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Effects of Changing the Focus of Attention on Accuracy, Acceleration, and Electromyography in Dart Throwing

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ABSTRACT

International Journal of Exercise Science 11(1): 1120-1135, 2018. Research over the past 15 years or so has shown that an external focus on the effects of one's movements improves performance relative to an internal focus of attention on bodily actions. More recent research has attempted to discover how the focus of attention (FOA) influences underlying motor control processes by using kinematic and EMG measures. Research has shown that an external FOA reduces EMG activity and the co-contraction between agonist and antagonist muscle groups relative to an internal FOA. The primary goal of the current study was to determine how the FOA influences the acceleration pattern during dart throwing, providing a more complete kinematic description relative to earlier work. Twenty-four participants threw 24 darts in both an external focus condition, focusing on the flight of the dart, and an internal focus condition focusing on the elbow angle at dart release. Surface EMGs were recorded from the triceps and biceps muscles and acceleration was recorded in the X, Y, and Z axes. Accuracy was better with an external focus relative to an internal focus. There was greater acceleration in the Y and Z axes in the second half of the movement in the external focus condition relative to the internal focus condition. An external focus generated less co-contraction between muscle groups compared to the internal focus condition. Overall, the results showed that an internal FOA reduces movement efficiency relative to an external FOA.

KEY WORDS: Mental processes, motor skills, throwing accuracy, kinematics, muscle activity

INTRODUCTION

Improving motor performance is a constant goal for athletes in team and individual sports and certain health care professions, like surgery. In order to optimize performance, physical training needs to be structured appropriately so motor control is achieved. However, recent evidence suggests that one's attentional focus also has a significant effect on physical performance. Adopting an external focus of attention on a target rather than an internal focus on the body movements has been shown to improve accuracy and movement efficiency in a variety of tasks (7, 22, 30) and transfer to novel skills (27). For example, basketball free-throw shooting accuracy has benefited from an external focus of attention on the basket or ball trajectory rather than an internal focus of attention on wrist flexion or movement form (1, 39). Studies have also demonstrated an advantage of an external focus of attention relative to an internal focus of attention with hitting golf balls (2, 38), serving volleyballs (35), and throwing (4, 13, 16, 23).

There have been three main attempts at providing an explanation for the difference in effects of an external and internal focus of attention. These are the constrained-action hypothesis (36, 37), the self-evoking trigger hypothesis (33), and more recently the OPTIMAL theory of motor learning (34). According to the constrained-action hypothesis, an internal focus of attention prompts a more conscious form of motor control relative to an external focus of attention.

These conscious processes interfere with the normally automatic control functions constraining the motor system (36, 37). In contrast, an external focus of attention engages more automatic control processes that are fast and require less attentional capacity (10, 29). The reduced attentional capacity with an external focus has been shown to improve balance (5, 11, 21, 36) particularly when one focuses further away from the body (18, 36). These studies concluded that increasing the distance of the effect from the action being done (external focus of attention) enhances performance, while a focus on close spatial proximity, or on the body itself (internal focus of attention), constrains the processes involved with the control of balance. With greater automaticity with an external focus of attention one would also expect less failure in skilled performance under pressure (19).

The self-invoking trigger hypothesis proposes that referencing one's body parts or movement is assumed to result in self-evaluative and self-regulatory processing by facilitating the access to the neural representation of the self. This hypothesis is consistent with the constrained action hypothesis and addresses a potential proximal cause of more automatic or conscious control of movements (33). So, any cues that cause an individual to reflect about themselves have the potential to disturb motor performance (15). Choking under pressure can also be an example of misdirected attention that triggers neural activation of the self that degrades performance (3, 19). Lastly, the OPTIMAL theory for improving motor performance takes social-cognitive-affective-motor nature into account, which suggests that motivational and attentional factors – with an external focus of attention – contribute to performance and learning by the coupling of goals to actions (34). According to the theory, an external focus of attention improves motor performance by directing attention to the task goal and by reducing a focus on the self. With greater success in achieving the task goal, an external focus of attention also leads to an enhanced expectation of future success relative to an internal focus of attention.

Regardless of the theoretical explanation for the advantage for an external focus of attention relative to an internal focus of attention, studies over the past 13 years or so have investigated the underlying causes of the benefit of an external focus of attention. For example, several studies have investigated the underlying causes for better accuracy with an external focus of attention by evaluating movement kinematics and/or movement efficiency with electromyography (EMG). For example, Kal et al. (12) showed that an external focus of attention improved movement fluency and regularity in a cyclic leg flexion-extension task relative to an internal focus of attention. In addition, Lohse et al. (14) found evidence for reduced co-contraction between agonist and antagonist muscle groups with an external focus of attention in an isometric force production task. One group was instructed to focus on their calf muscles (internal focus) and another group was instructed to focus on the force platform (external focus) while pressing against the platform with 30% of their maximum force. The internal focus instructions led to less accurate force production and more co-contraction between muscles, implying less efficient coordination between muscles. Marchant et al. (17) demonstrated similar results with an isokinetic force production task, but also showed that the control condition had the same higher level of EMG activity as the internal focus condition. The reduced co-contraction between muscle groups with an external focus of attention has been proposed as reason for increased jump height (31, 32), increased long jump distances (20), and faster running and swimming performances (8, 10, 26).

Other studies have shown that an external focus of attention reduces EMG activity relative to an internal focus of attention. For example, Vance et al. (28) showed reduced EMG activity in both the biceps and triceps muscles with an external focus relative to an internal focus in the biceps curl. These results were replicated by Zachry et al. (39) with a basketball free-throw task. Lohse et al. (13) showed that an external focus on the flight of the dart improved throwing accuracy and had reduced EMG activity in the triceps muscle compared to an internal focus on the throwing motion. An external focus also reduced the degree of co-contraction between agonist and antagonist muscles when compared to an internal focus (13). They also provided a kinematic analysis of the dart throw by videotaping the throw. The shoulder and elbow angle were determined for the dart release point, however, there was no difference between the internal and external focus conditions for either angle. In addition, elbow angular velocity was estimated, but again, there was no difference between the focus conditions. The main limitation of this study was that the kinematic measures were only taken at two points (i.e., the point of maximum elbow flexion and the point of dart release) rather than throughout the action. The current study proposes to assess acceleration throughout the dart throwing action to provide a more complete picture of movement kinematics in internal and external focus conditions.

