Effect of Focus of Attention on Rate of Torque Development in the Knee Extensors

by
Adam B. Kiff

A THESIS

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Background: The ability to produce rapid muscle force and joint torque is important for performance in sports, injury prevention and rehabilitation, and balance recovery. One way to measure rapid torque production is rate of torque development (RTD), which is the slope of the torque-time curve. Interventions aimed at increasing RTD are of interest. Adopting an external focus of attention, which is focused on one's environment, has been found to enhance peak torque production compared to an internal focus of attention, which is focused on one's bodily movements. However, the effects of focus of attention on RTD is unknown. **Methods:** Thirty participants evenly split between sexes (age = 22.1 ± 2.6 years, mass = 78.98 ± 11.71 kg, and height = 173.78 ± 11.00 cm) completed a minimum of three and a maximum of eight trials of maximal voluntary isometric contractions of the knee extensors under both external and internal focus conditions. External focus instructions were, "While looking straight ahead, try to push out as hard and fast as you can while focusing on the device arm." Internal focus instructions were, "While looking straight ahead, try to push out as hard and fast as you can while focusing on the muscles on the front of your thigh." Paired t-tests were used to compare the two conditions for both peak torque and RTD. **Results:** RTD was significantly greater during the external focus condition than during the internal focus condition (external focus 11.16 ± 4.98 $N \cdot m \cdot kg^{-1} \cdot s^{-1}$ versus internal focus 9.92 ± 4.22 $N \cdot m \cdot kg^{-1} \cdot s^{-1}$, $p = 0.0248$). There was no significant difference in peak torque between conditions (external focus 2.14 ±

0.60 N·m·kg^{-1} versus internal focus 2.08 ± 0.61 N·m·kg^{-1}, $p = 0.1887$). **Conclusion:** An external focus of attention elicited a 12.4% greater RTD than the internal focus of attention. However, there was no difference in peak torque condition. This improved rapid torque production may be important in situations that require explosive movement, such as in sport performance and the prevention of injuries and falls.

Key Words: explosive movement, peak torque, rate of force development, internal focus, external focus

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I understand that my project will become part of the permanent collection of Oregon State University, Honors College. My signature below authorizes release of my project to any reader upon request.

Adam B. Kiff, Author

INTRODUCTION

Production of muscle force is important in many circumstances, especially in athletic movements and injurious situations. Muscle force produces joint torques, allowing movement of limb segments and protecting a joint from injury. To quantify the capacity of muscle to produce joint torques, peak torque (PT), which is the greatest amount of torque produced during a contraction, has traditionally been used. However, it takes at least 300 ms from the onset of contraction to reach PT.[1] Quick movements during athletics or injurious situations usually occur within 250 ms of the onset of contraction and thus are time-critical.[2–4] Because an individual may not have enough time to reach PT during these movements,[1] it is of interest to identify methods for quantifying explosive movement, which requires the rapid production of muscle torque within a limited amount of time.

One way to measure rapid torque production is rate of torque development (RTD), which is the slope of a torque-time curve.[5] A higher RTD has been associated with increased explosive performance in elite-level athletes and increased postural stability and balance recovery – which relies on quick muscle corrections – in older individuals.[6] Additionally, rapid torque production in the knee extensors seems to be especially important for post-injury recovery,[7–9] performance,[10–12] and theoretically for injury prevention. Therefore, it is of interest to identify interventions or strategies that improve RTD.

One area that has been shown to improve certain performance variables is the orientation of an individual's attention during a task. Attention can be focused either internally or externally. An internal attentional focus (AF) is a conscious concentration on one's own bodily movements, while an external AF is a concentration on the effects of a movement on the environment.[13] For example, when weight-lifting, an internal AF would focus on the contraction of one's muscles, while an external AF would focus on the weight that is lifted. Previous researchers have shown that adopting an external AF improves movement accuracy,[14–17] jump performance,[18–21] and peak torque production.[22,23] However, the effect of AF on rapid torque production has yet to be described. Therefore, the purpose of this study was to examine the effect of AF on RTD in the knee extensors during a maximal voluntary isometric contraction.

LITERATURE REVIEW

Introduction

The ability to produce explosive torque contributes to performance in sport, rehabilitation from injury, and balance recovery and stability in older adults.[7,8,11,24] Measuring rate of torque development during a contraction offers insight into the explosive capacity of a muscle. Researchers have attempted to identify factors that can optimize explosive torque production. Focus of attention has been shown to improve other performance measures and may positively influence RTD.

Importance of Rapid Torque Production

Muscular strength has been traditionally measured by peak torque (PT), which is the maximum torque produced during a voluntary contraction. An individual's peak torque usually occurs after 300 ms from the onset of contraction.[1] However, some tasks and movements rely on the production of torque in a relatively short amount of time (i.e., within 250 ms of the onset of contraction). These are referred to as time-constrained movements and often rely on rapid or explosive muscle contraction, such as during ground contact in a sprint,[2] hamstring strains,[3] and noncontact ACL injuries.[4] During such movements, there is not enough time to achieve PT, and a different gauge of muscular strength is necessary.

