The Effect of an External and Internal Focus of Attention on EMG, Acceleration and Dart

Throwing with a Secondary Task

By

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Abstract

Many research studies have shown the advantages of an external focus of attention (FOA) on motor performance and the benefits of learning with an external FOA. For example, research such as Lohse, Sherwood, and Healy (2010) have found that an external FOA, such as on the flight of a dart, led to better performance and reduced errors compared to an internal FOA. Other findings include decreased preparation time and reduced agonist muscle EMG activity compared to an internal FOA (Lohse et al. 2010). A study by Hitchcock and Sherwood (in press) found that there was less muscular co-contraction and increased wrist acceleration with an external focus. The present study aims to investigate the effect of the FOA on the quality of movement and accuracy. This study used a combination of electromyography (EMG), x, y, z accelerometer, and a hand dynamometer to measure muscle activity, wrist movement, and force production respectively. Subjects focused either externally or internally on dart throwing or the force production task, while throwing darts and producing force in all conditions. In both task conditions, throwing accuracy was better with an external FOA. Mean force production was greater in the force task. There was greater maximum Y acceleration in the positive acceleration phase with an external FOA. In the negative acceleration phase, the darts task and the internal focus conditions had greater maximum and minimum X and Z acceleration. These data suggest better performance with an external FOA while focusing on either dart throwing or force production.

Keywords: Focus of attention, motor skills, performance, motor behavior, EMG, force, kinematics, muscle.

Introduction

Improving motor skills is a constant goal for many professions such as athletics, culinary arts or healthcare, for example. Athletes strive to improve their kinematics to make the next basket or to sink the next putt. Chefs might strive to perfect the cooking of the next cut of meat or make the ideal dish. Surgeons will need to improve their dexterity that might save the next life. In order to improve performance, practice must be structured in a way that maximizes motor performance. Recent evidence has suggested that shifting one's focus plays an important role in changing motor outcomes. An external focus of attention, one where subjects shift their focus towards the goal rather than that of internal body movements, have been shown to improve performance and accuracy such examples including Freudenheim, Wulf, Madureira, Corrêa and Corrêa (2010); Vance, Wulf, Tollner, McNevin and Mercer (2004); Winkelman, Clark, and Ryan (2017); Wulf, Shea, and Park (2001); Wulf, McNevin and Shea (2001). The benefits of an external focus of attention on motor performance has been shown in studies by Lohse, Sherwood, and Healy. (2010), Sherwood, Lohse and Healy. (2014), and Wulf (2013) in tasks like shooting a basketball or dart throwing.

There has been much research done to explain the benefits of an external focus of attention relative to an internal focus of attention. The leading hypotheses for the differences between an internal and external focus of attention are the constrained-action hypothesis, Wulf, McConnel, Gartner and Schwarz (2002); Wulf, McNevin and Shea (2001); Wulf, Shea and Park (2001) the self-evoking trigger hypothesis, (Wulf & Lewthwaite 2010), and the OPTIMAL theory of motor learning (Wulf & Lewthwaite 2016). Firstly, the constrained-action hypothesis states that an internal focus of attention induces more conscious processes in motor control than an external focus. The increases in conscious processes interferes with the automaticity of motor control system. This automaticity is characteristic of the fast and lower attention requiring

external focuses of attention. These external focuses have been shown to be better when one focuses on an object that is farther away from the body (Ille, Selin, Do, and Thon, 2013; Winkelman et al. 2017). Secondly, the self-invoking trigger hypothesis states that any internal reflection has the ability to disturb motor performance. For example, choking under pressure can be due to internal distractions that can misdirect attention and interfere with neural aspects of motor control and reduce performance. Thirdly, the OPTIMAL theory suggests that motivation and attention in an external focus of attention affect performance and learning. In this theory, an external focus of attention directs attention to the task goal and thereby reduces a focus on one's self and thus improving success on that task. These theories predicted that with the introduction of a secondary task, such as a force production task with dart throwing, that focusing externally on either the force or dart task will lead to better performances on both. Implementing the force task into the study will allow for the examination of a secondary task on motor performance and test for the effects of different focuses of attention with a secondary task on a primary task.