Based on the studies reviewed here, we expect acceleration to be higher for an external focus of attention and lower when attention is focused internally. We also expect performance to be more accurate and more efficient with less EMG activity in the muscles with less co-contraction when focused externally. These findings would replicate and support previous findings of improved movement effectiveness and efficiency with an external focus of attention relative to an internal focus of attention. This study will go beyond previous studies (13) that had limitations from using static kinematic measurements by measuring acceleration across the entire dart throw.

METHODS

Participants

Data were collected from 24 healthy subjects (16 female, 8 males, 20.2 ± 3.28 years). Participants self-reported their skill in dart throwing with the majority (n=19) only playing 1-3 times per year. There were three subjects who reported that they have never played before and two subjects who reported they play 1-2 times per month. Two of the subjects were left-handed and we did not include them in the statistical analysis to keep handedness a constant. One subject was removed from the statistical analysis of EMG activity and acceleration because of technical difficulties in the data collection. Subjects were recruited from introductory statistic classes at the University of Colorado at Boulder, and they participated in the experiment to receive extra credit in their course. Institutional approval was given for this work.

Equipment and Measurements: A commercially available competition dart-board was set to regulation height (1.73 m off the ground) and distance (2.37 m from the throwing line). The darts used were regulation steel tip darts (22 g). The center of the board, or "bullseye," was treated as the origin (point 0,0), and the radial error (RE) was calculated for each throw by measuring the X and Y coordinates as indicated by Equation 1.1 in Table 1. The mean radial error (MRE) was calculated as shown in Equation 1.2, Table 1, representing the average radial distance of all the *k* throws in a block from the target.

Table 1. Equations used to measure X and Y coordinates.

Equation 1.1	Equation 1.2	Equation 2.1
$RE_i = \sqrt{X_i^2 + Y_i^2}$	$MRE = \overline{RE} = \frac{1}{k}\sum_{i=1}^{k} RE_i$	$BVE = \sqrt{\frac{1}{k}\sum_{i=1}^{k}(X_i - X_C)^2 + (Y_i - Y_C)^2}$

Precision was calculated as bivariate variable error (BVE), shown in Equation 2.1, Table 1, the distance of each throw from the average distance of all *k* throws within a block (X_C and Y_C) on the X and Y axes, respectively. Thus, BVE represents the variation of throws around the centroid location (X_C,Y_C) for that block (analogous to the standard deviation in one-dimensional precision, 9).

A wireless tri-axial accelerometer (Bionomadix, Biopac Systems, Inc., Goleta, CA) was strapped to the back of the participant's wrist such that the X axis referred to the sagittal plane, the Y axis referred to the longitudinal plane, and accelerations in the frontal plane the Z axis Accelerations toward the target, upward, and rightward resulted in initial positive values while accelerations away from the target, downward and leftward resulted in initial negative values. However, because the upper arm was slightly internally rotated during throwing, accelerations toward the target were registered along both the X and Z axes.

Three movement phases were identified based on accelerations on the X axis, but measurements were only made during the latter two of phases. The first phase was the "backswing" phase that was initiated when the acceleration changed from zero to negative, indicating a backward movement of the upper arm. This phase ended when zero acceleration was achieved. The second phase was called the positive acceleration phase that was initiated when the upper arm moved toward the target (see Figure 1, window 1) and ended when zero acceleration was achieved. The third and final phase was called the negative acceleration phase (see Figure 1, window 2) that was initiated when X acceleration was again negative and ended when zero acceleration was achieved following the maximum negative peak in acceleration.

We suspected that greater levels of co-contraction between the agonist and antagonist muscles would reduce the peak acceleration primarily in the X and Z axes during the positive acceleration phase (window 1, Figure 1). However, for completeness, we also measured the peak positive or negative acceleration in the Y axis. During the negative acceleration phase (window 2, Figure 1) we suspected the sudden deceleration of the accelerometer at the end of the movement would result in movement artifacts as shown in the X axis record in Figure 1. So we measured the maximum positive value for the Z axis and the maximum negative values for the X and Y axes in window 2.

For the EMG recording, the subject's throwing arm was fitted with pairs of disposable self-adhesive Ag/AgCl EMG electrodes (Bio Protech U.S.A., Tustin, CA) on the surface of the skin over the belly of the biceps (antagonist) and over the belly of the long-head of the triceps (agonist). The skin was prepared using alcohol wipes, and the EMG electrodes were applied once the skin was allowed to dry. EMG and acceleration data were collected wirelessly at 1,000 Hz (Bionomadix, Biopac Systems, Goleta, CA) and analyzed using Biopac AcqKnowledge software (Biopac Systems, Goleta, CA). The raw EMG signal was rectified and converted to root mean squared error (RMSE). We measured the integral (i.e., the area under the curve) of the biceps and the triceps separately for windows 1 and 2 as shown in Figure 1. To access the amount of co-contraction we divided the biceps integral by the triceps integral.

Protocol

The participants gave their informed consent for participation and filled out a survey when they arrived in the laboratory. There was a brief orientation with the materials as far as showing the participants how to hold the dart, how to throw in one plane, and telling them that their feet could not cross the throwing line. Next, all of the participants completed 5 sets of 3 throws (total of 15) for a baseline warm up with no specific instructions other than to aim for the center of the dartboard. A within-subjects design was employed so each subject was engaged in both external and internal focus of attention conditions, but the order of which one they did first was randomly determined. All subjects were instructed to visually focus on the board, but in the internal focus of attention condition they were told to mentally focus on their elbow angle when they released the dart. In order to help the participants maintain an internal focus, they were asked to rate their elbow angle at release after each throw on a scale from 1 to 6, where a fully extended elbow was a 6 and an elbow fully flexed was a 1 (see Figure 2). In the external focus of attention condition, participants were instructed to mentally focus on the initial flight of the dart. To help them maintain an external focus, participants were asked to rate the angle of dart release after each throw with a larger angle of release a 6 and a smaller angle of release a 1 (see Figure 2). Both the external and internal conditions required 8 sets of 3 throws totaling 24 throws per testing condition. For all of the throwing sets, participants threw one dart at a time and accuracy measurements were made after three darts were thrown.