One way to measure explosive strength is rate of torque development (RTD), which is the slope of a torque-time curve.[5] By increasing this slope, an individual reaches a greater level of torque within a specified amount of time. Recent studies have shown that an increased RTD is important in numerous settings, such as for enhancing performance in sport[11] and for preventing injuries.[25–27] Additionally, an age-related decline in balance recovery ability is most likely due to decreased ability to produce rapid movements in the lower extremities.[28] Many researchers measure rate of force development (RFD); however, in this study, RTD was measured will used for consistency, whether referring to RFD or RTD.

While RTD appears to be important for the rapid contraction of various muscles, the knee extensors (i.e., the quadriceps) seem to be especially important for post-injury recovery[7–9] and performance.[10–12] First, it is important to consider the relative importance of the knee extensors in a performance task. In a study investigating the role of the triple extensor muscle groups in a maximal vertical jump, Chang et al. compared RTD and PT values of the hip, knee, and ankle extensors (plantar flexors) and their relative contributions to jump performance.[10] Subjects performed a countermovement vertical jump in addition to hip, knee, and ankle maximal isometric extensions to measure RTD at 50 ms and 200 ms from the onset of contraction. They found that greater vertical jump height was associated with greater RTD and PT of the knee extensors but not the ankle and hip extensors.[10] Therefore, in a healthy population, the knee extensors may be more important than other muscle groups in this type of movement.

Additionally, the knee extensors seem to be important in knee joint mechanics, rehabilitation, and risk of additional injury after ACL reconstruction. Blackburn et al. examined relationships between quadriceps dysfunction – particularly deficits in torque production – and gait biomechanics linked to knee osteoarthritis development after ACL reconstruction.[7] The researchers analyzed subjects' kinetics while walking barefoot on force plates and measured quadriceps function while seated on a dynamometer. Subjects performed both isometric and isokinetic rapid maximal voluntary contractions to measure PT and RTD to 100 ms and 200ms from the onset of contraction (i.e., a torque $\geq$ 20 N·m). They found that ACL reconstructed limbs displayed lower RTD values at all time-intervals and demonstrated high-rate loading of the leg, which is related to knee osteoarthritis development.[7] In other words, deficits in the ability to produce rapid torque in the knee extensors might be related to cartilage degradation in ACL-reconstructed knees.

In another study, Angelozzi et al. investigated the use of knee extensor RTD in determining readiness to return to sport among male professional soccer players who had undergone ACL reconstruction.[8] The study compared each athlete's maximal voluntary isometric contraction (MVIC) and RTD values between pre-injury, six months post-surgery, and twelve months post-surgery testing. The athletes completed a power-based training protocol throughout rehabilitation, which included high-force low-velocity, low-force high-velocity, and high-force high-velocity exercises. After six months of post-surgery power training, subjects' knee extensor MVIC values were almost fully regained, while RTD values still showed a significant deficit compared to pre-injury values.[8] However, recovery of RTD was achieved after the full 12-month program, which included 20 weeks of training which emphasized RTD improvement. This suggests that regaining RTD in the knee extensors following ACL reconstruction requires significant training beyond what is required to regain MVIC ability.

Similarly, Kline et al. conducted a cross-sectional study to compare knee extensor RTD in recreational athletes' ACL-reconstructed and non-injured knees.[9] All subjects were tested six months after surgery, had completed rehabilitation, and were cleared to return to sport by a physician. Subjects performed four isometric contractions of the knee extensors in both legs, from which RTD was measured in both an early phase (i.e., 0 to 100 ms) and a late phase (i.e., 100 to 200 ms). Subjects' reconstructed limbs produced significantly lower RTD values during both phases.[9] Granted, testing of RTD was performed in a relatively nonfunctional position and did not mimic a competitive situation. However, as noted by the authors of both studies, knee extensor RTD deficit following ACL reconstruction is of concern and requires consideration when determining an athlete's return to sport.[8,9]

The ability to produce torque rapidly also has implications for populations beyond athletes. In older adults, preventing a fall requires the production of torque within 200 ms,[29] so increasing RTD may be beneficial. A study by Bento et al. aimed to compare muscle PT and RTD in elderly individuals and relate these parameters to number of falls that the subjects had suffered in the preceding 12 months.[24] Subjects performed a series of maximal voluntary isometric tests of flexion and extension of the hip, knee, and ankle and adduction and abduction of the hip against a resistance cable. The subjects were instructed to contract as hard and fast as possible and to sustain the contraction for approximately three seconds. RTD was measured as the slope of the torque-time curve from 20% to 80% of the PT value. The only significant finding of this study was that individuals who produced greater knee flexor RTD suffered fewer falls. Meanwhile, RTD and PT of the other motions did not differ between fallers and non-fallers.[24] Therefore, the ability to produce rapid torque in the lower extremity, particularly in the knee flexors, may be especially important for preventing falls in older individuals.