Many studies have shown this benefit of an external focus of attention. One example includes Sherwood et al. (2014), who have found that an internal focus condition resulted in greater error in dart throwing than the external focus conditions. As expected, there was better dart throwing performance across more test days. Another study using dart throwing, Sherwood Lohse, and Healy (2016), showed reductions in motor performance errors in an external focus of attention condition when compared to an internal focus condition. The internal focus of attention conditions also resulted in greater variability in bivariate variable error as compared to an external focus. Although an external focus of attention was better in both vision and non-vision conditions, the difference was greater when concurrent visual feedback was not available. An internal focus of attention is more likely to be disruptive because it requires greater demand on

information processing than does an external focus. These results can be explained by the self-evoking hypothesis, such that any internal cues that reflect on the individuals own, thoughts, actions or behaviors can disrupt motor performance. When a secondary task is involved, such as a tone detection task in Sherwood et al. (2016), it was shown that with an external focus of attention with a non-task related factor such as a tone task showed improvements in performance compared to an internal non-task related factor (breath cycle task). This result can be explained by the self-evoking trigger hypothesis.

Some research has shown reductions in EMG activity in an external focus of attention. One example includes a study that found that there was reduced activity of co-contraction between agonist and antagonist muscles in external focus groups (Lohse et al. 2010). This study also showed that focusing externally on the flight of the dart decreased the activity of the agonist muscle during the throws as compared to an internal focus. Videotape data were provided in this study to observe how the throwing action was being performed along with data on the outcome. Other studies, such as Hitchcock and Sherwood (in press), have found that during the earlier half of dart throwing, the upper arm accelerated towards the target. Although, acceleration activity showed no difference in peak acceleration between the two focus groups. However, there was less muscular co-contraction in the external focus groups as compared to the internal focus. In the second half of the movement, EMG activity showed greater levels of co-contraction between the agonist and antagonist muscles as compared to the first half. Peak acceleration in the Y and Z axes was greater in the external focus condition than in the internal focus group. There was also better performance found in the external focus condition as compared to the internal focus. This current study proposes to assess force production (a secondary task) in addition to acceleration of the arm during dart throwing along with EMG recordings to determine the effects of force

production on muscle activity and acceleration. Research has debated whether performing two relatively simple tasks interferes with performance. The dual-task interference theory suggests that the combined tasks require higher mental processes that can hinder performance (Pashler, 1994). The force production task will serve as a secondary task to study its effects on dart throwing accuracy and kinematics and according to the theory, dart throwing accuracy should be hindered with an internal focus. This theory, along with the constrained action hypothesis and self-invoking trigger hypothesis suggest that when focusing internally on the secondary task and the primary task, accuracy and performance will be hindered greater than if each task is conducted individually.

From the studies reviewed, we expect that by implementing the focus of attention conditions that the difference in wrist acceleration to be higher in an external focus of attention than in an internal focus of attention. This is due to previous findings that the co-contraction of the agonist and antagonist muscles decreases when and external focus of attention is applied. However, the effect of different focuses of attention on peak wrist acceleration has yet to be determined. Some studies have shown no differences in peak wrist acceleration while others have found lower acceleration in the X axis and increased acceleration in the Y and Z axes. (Hitchcock & Sherwood, in press; Lohse et al., 2010) Also, we expect that with an external focus on the force production task motor performance would be better than with an internal focus on the force production task. This basis is due to previous finding such as Sherwood et al., (2016). We also expect that the performance will be better in the external focus of attention conditions and EMG activity of the muscles to be reduced due to less co-contraction of an external focus. The findings of this study will replicate other studies of the improvements in kinematics and performance outcome with an external focus of attention relative to an internal focus of attention.

It will also aim to replicate other studies for the effect on movement and muscle activity on EMG with different focuses of attention. This study will build on previous studies by studying the effects of a secondary force production task on wrist acceleration, muscle activity and throwing accuracy.

Method

Participants

Data were collected from 20 healthy undergraduate subjects (5 females, 15 males with an average age of 20.75 years +/- 1.20 years). Seventeen subjects rarely played darts and 3 subjects have never played darts before. Subjects volunteered for the study and were interested in kinematics and motor behavior from the University of Colorado at Boulder. Institutional approval was given for this work.