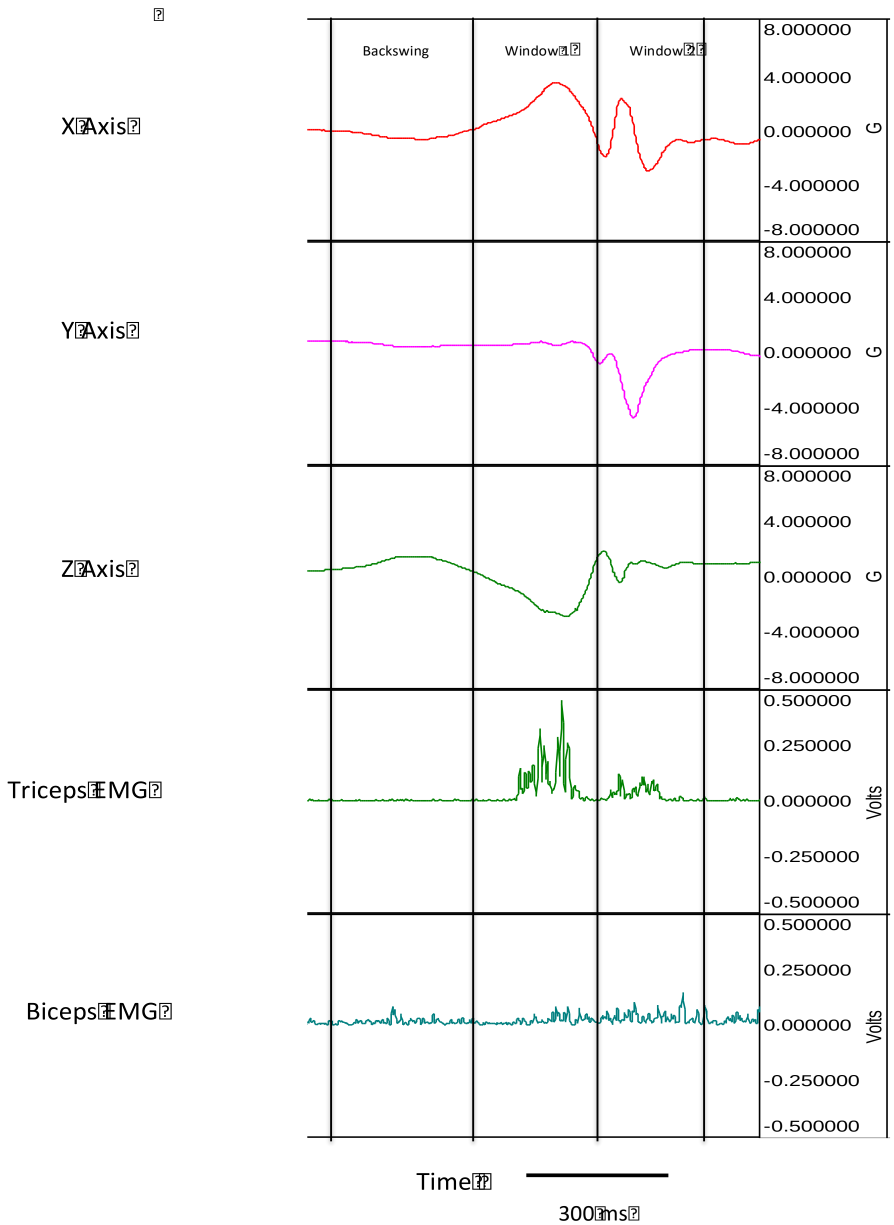

Figure 1. Sample integrated EMG for the biceps and triceps muscles and acceleration records for the X, Y, and Z axes from one trial. The three phases of the movement are identified on the figure as well.

Statistical Analysis
MRE, BVE, and the amount of co-contraction were calculated in Excel for each set of 24 throws in the internal and external focus conditions, averaged across trials, and analyzed with separate one-way ANOVAs with repeated measures on focus of attention (FOA) condition. The baseline trials were not analyzed because they always preceded the focus of attention trials and were not true control trials due to possible warm-up effects. The positive and/or negative peaks in acceleration identified in the positive and negative acceleration phases were analyzed with separate 2 (FOA) x 3 (Axis) ANOVAs with repeated measures on both factors. The integrals of EMG activity in the biceps and triceps were compared with a 2 (FOA) x 2 (Muscle) ANOVA

with repeated measures on both factors. Mauchly's test of sphericity was done before each analysis and, if significant, the degrees of freedom were adjusted with the Greenhouse-Geisser correction.

In order to determine the relation between peak acceleration and accuracy the errors in the Y-plane (i.e., the vertical plane) were correlated with the peak acceleration in the X, Y, and Z axes during the positive acceleration phase for each FOA condition for each participant. Errors in the Y plane were chosen for analysis rather than the X plane because lower peak accelerations should result in undershooting of the target and negative scores in the Y plane. The correlations were converted to Fisher's Z scores and entered into 2 (FOA) x 3 (Axis) ANOVA with repeated measures on both factors The same process was used to determine the relation between the level of muscular co-contraction and the peak acceleration in the X, Y, and Z axes during the positive acceleration phase. Finally, the level of co-contraction during the positive acceleration phase was also correlated with the Y plane errors. Partial eta-squared ($\eta_p{}^2$) was provided as a measure of effect size. Descriptive statistics are presented as *M* ± *SEM*. All of the statistical analyses were done using the Statistical Package for the Social Sciences (SPSS) version 24.

