luca & Kline (2012) reported motor unit recruitment thresholds and rate coding vary amongst different muscle groups, which may occur below 100% of maximum isometric voluntary contractions.

This would suggest a possible ‘ceiling effect’ may be present in reducing the neuromuscular benefits associated with an EF for maximal force production tasks. More specifically, at high intensity loads, the efficiency of motor unit recruitment and firing are likely already maximized in experienced populations. From an intermuscular perspective, the co-activation of agonist and antagonist muscles acting on the hip are also likely minimized at loads nearing an individual’s 1RM, thus maximizing one’s efforts in completing the lift. Given that muscle activity was not directly measured, future studies are required to confirm these speculations.

4.2 Attentional focus effects on posture during the conventional deadlift

Interestingly, adopting an EF still resulted in less barbell position variability in the AP direction ($p < 0.05$), suggesting a more consistent deadlift performance than adopting the IF or performing the COG. While Lohse et al. (2010) have previously suggested that movement variability can be related to “functional variability”, we presume that this may be due to the EF yielding superior postural stability as evidenced by a significantly lower mean velocity ($p < 0.05$) and SD of COP ($p < 0.05$) in the AP direction, along with a trend for less sway amplitude ($p = 0.074$). Though an increase in movement variability may be related to “functional variability” for a dart throwing task, the same rationale should be applied with caution when considering heavily loaded conventional deadlifts. Lohse et al. (2010) noted that an increase in muscle recruitment resulting from an IF may have reduced the degrees of freedom available at the shoulder joint that could have otherwise compensated for changes in other movement parameters during dart throws. This would effectively reduce an individual’s ability to use “functional variability” to yield the desired outcome (i.e. the dart landing on the bullseye). As previously mentioned, when performing heavily loaded conventional deadlifts, motor unit recruitment and muscle activation are likely maximized. Similar to the IF condition in Lohse et al. (2010)’s study, this would limit

the influence of “functional variability” by restricting the degrees of freedom about each joint. Rather, the reduction in barbell position variability in the AP direction during an EF may be the by product of greater postural stability derived from greater automaticity. This rationale is more consistent with previous findings made by Polskaia et al. (2014), Richer et al. (2017), and the constrained action hypothesis. According to this hypothesis, consciously attending to one’s movements (i.e. IF) may interfere with the automaticity of motor control processes that regulate movement, whereas focusing on movement effects (i.e. EF) may promote the automaticity of said motor control processes (McNevin et al., 2003). However, without EMG, Polskaia et al. (2014) were unable to determine if the greater postural stability from the EF was from an increase in automaticity, or if it was due to an ankle stiffening strategy. Richer et al. (2017)’s findings provided evidence (i.e. increase in MPF with no increases in muscle activity about the ankle joint) that the increase in postural stability measures were the result greater automaticity. Drawing from this chain of logic, we rationalize the decrease in barbell position variability in the AP direction is the result of greater automaticity as suggested by the constrained action hypothesis. However, without the addition of EMG data, we can only speculate that this is the correct rationale. Further research is merited to determine the underlying mechanisms behind the decrease in AP barbell trajectory for heavily loaded barbell exercises.

4.3 Dual-tasking effects on conventional deadlift performance

The findings of the present study revealed the COG yielded similar results to the attentional focus conditions with regards to barbell kinematics and force production. That is, no significant differences were found when comparing the COG with the attentional focus conditions for lift duration, peak barbell velocity in the inferior-superior direction, pVGRF, peak hip moments, and peak hip powers. Given that the same loading intensity was used across all

conditions, the same rationale for the lack of difference between attentional focus conditions can be applied here (i.e. near maximal motor unit recruitment and muscle activation may cause a potential ‘ceiling effect’ that reduces an individual’s ability to express the neuromuscular effects of attentional focus).

4.4 Dual-tasking effects on posture during the conventional deadlift

Moreover, the results of the present study suggest that performing the COG yielded a less posturally stable performance relative to an EF as evidenced by a greater SD of COP ($p < 0.05$), a greater mean velocity ($p < 0.05$) and a trend for larger sway amplitude ($p = 0.074$) in the AP direction. This is inconsistent with previous postural control studies (Polskaia et al., 2014; Richer et al., 2017) that found greater postural stability to be associated with a COG in comparison to an IF or EF. The difference between these studies and the present work may be due to the difference in cognitive demand resulting from the motor task. The limited attentional capacity sharing model for explaining dual-task interference would suggest that a competition for information processing resources would occur between the COG and the motor task (Lorist, Kernell, Meijman, & Ziidewind, 2002). Given that information processing resources are finite, and the summation of information processing demands exceeds the capacity of the individual, the performance of one or both tasks would be compromised (Lorist et al., 2002). More specifically, the information processing demands of performing a COG during quiet standing are likely within one’s information processing capacity, whereas performing a heavily loaded conventional deadlift in conjunction with the COG may exceed one’s information processing capacity. Since COG trials that exceeded the error count threshold were removed from the data set, only the trials where the participants placed greater information processing capacity on the COG remained. Therefore, the decrease in postural stability when performing the COG and the

conventional deadlift simultaneously may be the result of cognitive resource competition between tasks. Alternatively, the bottleneck model suggests that critical tasks are processed sequentially (Lorist et al., 2002) and presents an equally viable rationale for the present findings. During the experimental testing sessions, several participants verbalized that they performed the COG and motor task sequentially. Given the short duration of the motor task and the rate at which the number sequence is presented, participants adopting this strategy would be able to score below the error threshold. Furthermore, the lack of significant differences between the COG and the IF for all the variables in the present study suggests that the participants may have opted for an IF when performing the conventional deadlift during the COG trials. This potential phenomenon would be congruent with previous literature suggesting that athletes primarily adopt an IF and may switch between an IF and an EF during skill execution (Porter, Nolan, Ostrowski, & Wulf, 2010; Porter, Wu, & Patridge, 2010).