Based on these studies, it is apparent that RTD is important in a variety of settings, such as for performance, injury recovery and rehabilitation, and prevention of falls. Therefore, improving RTD and rapid torque production has beneficial implications. Long-term strategies, such as training, have been shown to have a significant effect on RTD.

Training Rate of Torque Development

Zaras et al. implemented a periodized training program for track and field throwing athletes.[11] The program consisted of 10 weeks of power training, which included various bounds, agility exercises, and short-distance maximum-velocity sprinting. The first five weeks of the program also included hypertrophy and maximal strength training. The throwers experienced both increased leg press RTD and improved shot put performance at the end of the training period.[11] This result suggests that an athlete's lower extremity RTD can be trained and improved to enhance performance in competition.

To examine how different types of training programs affect RTD, Mangine et al. assigned untrained subjects to one of two training programs for eight weeks.[30] One program was a high-intensity, long rest interval program (which included 4 x 3-5 repetitions at 90% of 1-RM with 3 minutes of rest) and the other a high-volume, short rest interval program (which included 4 x 10-12 repetitions at 70% of 1-RM with 1 minute of rest).[30] RTD was measured using an isometric mid-thigh pull. The study found that a high-intensity training program was more effective than a high-volume program for stimulating changes in RTD.[31] This information may help in designing training programs meant to improve RTD.

Researchers have also examined eccentric strength training as a method for increasing RTD. Through an eccentric contraction-based program, Oliveira et al. compared changes in early-phase (i.e., < 100 ms) and late-phase (i.e., > 100 ms) RTD.[12] Subjects performed tests of maximal isometric knee extensor contractions both before and after the training program to quantify changes in performance. During the eight-week training program, subjects performed maximal eccentric contraction exercises. The number of sets of eight maximal contractions increased every two weeks until the last week of training. The researchers compared subjects' pre- and post-training peak isometric torques (PT) as well as RTD in successive 50-ms windows to 250 ms from the onset of contraction. The main finding was that both PT and maximal RTD experienced significant increases after the training program.[12] Thus, a maximal eccentric training program of the knee extensors seems to be a valid training strategy for increasing RTD as well as PT.

Many studies aimed at improving RTD utilize certain stimuli or cues that focus on explosive movement or the subject's intention to move quickly. The specific training stimulus, such as an explosive-type movement, may account for why improvements in RTD have been observed. To better understand the implications of different training protocols, Tillin and Folland compared the effects of both maximal strength and explosive strength training programs on maximal and explosive torque production in an isometric knee extension.[32] Subjects were assigned to either maximal or explosive strength training programs, which consisted of isometric knee extension exercises. The maximal strength group was instructed to contract to increase torque over a one-second period and hold at a submaximal exertion for three seconds. Alternatively, the explosive strength group was instructed to contract as "fast and hard" as possible for about one second and then rest for five seconds between repetitions. Following the training period, all subjects' maximal and explosive strengths were measured by performing both maximal strength-based and explosive strength-based contractions. The researchers found that the maximal strength program was more effective at improving maximal strength while the explosive strength program was more effective at improving explosive strength.[32] Thus, a specific training stimulus can elicit a specific improvement in maximal or explosive strength. Among training programs that have been successful in improving RTD, the subjects' intention to be explosive in their movements seems to be one of the fundamental factors influencing increases in explosive strength.

Long-term training strategies appear to improve RTD among athletes. However, an acute strategy may be more beneficial for situations such as injury prevention, balance recovery, and in sports performance settings.

Implications of Attentional Focus

One strategy that has been shown to improve performance acutely is attentional focus (AF), which is the orientation of one's focus of attention. Researchers distinguish AF as either internal, focusing on one's bodily movement, or external, focusing on the outcome or effect of a movement. An external AF has been shown to consistently improve movement outcomes such as peak torque production[22,23] as well as movement accuracy,[14–17] maintenance of balance and posture,[33,34] ski-simulator and golf performance,[33,35] and jump performance.[18–21]

To investigate the use of attentional focus in a performance setting, Wu et al. examined how different attentional focus instructions affected performance in a standing long jump.[19] After a cycling warm-up, subjects jumped off a force platform toward a green target placed at an unreachable distance of 4.57 m from the starting position. The researchers measured distance jumped toward the target as well as peak force produced during the jump. Subjects performed one baseline jump, followed by two jumps under each verbal AF instruction. The internal focus instructions were, "Jump as far as you can. While you are jumping, I want you to think about extending your knees as rapidly as possible." The external focus instructions were, "Jump as far as you can. While you are jumping, I want you to think about jumping as close to the green target as possible." The order of the conditions was counterbalanced between subjects to avoid learning and fatigue effects. It was found that both male and female participants jumped significantly farther with an external focus (153.6 ± 38.6 cm) than with an internal focus (139.5 ± 46.7 cm).[19] However, there was no significant difference between conditions in the peak force produced against the force plate. One concern about this study is that the attentional focus instructions did not specify a consistent movement type in both conditions. Extending one's knees "as rapidly as possible" is a more explosive task than jumping as close to a target as possible, which implies an accuracy-based task, even while the target is placed at an unreachable distance.