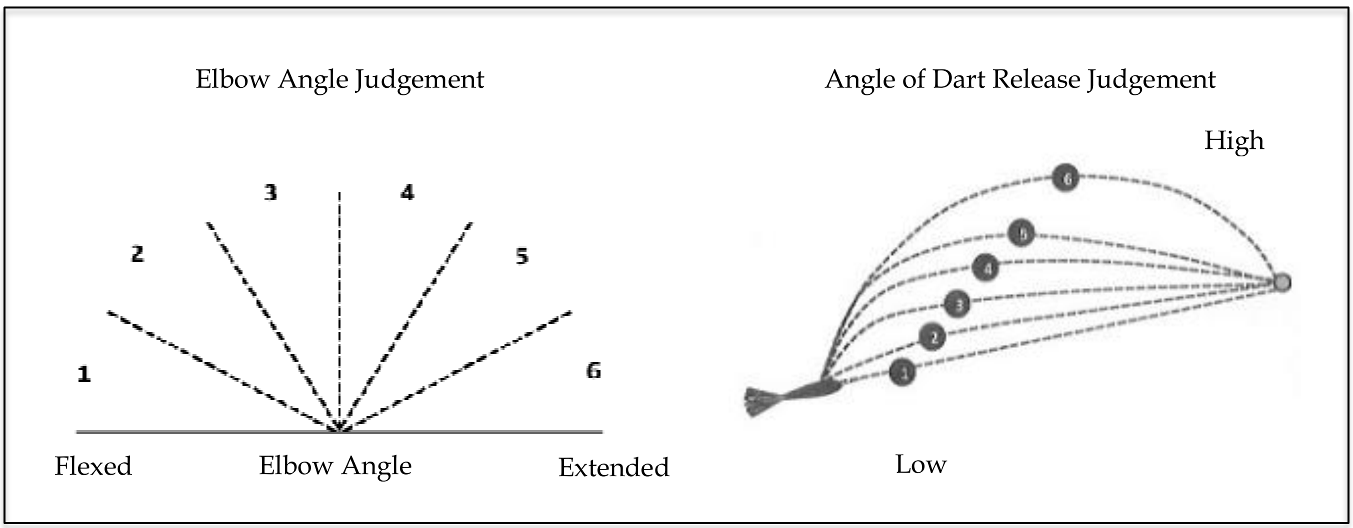

Figure 2. Rating scales used to help maintain the instructed internal focus on elbow angle (left) and the external focus on the angle of dart release (right).

RESULTS

Errors: The MRE was lower for the external focus of attention condition (10.27 ± 0.84 cm) as compared to the internal focus of attention condition (11.01 ± 0.93 cm). The effect of FOA condition was significant, $F(1,21) = 4.32$, $p = .050$, $\eta_p{}^2 = .171$. There was little difference ($p = .93$) in the BVE scores between the focus conditions (external = 8.21 ± 0.55 cm, internal = 8.18 ± 0.48 cm).

Positive Acceleration Phase: The mean peaks in acceleration in the X, Y, and Z axes are shown in Figure 3. The peak acceleration in the X axis tended to be lower for the external focus of attention (2.83 ± .12 G) than the internal focus of attention (2.88 ± .12 G), but slightly higher in the Y axis (external = 0.98 ± .10 G, internal = .97 G ± .08 G) and the Z axis (external = -2.85 ± 0.16 G, internal = (-2.77 ± 0.17 G) but the FOA x Axis interaction was not significant, $F(2,40) = 2.25$, $p = .12$, $\eta_p^2 = .10$. The main effect of FOA was not significant ($p = .46$). The effect of axis was significant, $F(2, 40) = 71.29$, $p < .001$, $\eta_p^2 = .78$. The peak accelerations in the X and Z axes were both greater than in the Y axis (ps < .001).

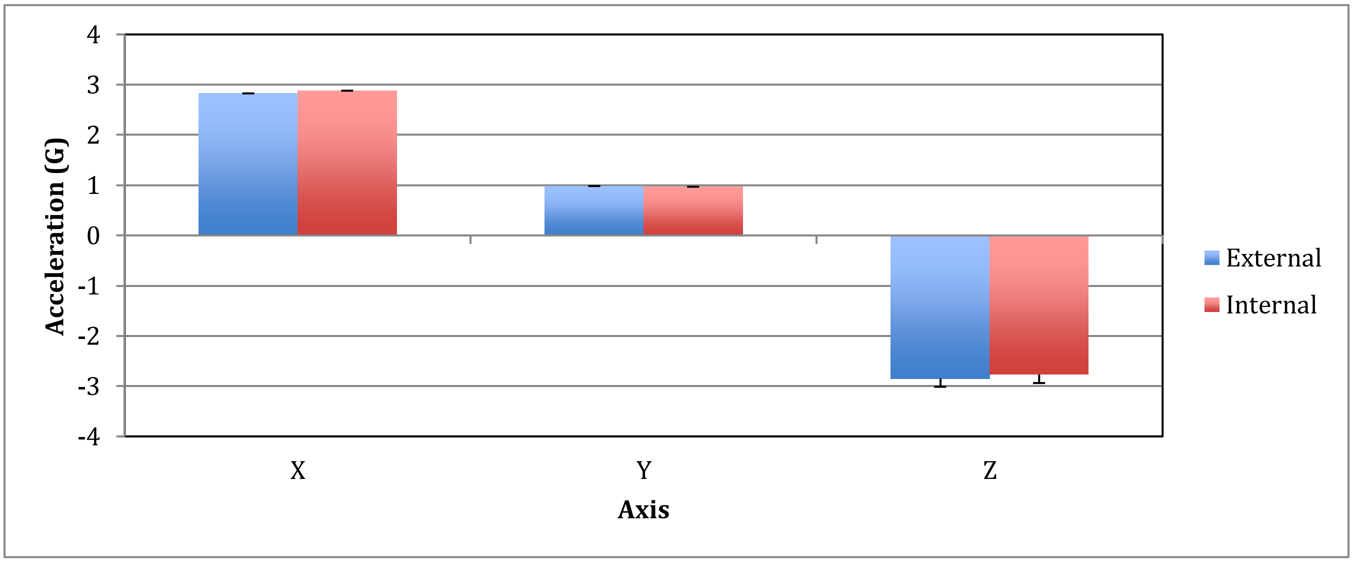

Figure 3. The mean peaks in acceleration in the X, Y, and Z axes during the positive acceleration phase in the external and internal focus conditions. Error bars are SEMs.