Equipment and Measurements

A commercially available regulation bristle dart board was attached to a plywood board that measured 91 cm x 121 cm and covered with burlap. The dart board was mounted at regulation height (1.73 m off the ground) and distance (2.37 m from the throwing line). Styrofoam pads wrapped in penetrable plastic sheets were positioned below the dartboard and plywood apparatus; this served as protection to catch any darts that flew under the dart board apparatus. Participants threw regulation steel tip darts that weighed 22 g. The darts were each labeled with a different patterned tail in order for the sequence of the darts that were thrown to be kept track of and match to their respective (x,y) location on the dart board and for the value to be matched to the accelerometer data and EMG. The performance of the subjects was measured by

the accuracy on the dart board determined by x and y errors from the bull's eye using the

Cartesian Coordinate System that marked the bull's eye as the origin (0,0) on the grid.

For the EMG recording, the device used was a wireless Bionomadix EMG recorder model

number BN-TX. Prior to the experiment, the throwing arm was fitted with pairs of circular EMG

electrodes (Ag/AgCl electrodes) on the surface of the skin on the biceps brachii and triceps

brachii along with a ground placed between the clavicle and shoulder. The skin was prepared

using alcohol wipes and the electrodes were attached with conductive gel and an adhesive.

For the accelerometer, the device was a Bionomadix accelerometer model number BN-TX

which was attached to the dominant wrist of the subject via a Velcro strap. The raw acceleration

data were collected in the x, y, and z direction of the movement of the wrist. The X direction was

measured as wrist movement towards and away from the dart board, the Y with the vertical axis,

and Z with the horizontal axis of the dart board. All acceleration and EMG data were collected

wirelessly at 1000 Hz.

Gripping force was measured using a hand dynamometer. The device used was a non-digital

stainless-steel force gauge that displaces the pointer towards a certain value marked on the

chassis of the dynamometer in relation to the peak force that was squeezed in the gripping

section.

Dart throwing performance was analyzed through consistency (bivariate variable error, BVE)

and accuracy (radial error, RE). The RE represented the radial distance from the origin, or the

bulls' eye.

$$RE_i = \sqrt{X_i^2 + Y_i^2}$$

BVE was used to calculate the variation in the X and Y directions from the mean score in

each axis (X_c and Y_c) across the k number of throws in each set.

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

Procedures

The participants were given an information sheet about the study and asked to fill out a survey after arriving to the laboratory. After completion of the survey, the electrodes for the EMG and a wrist accelerometer were attached to the throwing arm of the subject. In the non-throwing arm, the subject was asked to grip a hand dynamometer. Next, all the participants were instructed to give three trials of their maximum gripping strength (without looking at the force gauge) and the highest value was used for the reference point for the 50% grip strength goal for the rest of the experiment. Participants were allowed a total of nine throws, three darts for three sets, to accustom themselves to throwing the darts and were instructed to aim for the center of the dart board. Proper throwing technique was also instructed such as keeping the arm aligned with the dart board when throwing. In these warm up throws, the participants would throw the dart and grip the hand dynamometer, in their non-dominant hand, while aiming at their force goal. During each throw, EMG and wrist acceleration activity were monitored on a computer. Each subject was involved in the external and internal focus of attention condition, but which condition they underwent first was randomized using a balanced Latin Square Design. In all conditions, subjects were instructed to pay attention to the board and additional instructions were given depending on the condition. In the internal-darts condition they were asked specifically to focus on the angle at which they bent their elbow when the dart was released. Subjects were also asked to rate the angle of their elbow at the release of the dart from 1 to 6, with 1 being the elbow fully flexed and 6 being the elbow fully extended (see Figure 1). This was done in order to

help the participants maintain an internal focus. For the external-darts condition the subjects were asked to focus on the flight of the dart from when it leaves their hand. This was also rated on a scale from 1 to 6, with 1 being a smaller angle of release or the dart was thrown more horizontally, and 6 being a larger angle of release or the dart had a higher curve when thrown. For the internal-force condition, the participants were instructed to focus on the muscles of the forearm and gauge the level of activation of the finger flexor muscles from a scale of 1-6, with 1 being a relatively easy squeeze and low muscle activation and 6 being a tough squeeze with high muscular activation. In the external-force condition, subjects were asked to mentally focus on the pointer of the hand dynamometer. Subjects were instructed to give a rating between 1-6, with 1 being that the mentally focused force pointer did not go very far in relation to the force goal and 6 being that the pointer was thought to have gone far over the force goal. For each condition, subjects threw 15 darts total, three darts for five sets. The darts were thrown one at a time for all participants and accuracy measurements were taken after three darts had been thrown.