The authors explain the results using the constrained action hypothesis, which suggests that an individual focusing internally is likely to disrupt the automaticity of innate motor control processes.[13] By directing one's attention externally, these automatic processes allow for efficient and natural regulation of the motor action.[36] That is, an external AF enhances movement performance with relatively little physical or mental effort. The authors suggest that this is why an external AF elicited better performance with the same amount of force production.[19] In a complex movement, such as a jump, these automatic processes may govern coordination and synchronicity between muscles to enhance performance.[18–20] Additionally, an internal AF has been shown to elicit increased cocontraction of antagonist muscles,[16,17] which may decrease the efficiency of both complex (e.g., jump) and simple (e.g., knee extension) movement.

In a follow-up study to Wu et al., Ducharme et al. examined the effect of AF on jump projection angle of the standing long jump task.[20] Similarly to the former study, the authors analyzed trials in which subjects were instructed to jump as far as they could for control, external AF, and internal AF conditions. Subjects were instructed to focus on jumping toward a target during the external AF condition and to focus on the extension of their knees during the internal AF condition, while no additional instruction were given during control trials. Jump projection angle was measured as the angle of the lower limb from horizontal immediately after toe-off (90° = standing). They found that subjects jumped with a more optimal projection angle (i.e., near 45°) while adopting an external AF, which resulted in a longer jump distance.[20] This finding partially supports the constrained action hypothesis, considering that an external AF elicited a more optimal movement coordination to produce better performance. It is unknown if the external AF jumps had lower cocontraction because the study did not measure muscle activation.

In another study, Wulf et al. examined how attentional focus instructions affected jump-and-reach height in a vertical jump task.[18] The researchers measured jump height (using a Vertec™ vertical jump measurement device) as well as EMG activity of the tibialis anterior, biceps femoris, vastus lateralis, rectus femoris, and gastrocnemius muscles. Before each trial, participants were instructed to reach as high as possible during each jump with the addition of either an internal or external focus of attention instruction. During internal focus conditions participants were instructed to "concentrate on the tips of their fingers" versus "concentrate on the rungs" of the measurement device during external focus conditions. Each subject performed 10 jumping trials under each attentional focus condition in a counterbalanced order. The study found that jump-and-reach height was significantly greater when participants adopted an external focus (32.4 ± 3.1 cm) than an internal focus (31.0 ± 3.2 cm).[18] Additionally, EMG root-mean-square error was consistently and significantly lower during the external focus condition. Performance was enhanced with relatively low neural activation, implying that an external AF elicited a more efficient movement.

To examine the effects of AF on PT production, Marchant et al. compared subjects' elbow flexion torques when prompted by different focus instructions.[22]

Subjects first completed control trials without specific attentional instructions to record maximal voluntary contraction (MVC) values used for normalization (i.e., the researchers reported the AF trials as percentages of the control MVC trials). Before each trial, subjects were instructed to produce maximal force throughout the full range of elbow flexion. Subjects then completed the experimental trials, during which they followed specific AF instructions. The internal AF instructions were, "Focus upon the movement of your arm and muscles during the lift." The external AF instructions were, "Focus upon the movement of the crank hand bar during the lift." Each subject performed 10 trials for each condition (i.e., control, internal, and external) and AF condition order was counterbalanced between subjects. It was found that subjects exhibited a significantly greater peak joint torque when adopting an external focus (102.10 ± 2.42% MVC) than when adopting an internal focus (95.33 ± 2.08% MVC).[22] This finding provides more insight into the implications that AF may have on a movement outcome. Considering that an external AF may enhance peak joint torque production, it may affect other aspects of maximal contractions.

Conclusion

It is apparent that rapid torque production is important in numerous settings, including performance,[10,11] returning to sport after an injury,[7–9] and prevention of falls.[24] While RTD has been found to improve with training,[11,12,31] a more immediate strategy, such as the orientation of one's attention, may be more beneficial in acute settings. AF has been shown to affect various performance and torque production outcomes, including jump performance[18–21] and peak joint torques.[22,23] However, there is a lack of evidence regarding its effect on *rapid* torque production.