Negative Acceleration Phase: The mean peaks in acceleration in the X, Y, and Z axes are shown in Figure 4. The peak acceleration in external focus of attention condition was greater than the internal focus of attention for the X axis (external = -4.29 ± .41 G, internal = -4.20 ± .35 G), the Y axis (external = -9.01 ± .78 G, internal = -8.24 ± .75 G) and the Z axis (external = 3.56 ± 0.34 G, internal = (3.22 ± 0.27 G). The FOA x Axis interaction was significant, $F(2,40) = 7.24$, $p < .01$, $\eta_p^2 = .27$. LSD post-hoc tests revealed significant differences between the focus conditions for the Y ($p < .01$) and Z ($p < .01$) axes only. The main effect of FOA was also significant, $F(1,40) = 4.82$, $p < .05$, $\eta_p^2 = .19$. The effect of axis was significant, $F(2, 40) = 62.59$, $p < .001$, $\eta_p^2 = .76$. The peak accelerations in the X, Y and Z axes were all significantly different (ps < .05).

EMG Activity during the Positive Acceleration Phase: The EMG integrals of the biceps and triceps for the two FOA conditions are shown in Figure 5. EMG activity was greater in the agonist triceps compared to the antagonist biceps, with the effect of muscle significant, $F(1,20) = 35.49$, $p < .001$, $\eta_p^2 = .640$. There was a tendency for the biceps to have less activity in the external focus condition (.006 ± 0.001 v-s) compared with the internal focus condition (.007 ± 0.001 v-s), but the muscle x FOA condition interaction was not significant, $F(1,20) = 2.50$, $p = .129$, $\eta_p^2 = .11$. Overall, the effect of FOA condition was not significant, $p = .89$. There was significantly less co-contraction in the external focus condition (.439 ± .044) than the internal condition (.464 ± .046), $F(1,20) = 6.080$, $p = .023$, $\eta_p^2 = .233$.

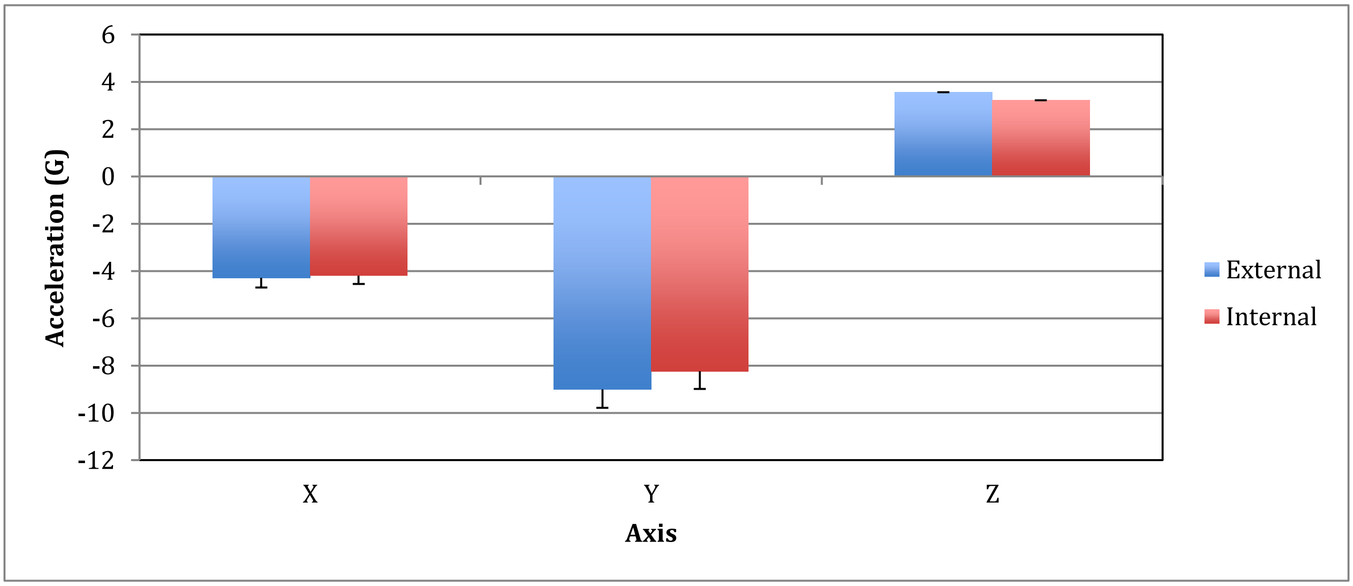

Figure 4. The mean in acceleration in the X, Y, and Z axes during the negative acceleration phase in the external and internal focus conditions. Error bars are SEMs.

EMG Activity during the Negative Acceleration Phase: During deceleration in the X plane, muscle activity was equal in the biceps (.01 ± .001 v-s) and triceps (.01 ± .001 v-s). There was no significant effect of FOA condition ($p = .36$), muscle ($p = .64$), or any interaction between FOA condition and muscle ($p = .81$). There tended to be less co-contraction in the external focus condition (1.38 ± .15) than the internal condition (1.43 ± .17), but the effect of FOA condition was not significant, $p = .53$. See Figure 6.

Correlations between Accuracy and Peak Acceleration: The average within-subject correlations between the Y-errors in throwing and peak acceleration in the X, Y, and Z axes for both focus conditions are shown in Figure 7 (note since greater accelerations in the Z axis were larger negative values, we used the absolute values of these scores when computing the correlations). The main effect of FOA ($p = .37$) and the FOA x Axis interaction (p = .68) were not significant.

The effect of axis was significant, $F(1,40) = 28.33$, $p < .001$, $\eta_p^2 = .59$. LSD post-hoc tests revealed that the correlation in the Z axis was greater than that of the X axis, and both the Z and X correlations were greater than the Y axis correlation. However, even though the average correlations between accuracy and peak acceleration were low, individual participants tended to show higher correlations between accuracy and peak acceleration for either the X or Z axis, or both. See Figure 8 for a depiction of the pattern of correlations for each participant.