Elbow Angle Judgement

A.
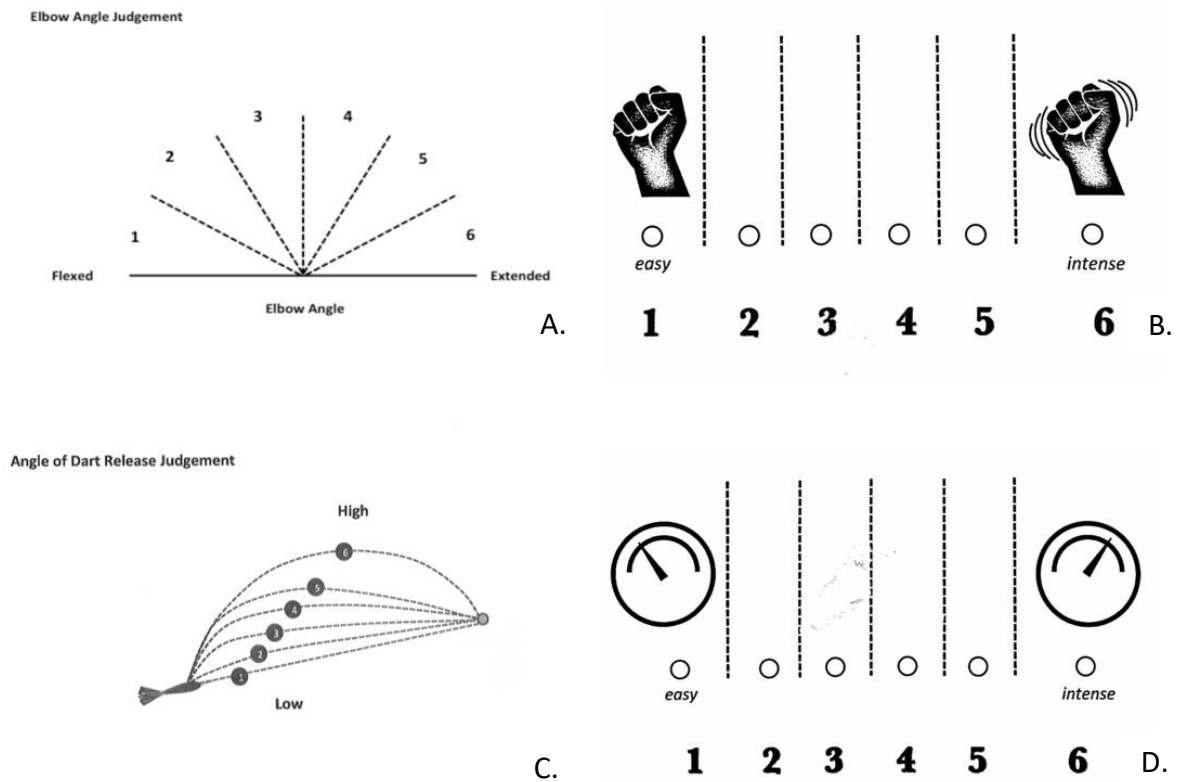
B.

Angle of Dart Release Judgement

C.

D.