METHODS

Participants

A total of 30 participants (15 male and 15 female) volunteered for the study (age = 22.1 ± 2.6 years, mass = 78.98 ± 11.71 kg, and height = 173.78 ± 11.00 cm). Prior to participation, all participants read and signed a written informed consent approved by the Oregon State University Institutional Review Board. Inclusion criteria were:

1. Between the ages of 18-30.
2. Participation in a weightlifting program targeting the legs in the previous six months.
3. No current injuries or illnesses limiting participation in regular physical activity.
4. No history of injury to the legs or back that limited regular physical activity.
5. No history of knee injuries requiring surgery.

Participants were asked to avoid any strenuous, fatiguing physical activity prior to participating in the study on the day of data collection.

Experimental Protocol

Each participant first warmed up on a stationary bicycle for five minutes at a submaximal intensity. The participant was then oriented to the Biodex System 3 dynamometer (Biodex, Inc, Shirly, New York). He or she was familiarized with the machine, were informed that it would record the torque exerted against the device arm, and that the device arm would not move. This study was part of a larger study that also investigated muscle activation, so each participant was also oriented to the EMG data collection procedures. Following the familiarization, leg dominance was ascertained by the leg preferred to use for the majority of the following three tasks: (i) kicking a ball, (ii) stepping up onto a step, and (iii) recovering from a small perturbation from behind.[37] Each participant's height and weight were then determined using a wall-mounted stadiometer and a scale, respectively.

Since EMG of the hamstrings were being collected as part of the larger study, the seat of the dynamometer was replaced with a modified high density foam seat that was constructed with 19 cm x 10 cm cutouts (see Figure 1) to avoid any pressure on the electrodes. The participant was then positioned with the dynamometer aligned with the lateral epicondyle of the dominant leg, the knee flexed at a 70° angle (0° = full knee extension), and the attachment of the dynamometer secured just above the ankle. The participant was further secured to the dynamometer seat with straps above

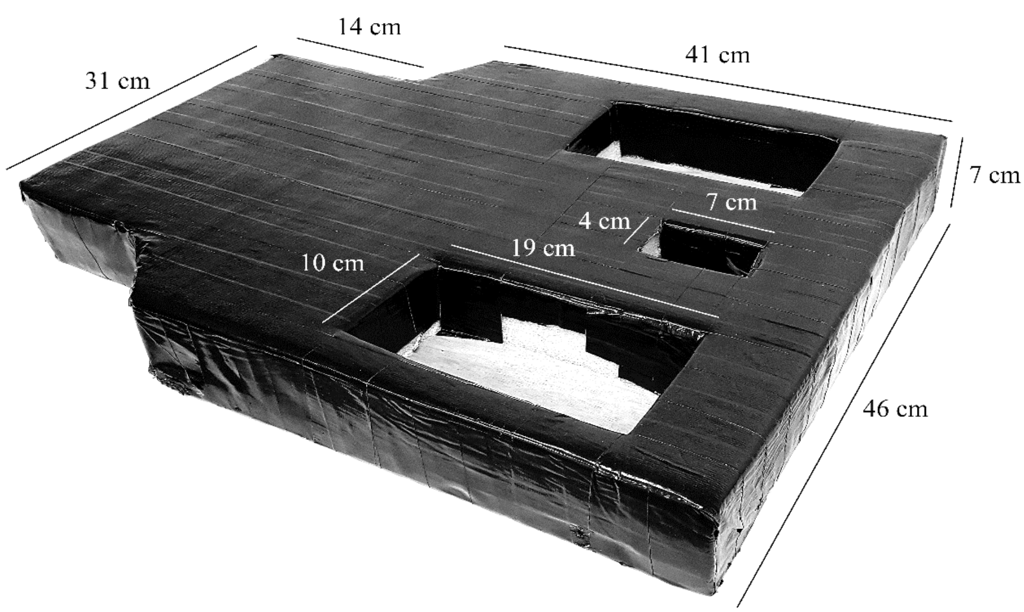

Figure 1. Modified seat dimensions.

the knee and around the waist. The non-test leg was placed in a position of comfort. (See Figure 2)

Figure 2. Participant positioning.

Each participant was instructed to cross their arms over the chest and perform isometric contractions of the knee extensors under three conditions (i.e., control trials, external focus trials, and internal focus trials). Participants were provided with the instructions described in Table 1.

Strength testing began with control maximal voluntary isometric contraction (MVIC) trials of the knee extensors with no specific internal or external focus of attention instruction. The control trials served as practice prior to the AF conditions. Next, the participant performed the internal and external focus trials in a counterbalanced order (see Table 1).