CHAPTER V: CONCLUSION

5.1 Summary of Findings

The results of the present work indicate that the effects of attentional focus diminish when conventional deadlifts are performed at loading intensities that are close to an individual's one repetition maximum, which is consistent with previous literature attentional focus effects on muscle activation (Snyder & Fry, 2012; Calatayud et al. 2016). This was shown by the lack of significant differences between attentional foci for lift duration, peak barbell velocity and the kinetic measures (i.e. pVGRF, peak hip moments and peak hip powers). Furthermore, performing the COG resulted in no significant differences when compared to the attentional foci for the aforementioned variables suggesting that the intensity of the motor task may be causing a 'ceiling effect'. Moreover, adopting an EF appears to improve the consistency of barbell positioning in the AP direction (i.e. lower SD of barbell position in the AP direction) and improve postural stability (i.e. Smaller SD of COP in the AP direction, slower mean velocity in the AP direction, and a trend for less sway amplitude), which may be due to greater automaticity. Conversely, performing the COG increased variability in barbell positioning in the AP direction and resulted in less postural stability relative to the EF. This was attributed the large amount of dual-task interference experienced by the participants when performing the COG and the conventional deadlift. Collectively, these findings suggest that only adopting an EF provides greater postural stability when performing heavily loaded barbell exercises typically seen in some strength-based sports.

5.2 Limitations

Though the present thesis has revealed several unprecedented findings, it is critical to note several limitations. Firstly, without EMG data about the muscles of the lower body joints, we are only able to speculate that muscle activation and motor unit recruitment were nearly maximized due to the loading intensity. Including EMG would enable us to not only examine the magnitude of muscle activation, but also the timing of those activations. As previously mentioned, our decision to exclude EMG from our study stems from prior attentional focus studies on muscle activation (Snyder & Fry, 2012; Calatayud et al., 2016) suggesting that attentional focus effects become less prominent with greater loading intensities. Furthermore, Wulf et al. (2010) found no significant differences for lower body muscle activation timing between an EF and an IF during vertical jumps. Despite these previous findings and the logistical barriers (e.g. electrodes on the anterior side of the body inhibiting regular AP barbell trajectory, cost, etc.) that may prevent the use of EMG, measuring muscle activity about the ankle joints (i.e. dorsiflexors and plantar flexors) and the knee joints (i.e. knee extensors and knee flexors) may still provide valuable information regarding the differences in postural control between conditions. Based on the present data and data from previous deadlift studies (Escamilla, Franciso, Fleisig, Barrentine, Welch, Kayes, Speer, & Andrews, 1999; Escamilla, Lowry, Osbahr, & Speer, 2000), the greatest joint moment during the conventional deadlift occurs at the hip, which suggests that the hip extensors may be fully activated. However, the joint moments about the ankles and knees are miniscule by comparison, which may be linked to the differences in postural stability between experimental conditions in the present work. Future studies examining the effects of any manipulation on heavily loaded conventional deadlifts should consider including EMG about agonist and antagonist muscles of the lower body.

Secondly, the difficulty of the COG used in the present study erred on the difficult side in the efforts to prevent participants from allocating any attentional resources to the motor task. While with respect to the constrained action hypothesis this would induce greater automaticity, the difficulty seems to have been set too high and resulted in a large amount of cognitive-motor interference which ultimately overwhelmed the participants. Future studies comparing attentional focus to a COG should consider scaling the difficulty of the cognitive task such that it does not overwhelm the participant, but still fully engages their attentional resources.

Lastly, the present work only included a single set of instructions for each attentional focus type. Given that there are numerous coaching cues that can be used to evoke an IF or an EF, future studies should also include multiple sets of instructions that compare the effects of different coaching cues within the same sub division of attentional focus.

5.3 Practical Applications

Although more research is warranted, novel and sport specific recommendations can be made based off the findings of the present work and the current state of the literature. First, athletes performing heavily loaded barbell movements in competition (e.g. powerlifters, strongman, weightlifters etc.) should consider using EF cues to acquire the postural stability benefits when performing heavy repetitions. This is true whether the athlete is attempting to improve the quality of their repetitions in training or trying to maximize their performance in competition. Perhaps the only period when these athletes consider should use an IF rather than an EF would be when attempting to maximize muscle hypertrophy during the off-season. Schoenfeld et al. (2018) found that using an IF over time yields greater muscle hypertrophy

relative to an EF. Given that postural stability demands are likely not the limiting factor in performing resistance exercises at the moderate intensities typically used when training for muscular hypertrophy, adopting an IF would be the superior option. Lastly, until further research is completed on the use of a COG on sport performance, athletes and coaches should avoid using it in their training and competition performances.

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