Figure 1. Rating scales used for internal focus on the elbow angle of the darts task (Panel A), internal focus on the muscles of the forearm in the gripping task (Panel B), external focus on the angle of dart release of the darts task (Panel C) and external focus on the pointer of the force gauge in the force task (Panel D).
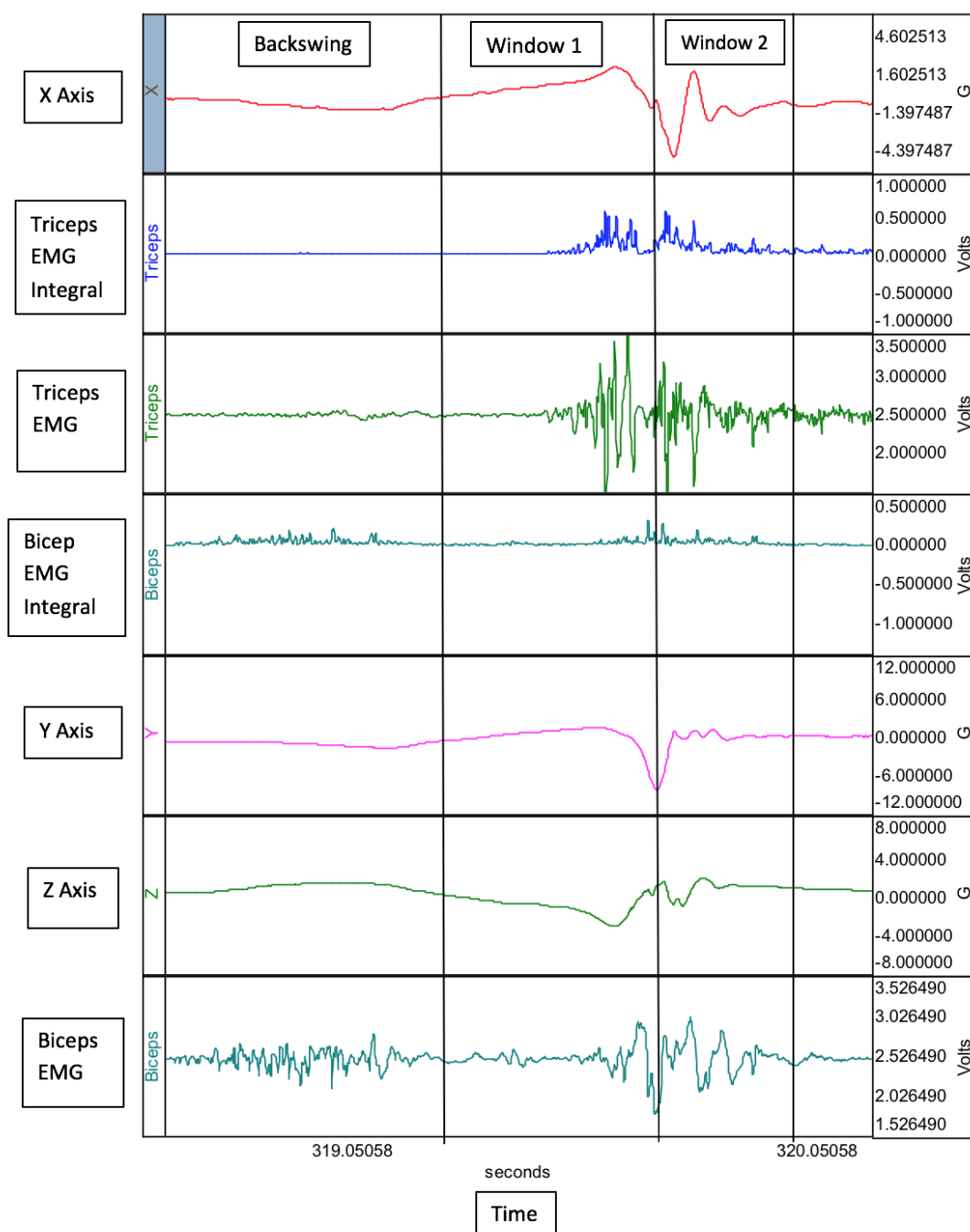
Figure 2. Sample of EMG and integrated EMG activity for biceps and triceps muscles and acceleration records for the X, Y, and Z axes for a trial. The three phases (backswing, window 1, and window 2) are labeled as well.