All trials were 1-3 seconds in duration with 60 seconds of rest between trials and 120 seconds of rest between conditions. After every trial, the torque signal was visually inspected to determine its validity. Trials containing a plateau, signifying peak torque, and no obvious countermovement at torque onset were deemed valid. Trials containing countermovement or lacking a plateau were deemed invalid. For each condition (control, external, and internal) invalid trials were repeated for a maximum of eight trials per condition so that three to five valid trails were recorded. The number of trials was limited to eight to avoid fatigue. Three to five valid trials were recorded to provide an accurate representation of each subject's best performance of RTD and PT. After each AF condition trial, participants were asked if they adhered to the instructions. If not, the trial was deemed invalid.

Table 1. Instructions for knee extensor MVIC trials.

Testing Order	Condition	Instructions
1	Control	"While looking straight ahead, try to push out as hard and fast as you can."
2 or 3*	External	"While looking straight ahead, try to push out as hard and fast as you can while focusing on the device arm."
2 or 3*	Internal	"While looking straight ahead, try to push out as hard and fast as you can while focusing on the muscles on the front of your thigh."

*Experimental condition testing order was counterbalanced between subjects.

Data Analysis

The dynamometer was interfaced with a Biopac MP100 Data Acquisition system (Biopac Systems, Inc. Goleta, CA) to collect the torque data at 2,000 Hz. A custom-built LabVIEW program (National Instruments, Inc. Austin, TX) was used to analyze the data which were filtered using a lowpass, 4^{th} order Butterworth filter with a 10 Hz cutoff. Each trial was visually reviewed to verify the measures of PT, torque onset (defined as 2.5% of PT), time at PT, and the absence of a countermovement greater than 2.5% of PT. RTD was calculated using a 10 ms sliding window from torque onset to 250 ms. The 10 ms window with the greatest slope was considered the maximum RTD.

Following data processing, each participant's trial that produced the greatest maximum RTD (i.e., the trial with the greatest slope of the torque-time curve within a

10 ms sliding window) was selected for analysis of RTD changes. The trial with the greatest PT was selected for analysis of PT changes. In cases where the same trial had the greatest RTD and PT, that trial was used in both analyses. RTD and PT values were normalized to each participant's body mass prior to statistical analysis.

Statistical Analysis

Normalized PT and RTD for both attentional focus conditions were analyzed using RStudio Version 1.0.143 (RStudio, Inc., Boston, MA). Normality and homogeneity of variances were assessed for each variable using the Shapiro-Wilk test and the Bartlett test, respectively. Paired t-tests were used to compare external and internal AF conditions for both PT and RTD. The level of significance for all statistical analyses was set a priori at 0.05.

RESULTS

Both the Shapiro-Wilk and Bartlett tests were not significant, indicating that the data were normal and variances were equal. Results of the paired t-test revealed that RTD during the external AF condition was significantly greater than during the internal AF condition (external AF 11.16 ± 4.98 $N \cdot m \cdot kg^{-1} \cdot s^{-1}$ versus internal AF 9.92 ± 4.22 $N \cdot m \cdot kg^{-1} \cdot s^{-1}$, $p = 0.0248$) (Figure 3). In contrast, there was not a significant difference between conditions for PT (external AF 2.14 ± 0.60 $N \cdot m \cdot kg^{-1}$ versus internal AF 2.08 ± 0.61 $N \cdot m \cdot kg^{-1}$, $p = 0.1887$) (Figure 4).

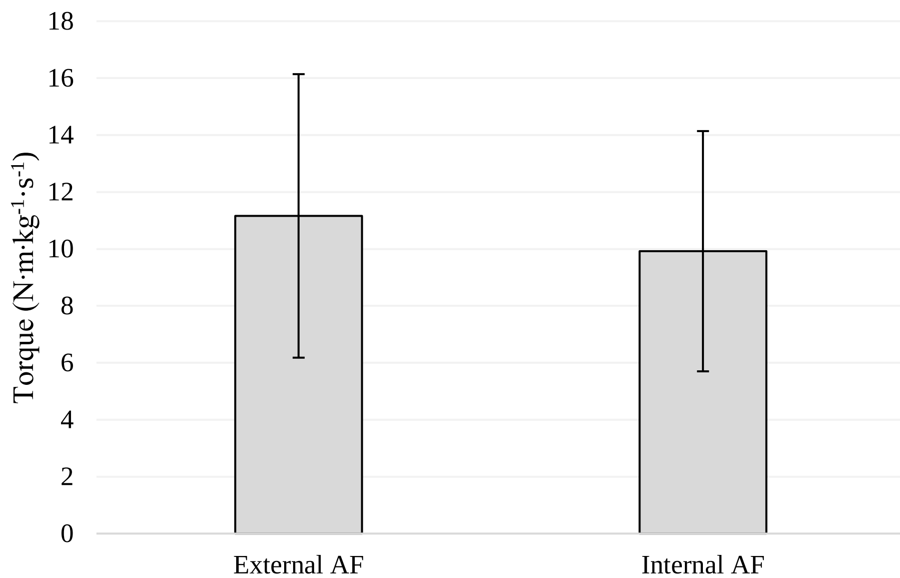

Figure 3. RTD produced during different AF conditions was significantly different (p = 0.0248).