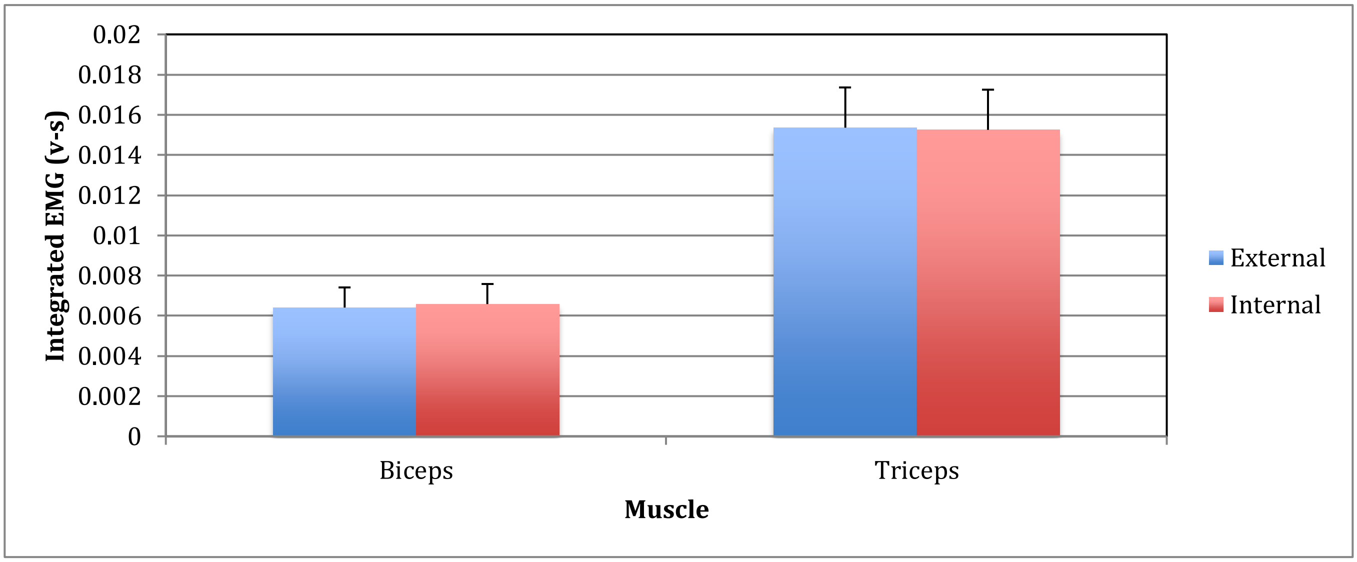

Figure 5. Average integrated EMG activity for the biceps and triceps muscles while X was positive in the external and internal focus conditions. Error bars are SEMs.

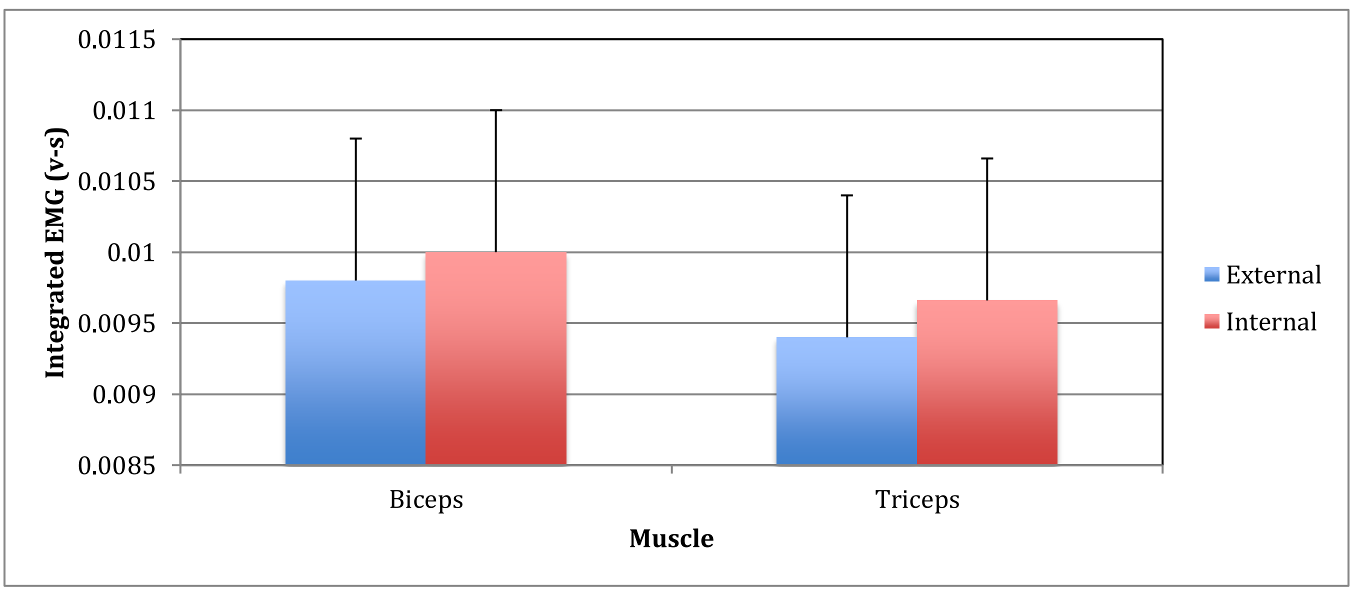

Figure 6. Average integrated EMG activity for the biceps and triceps muscles while X was negative in the external and internal focus conditions. Error bars are SEMs.