Data Analysis

The raw EMG recordings were rectified by converting all negative values into positive values. The rectified EMG data for the triceps and biceps were integrated across 5 samples with baselines removed for a smoothed curve. The processed EMG for every throw was divided into 3 separate sections. The backswing section was excluded from analysis which is characterized by its slight negative X phase before the throw. Window 1 was defined as the phase where X was positive which was measured when X began to increase then reach a peak and then decrease until it reached the original value. Window 2 was defined as when X was negative, and this was found beginning at the end of window 1 until X reached a peak negative value and ended at the original value at the beginning of the window. In both windows 1 and 2, triceps and biceps activity and their respective integrals were taken. In terms of acceleration in window 1, maximum X, maximum and minimum Y, and maximum and minimum Z were analyzed for each throw. However, in window 2, maximum and minimum X, minimum Y, and maximum Z were taken. These values were taken due to their respective representative peaks in each window. After analysis, the MRE, BVE, and the amount of co-contraction between the integrated EMG data of the biceps and triceps were calculated in Excel for each set of 15 throws in the internal and external dart and force focus conditions. The results were averaged across trials, and analyses were run using separate two-way ANOVAs with repeated measures on task and focus of attention (FOA) conditions. The warm up trials were not used in the analysis because they preceded all focus conditions and were not a true control trial due to possible practice and warm up effects. Peak EMG activity and the integral of the biceps and triceps were analyzed using 2 (FOA) x 2 (Muscle) x 2 (Task) ANOVAs with repeated measures on all three factors. Acceleration was also measured in the X, Y, and Z axes and the positive and/or negative peaks

were identified in the positive and negative acceleration phases of the dart throw. Analysis of the acceleration measures were done with 2 (FOA) x 2 (Task) ANOVAs with repeated measures on both factors. In order to determine if the variances were equal across repeated measure conditions, Mauchly's test of sphericity was performed before each analysis and if significant, the degrees of freedom were adjusted.

Co-contraction was measured by taking the activity of the bicep and dividing by the activity of the triceps. The means were analyzed with repeated measures ANOVA. The same process was used for peak acceleration and co-contraction. 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.

Results

Errors

The radial errors (RE) were higher in the internal focus of attention condition (10.659 +/- 0.624 cm) as compared to the external focus of attention (9.446 +/- 0.626 cm). See Figure 3. The effect of FOA was significant, $F(1,19) = 6.996$, $p = .016$, $\eta_{p2} = 0.269$. In terms of BVE, the effect of FOA was also significant, $F(1,19) = 12.970$, $p = .002$, $\eta_{p2} = 0.406$. See Figure 4. There were no significant differences between the task conditions (darts vs. force production) for both RE, $F(1, 19) = 0.63$, $p = .437$, $\eta_{p2} = 0.032$, and BVE, $F(1, 19) = 0.23$, $p = .638$, $\eta_{p2} = 0.012$. The Task x FOA interactions were also not significant for RE, $F(1,19) = 1.20$, $p = .287$, $\eta_{p2} = 0.059$ and BVE, $F(1,19) = 1.77$, $p = .20$, $\eta_{p2} = 0.085$.
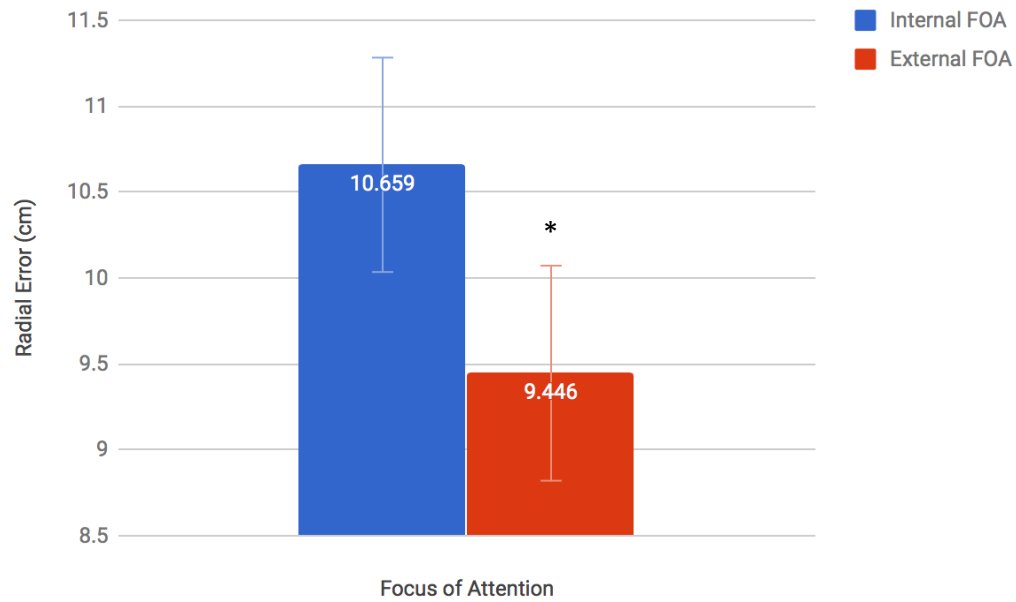
Figure 3. Radial errors for the internal focus of attention (left) and external focus of attention (right). * p<0.05 indicates significance. Error bars indicate SEMs.