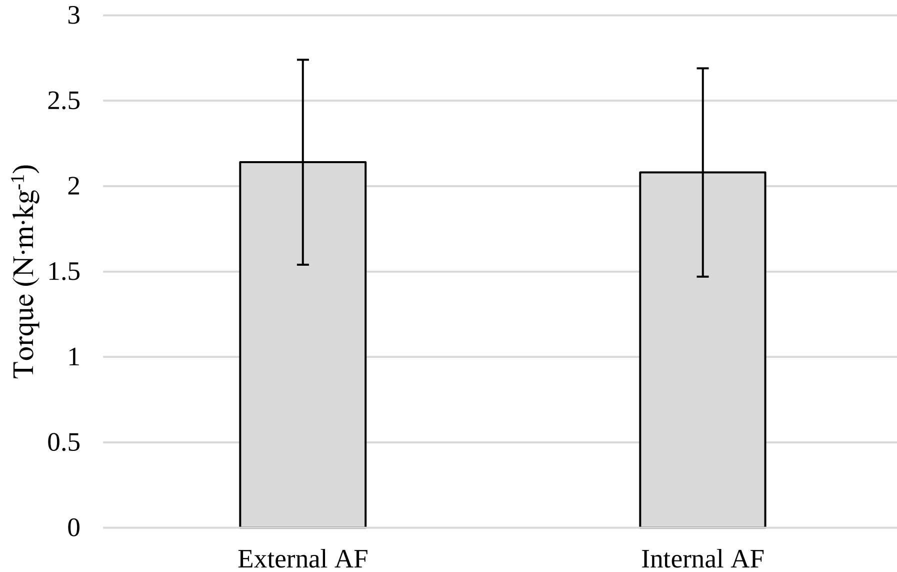

Figure 4. PT produced during different AF conditions was not significantly different ($p = 0.1887$).

DISCUSSION

The present study examined the effect of attentional focus on RTD and PT in the knee extensors. A novel finding of this study was that adopting an external AF resulted in a significant increase in RTD of 12.4% compared to an internal AF. However, there was not a significant difference in PT between conditions, which contrasts with previous research.

The results are potentially important for improving rapid torque production in the knee extensors during time-constrained movements by focusing one's attention externally. For example, a coach may cue a sprinter to focus on pushing against the starting blocks as hard and fast as possible instead of focusing on the leg muscles. In a rehabilitation setting, therapists could cue a patient to focus externally on the weight when performing rapid knee extension exercises instead of the quadriceps muscles, or to focus on the landing surface and not the leg muscles when landing from a jump.

This is the first study that examined the effects of AF on RTD. However, other studies have examined the effects of AF on different explosive movements, particularly jumping. Several studies have examined the effects of AF on the standing long jump.[19–21] In a between-subject study by Porter et al., 120 subjects were instructed, "Jump as far as possible."[21] Additionally, those in the internal AF group were instructed, "Focus your attention on extending your knees as rapidly as possible," while those in the external AF group were instructed, "Focus your attention on jumping as far past the line as possible." They found that the external AF group jumped 5.7% farther than the internal AF group.[21] Wu et al. aimed to replicate these results in a within-subject experiment while additionally measuring peak force to identify whether the benefits in performance were due to increased peak force production.[19] They used a different external AF instruction, which focused on jumping as close as possible to an unreachable target. They found that, when using an external AF, subjects jumped 10.1% farther than with an internal AF and 14.8% farther than during control trials, during which the only instruction provided was, "Jump as far as you can."[19] In a follow-up study, Ducharme et al. studied the effect of AF on jump projection angle to identify a mechanism to explain the results from Wu et al.[20] They revealed that an external AF elicited a more optimal jump projection angle in addition to better jump performance, though no change in peak force nor in mean impulse values was observed.[20] Interestingly, Ducharme et al., Wu et al., and the present study found that, while explosive performance increased with an external AF, there was no significant change in peak force or PT, respectively.[19,20] This finding contrasts with previous research, which has shown that an external AF elicits a greater PT than does an internal AF.[22,23]

Another study tested the effect of AF on an explosive movement on jump height and muscle activation during a vertical jump.[18] They found a significant 4.5% higher jump height and significantly less EMG root-mean-square error of the quadriceps during the external focus condition.[18] Vance et al. also found this result of lesser EMG during greater performance.[23] They examined the effect of AF on muscle activation during both isokinetic and freely-moving biceps curls. The latter task was executed more quickly and both tasks were performed with significantly lower integrated EMG activity of both biceps and triceps muscles during the external AF condition.[23]

In these studies, the fact that performance improves while EMG activity decreases has led to the suggestion that an external AF results in more economical or efficient movement.[13] In other words, a more efficient movement achieves better performance with less input of neural effort. Further, it has been proposed that an external AF allows for the automatic, unconscious, and reflexive control of bodily movement, whereas an internal AF may interfere with natural and automatic motor control processes.[13] This idea has been termed the constrained action hypothesis.