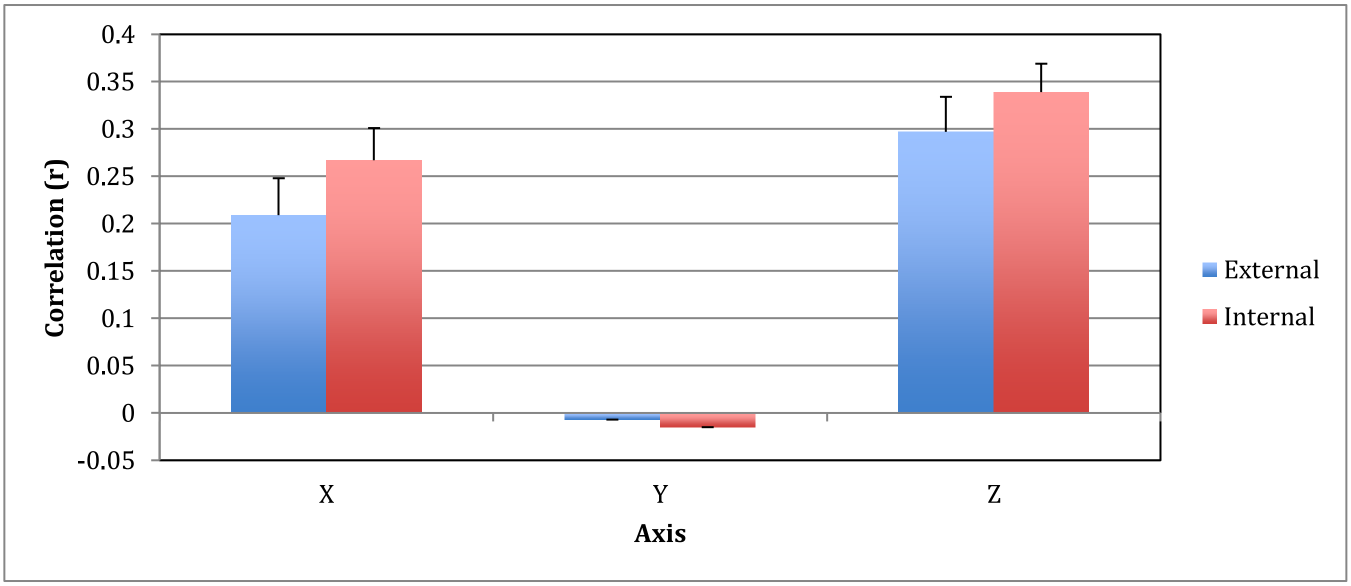

Figure 7. The average within-subject correlations between the Y-errors in throwing and peak acceleration in the X, Y, and Z axes for both focus conditions. Error bars are SEM.

Correlations between Accuracy, Peak Acceleration, and the Level of Muscular Co-Contraction: The average within-subject correlations between peak acceleration in the X, Y, and Z axes and the level of co-contraction was .02, .15, and .08, respectively for the external focus and -.02, .09 and .03, respectively for the internal focus condition. No effects were significant. However there were large individual differences in the correlations as shown in Table 2. The correlation between the level of co-contraction and Y-errors was .02 and -.05 for the external and internal focus of attention conditions, respectively, and they were not significantly different. The range in the correlations for the external focus condition was greater (-.53 to .36) compared to the internal focus condition (-.44 to .42).

DISCUSSION

The primary goal of the study was to determine how changes in the focus of attention influences the acceleration pattern in dart throwing. During the first half of the movement when the upper arm accelerated toward the target, the agonist triceps EMG activity was greater than the antagonist biceps, as expected, but there was no difference in peak acceleration between the focus conditions. However, there was less co-contraction in the external focus condition relative to the internal focus condition. During the second half of the movement during deceleration, the EMG activity in both muscles was equal showing greater levels of co-contraction compared to the first half of the movement. There was greater peak acceleration in the Y and Z axes in the external focus condition compared to the internal focus condition. As expected, accuracy was better in the external focus condition relative to the internal focus condition.

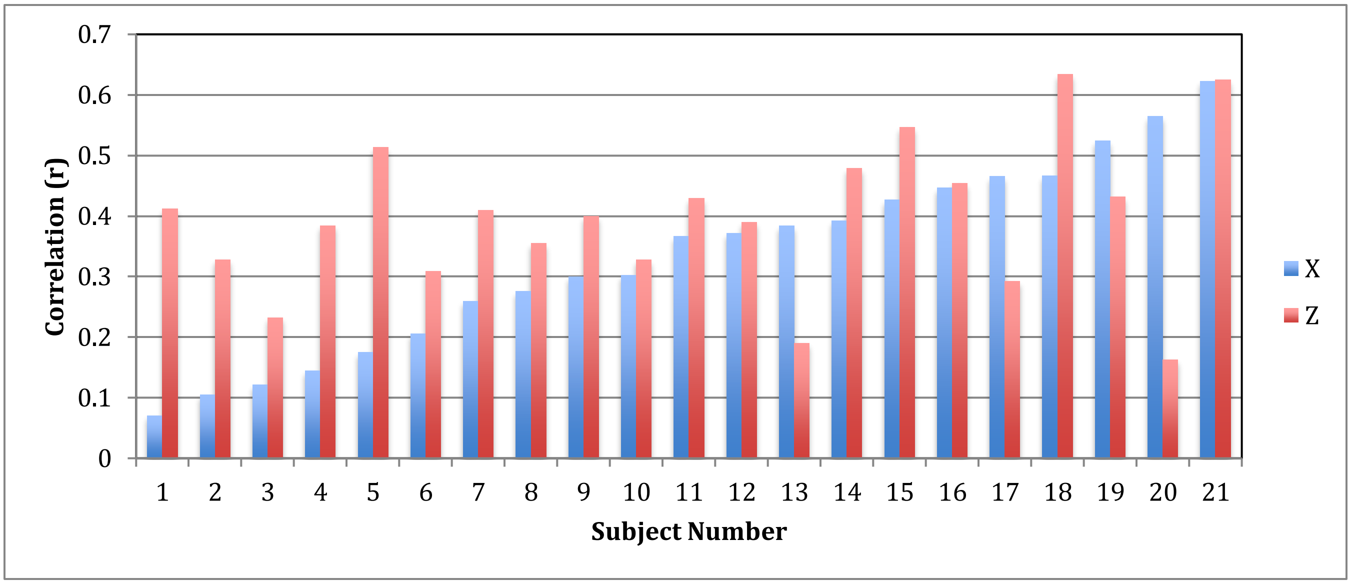

Figure 8. The within-subject correlations between the Y-errors in throwing and peak acceleration in the X, and Z axes for each participant averaged over both focus conditions, ordered by the magnitude of the X axis correlation.