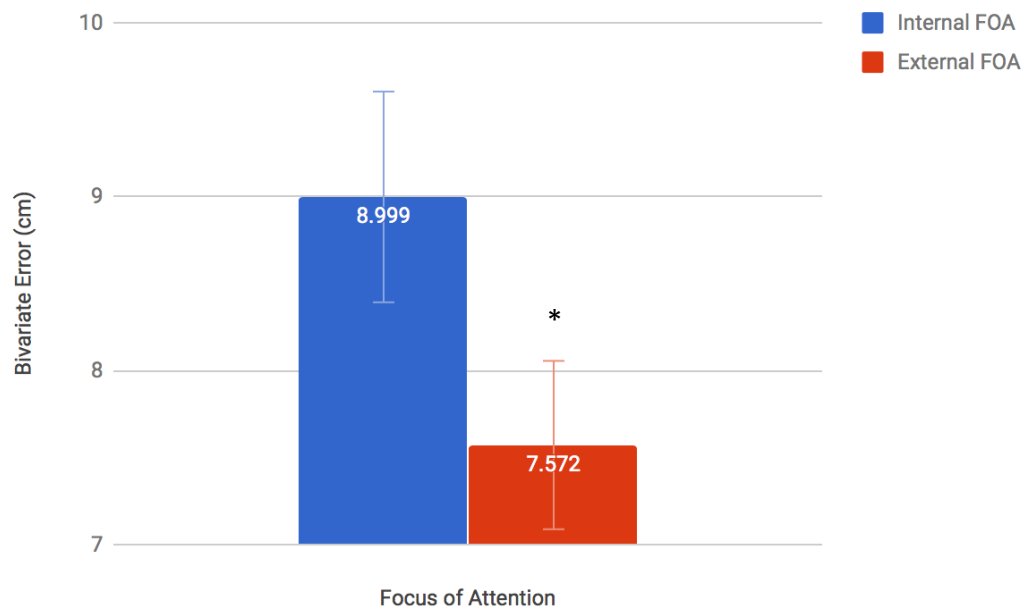Figure 4. Bivariate variable errors for the internal focus of attention (left) and external focus of attention (right). * p<0.05 indicates significance. Error bars indicate SEMs.