In examining the contention that an internal AF disrupts automatic motor processes, researchers have found that subjects experience greater cocontraction of antagonist muscles while adopting an internal AF.[16,17] While cocontraction is important in movement accuracy and control,[38–40] Lohse and Sherwood suggested that reduced cocontraction allows for more efficient patterns of muscle activation while producing maximal torque.[17]

These specific mechanisms have not been examined in studies examining AF and explosive movement; therefore, it is unknown if the external AF had different muscle activation compared to the internal AF. Further, it unlikely that cocontraction was a factor in this study. Participants performed an isometric contraction in a seated position and were secured to prevent any movement; what cocontraction was present was probably minimal. However, until muscle activation patterns during the explosive contraction are examined, this is speculation.

While cocontraction may not explain the findings, other changes in muscle activation occur during explosive movements. In fact, Wu et al. speculated that using an external AF during the standing long jump may have elicited a greater efficiency in motor unit recruitment.[19] However, they did not specifically propose what was meant by greater efficiency in motor unit recruitment nor did they examine motor unit recruitment or muscle activation in their study. Meanwhile, researchers have shown that explosive or ballistic contractions have unique motor unit activation strategies compared to ramped contractions. Specifically, previous research has shown that dynamic training induces an increase in maximal firing frequency of motor units.[41] Additionally, it has been suggested that the most likely functional role of motor unit synchronization is to increase rate of torque development in rapid contractions.[42] Considering that participants in the current study were asked to contract as hard and as fast as possible it possible that there was as increase in motor unit discharge frequency and/or synchronization.

The intention to move fast may also explain the finding that PT was not different between AF conditions,[32] despite previous research contrarily showing greater PT with external AF.[22] In the study by Marchant et al., participants were instructed to contract as hard as they could,[22] while in the current study they were instructed to contract as hard *and as fast* as they could. If the nervous system uses different strategies to activate motor units in explosive movements compared to non-explosive movements, it may result in the differential response. As previously mentioned, Wu et al. reported similar findings of changes in explosive movement without concurrent changes in PT.

To help answer this, future research should investigate the underlying mechanisms of AF during rapid torque production. Specifically, analysis of muscle activation patterns with EMG would lead to a better understanding of the recruitment patterns of muscles. Study of motor unit recruitment, firing frequency, and synchronization may lead to additional insight into the changes observed in this study.

Future research may also delve into the effects of different subtypes of external and internal foci of attention. One such subtype is the relative distance of the external focus of attention.[13] For example, the focus could be on something farther versus closer to the subject's body or on something that the subject moves versus a stationary object. In a performance setting, such as a sprint, an athlete may focus on either the ground below her or a target straight ahead, beyond the finish line. Similarly, in the recovery of balance to prevent a fall, an older adult may focus on the ground below him or on a distant stationary object. While each of these are external foci, their relative distances may further affect rapid torque production during the respective tasks.

One limitation of the present study is that the knee extensor contraction was produced in a relatively nonfunctional position. Individuals producing rapid torque will most likely be engaged in a dynamic weight-bearing movement, such as during a sprint, jump, landing, or while preventing a fall. However, the present study examined seated isometric contractions to isolate the knee extensor muscles, since they are important for post-injury recovery[7–9] and performance.[10–12] Because it is difficult to study a single muscle group during a dynamic movement, this position allowed for reliable measurement of the knee extensors during maximal contraction.

Additionally, the population represented in the subject sample was a limitation. The present study examined healthy, physically active, and younger subjects. Beyond sport performance, RTD is important for injury recovery and fall prevention. Studying injured athletes and older individuals may provide more insight about the effect of focus of attention in other situations. Therefore, future research should investigate how age and injury history influence the effect of AF on RTD.

CONCLUSION

In many situations, rapid torque production is vital for athletic performance and avoiding injury. Therefore, identifying methods for improving RTD is important. AF is one method that has been shown to affect various types of movement tasks and outcomes, including PT. However, up to this point, the effect of AF on rapid torque production has been unknown. Based on the results of this study, the orientation of one's focus of attention is an effective intervention for improving RTD in an acute or immediate setting. Specifically, adopting an external AF appears to be better for improving RTD than an internal AF in the knee extensors. Meanwhile, AF did not affect PT production. The underlying mechanisms of greater RTD with external AF are unknown. Thus, future research should aim to answer this. Additionally, future research should examine if a greater RTD elicited by an external AF leads to fall prevention, injury prevention, and enhanced performance.

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