Table 2. The means and ranges in the correlations between peak acceleration and the level of muscular co-contraction for the internal and external focus conditions

	Axis X	Axis Y	Axis Z
External			
Mean	.02	.15	.08
Min	-.36	-.50	-.43
Max	.51	.61	.57
Internal			
Mean	-.02	.09	.03
Min	-.57	-.49	-.51
Max	.50	.68	.45

The better throwing accuracy with an external focus of attention relative to internal focus, is consistent with other research that has shown improvement in performance (1, 12, 13, 14, 16, 23). The accuracy findings here are consistent with the constrained action hypothesis, the self-evoking trigger hypothesis and the OPTIMAL theory, with respect to motor performance, but the accuracy data alone cannot distinguish between the three explanations. It could be that an internal focus of attention causes the engagement of conscious control whereas an external focus of attention involves a more automatic, unconscious control process as predicted by the constrained action hypothesis (36). Or, it could be that internal focus instructions activate self-evaluative and/or self-regulatory processes leading to poorer performance as expected by the self-evoking trigger hypothesis. Regardless of the explanation, an internal focus of attention results in larger errors than an external focus of attention.

It should be noted that care was taken to control the temporal aspects of the focus instructions to coincide with the release of the dart. Participants made judgments about the angle of dart release in the external focus of attention condition and the elbow angle at dart release in the internal focus condition. We believe our methods provided a better temporal control of attention compared to studies where the participant was asked to focus on the "motion of the arm," for example, in an internal focus condition (13). Achieving temporal control of attention has been a criticism of focus of attention work in the past (3), so we believe our methods provided an important control in this regard.

Focus of Attention and Motor Control: What is clear from this and previous work is that changing the focus of attention has a significant effect on motor control. For example, muscle activity appears to be more efficient with an external focus of attention relative to an internal focus of attention. That is, less EMG activation is necessary to carry out tasks relative to an internal focus of attention. In the current study there was a tendency for less EMG activity in the antagonist muscles under external focus conditions compared to internal focus conditions. Although the differences between the focus conditions were not statistically significant, the pattern of results was the same as those shown by Lohse et al. (13) and Zachry et al. (39). Taken as a whole, we believe that the reduced muscular activity and the better accuracy with an external focus of attention is an indication of better neuromuscular efficiency. In addition, an external focus of attention seems to also improve intermuscular coordination relative to an internal focus of attention. We showed there was less co-contraction between the muscle groups during the first half of the movement when attention was focused externally, and the same trend was shown during deceleration although the effect of focus condition was not quite significant. The reduced co-contraction in the external focus condition is consistent with previous findings as in Lohse et al.'s study (13) and suggests that movement efficiency increases with an external focus of attention. Moreover, the increased co-contraction with an internal focus of attention suggests an increase in muscle stiffness and decreased movement efficiency relative to an external focus of attention.

Although the accuracy and EMG findings support the published literature, the new findings of the current study show that the acceleration pattern of the dart throw is affected by the focus of attention. Past work by Lohse et al. (13) had shown no difference in angular velocity, or static elbow and shoulder angle at dart release between internal and external focus conditions. However, by measuring acceleration at a higher resolution during the full motion of the dart throw we were able to show differences between the internal and external focus conditions. Although there were no significant differences found during acceleration while X was positive, there was greater acceleration in the Y and Z axes during deceleration when focused externally rather than internally. The findings of increased acceleration with an external focus support those studies showing that movement speed increases with an external focus relative to an internal focus (10, 26). Although the average correlations between throwing errors and peak acceleration were fairly low, the results here support the expected relation between peak acceleration and accuracy. Most participants showed positive correlations between acceleration in the X and Y axes and errors. Higher peak correlations were associated with positive errors and lower peak correlations were associated with greater undershooting of the target.

Taken together, our kinematic and EMG data suggest there is less co-contraction and therefore greater acceleration on average with an external focus of attention compared to an internal focus of attention. The mean findings support the idea that movement is more automatic, fast, and reflexive with an external focus of attention, which is consistent with the constrained action hypothesis. Reduced acceleration and increased co-contraction with an internal focus of attention might reduce accuracy by increasing muscle stiffness and disrupting intermuscular coordination. Although we showed that an internal focus of attention increases the level of muscular co-contraction relative to an external focus of attention, the correlational analysis did not support the expected links between the level of co-contraction, peak acceleration, and accuracy. We expected higher levels of co-contraction to be associated with lower peak accelerations and greater undershooting of the target. On average, the correlations between the level of co-contraction, peak acceleration and accuracy were quite low and close to zero in most cases. The lack of a relation between the level of co-contraction, accuracy, and acceleration could be due to several reasons. We recorded EMG from only two muscle groups (i.e., biceps and triceps) but other muscles (i.e., brachialis, brachioradialis) could have contributed to the level of co-contraction. We were unable to assess the actual timing and angle of the dart release that likely affected accuracy in addition to the accelerations we measured. Also, each participant may have had a different throwing style or a different neuromuscular control strategy that involved different levels of co-contraction. For example, those participants showing a positive correlation between the level of co-contraction and accuracy could have used a higher level of co-contraction to stabilize the elbow joint to increase stability and maintain accuracy (24, 25). For those subjects showing a negative correlation between the level of co-contraction and accuracy, increased levels of co-contraction did not result in increased joint stability and increased accuracy. This finding supports research suggesting that co-contraction and accuracy are not always directly related (6). Perhaps a future study could use high-speed video techniques along with acceleration and EMG measures to provide a complete kinematic profile of dart throwing under different attentional focus conditions.

In summary, this study succeeded in replicating previous work on the focus of attention and accuracy in dart throwing, but extended the literature by showing how the acceleration pattern was influenced by the focus of attention. Research on the focus of attention continues to show that differences in the wording of instructions can have strong effects on movement accuracy and motor control.

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