Positive Acceleration Phase

The mean peaks in wrist acceleration in the Y axis are shown in Figure 5. The only significant difference was in the maximum Y acceleration with higher Y acceleration in the external focus condition, $F(1,19) = 5.911$, $p = .025$, $\eta_{p2} = 0.237$ compared to the internal focus condition. In terms of the effects of task on maximum Y acceleration, there was no significant differences, $F(1,19) = 1.409$, $p = .250$, $\eta_{p2} = 0.069$. There was also no significant difference in maximum acceleration in the X axis in either the FOA, $F(1,19) = 0.204$, $p = .657$, $\eta_{p2} = 0.011$ or the task conditions, $F(1,19) = 0.089$, $p = .769$, $\eta_{p2} = 0.005$. There was slightly more negative Y acceleration in the external FOA condition, but this difference was not significant, $F(1,19) = 3.617$, $p = .072$, $\eta_{p2} = 0.047$. In terms of task (darts vs. force) the Y minimum accelerations were also not significantly different, $F(1,19) = 0.932$, $p = .347$, $\eta_{p2} = 0.047$. The differences in the maximum Z acceleration were also not significantly different between the tasks, $F(1,19) = 2.362$, $p = .141$, $\eta_{p2} = 0.111$ and focus conditions, $F(1,19) = 0.656$, $p = .428$, $\eta_{p2} = 0.033$.
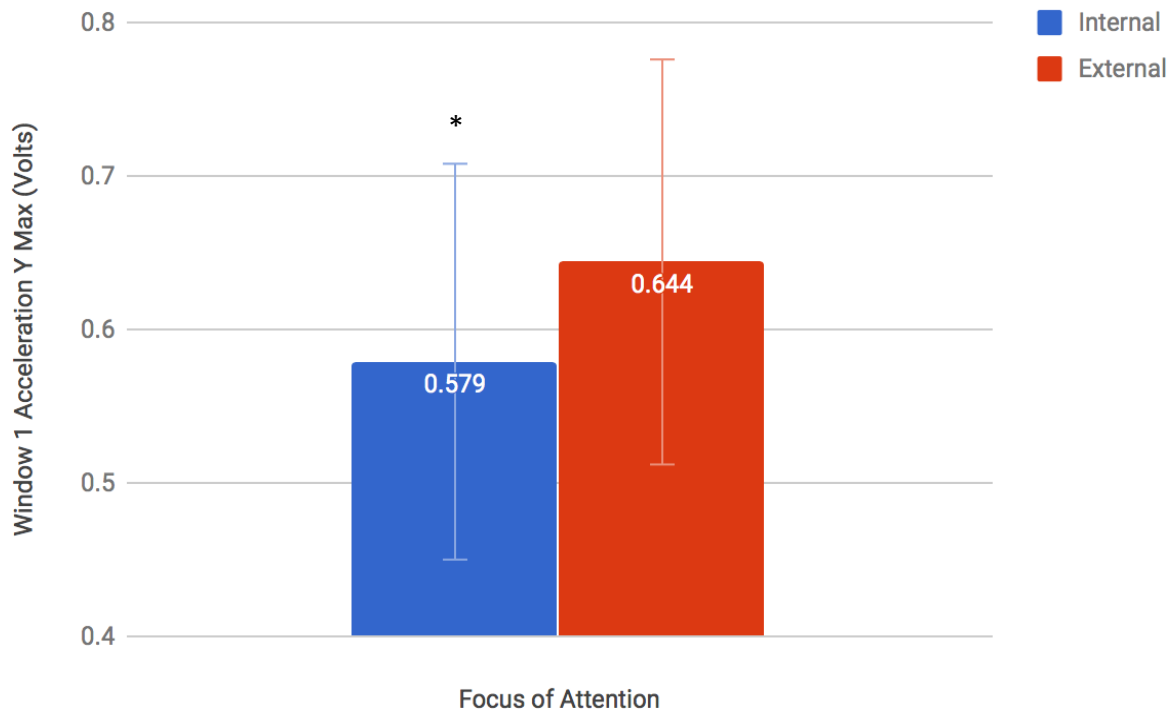
Figure 5. Differences in wrist acceleration in the Y axis in the internal and external focus of attention. Error bars are SEMs. * p<0.05 indicates significance. Error bars indicate SEMs.

Negative Acceleration Phase

The mean peaks of X minimum and Z maximum are shown in Figures 6, 7, 8 and 9 respectively. The minimum X acceleration was significantly different in the two task conditions with higher negative acceleration in the darts conditions than the force conditions, $F(1,19) = 10.459$, $p = .004$, $\eta_{p2} = 0.355$. There was almost a significantly higher negative acceleration in the internal focus conditions than the external focus conditions, $F(1,19) = 4.350$, $p = .051$, $\eta_{p2} = 0.186$. In terms of maximum Z acceleration, there was greater positive acceleration in the internal focus conditions, $F(1,19) = 6.772$, $p = .017$, $\eta_{p2} = 0.263$, and almost a higher Z acceleration in the darts conditions, $F(1,19) = 4.352$, $p = .051$, $\eta_{p2} = 0.186$. The X maximum accelerations for task, $F(1,19) = 1.783$, p =.198, $\eta_{p2} = 0.086$ and FOA $F(1,19) = 0.961$, p = .339,

$\eta_{p2} = 0.048$ were not significantly different. This was also true for the Y Minimum accelerations in terms of task, $F(1,19) = 0.482$, p = .496, $\eta_{p2} = 0.025$ and FOA $F(1,19) = 0.459$, p = .506, $\eta_{p2} = 0.024$.
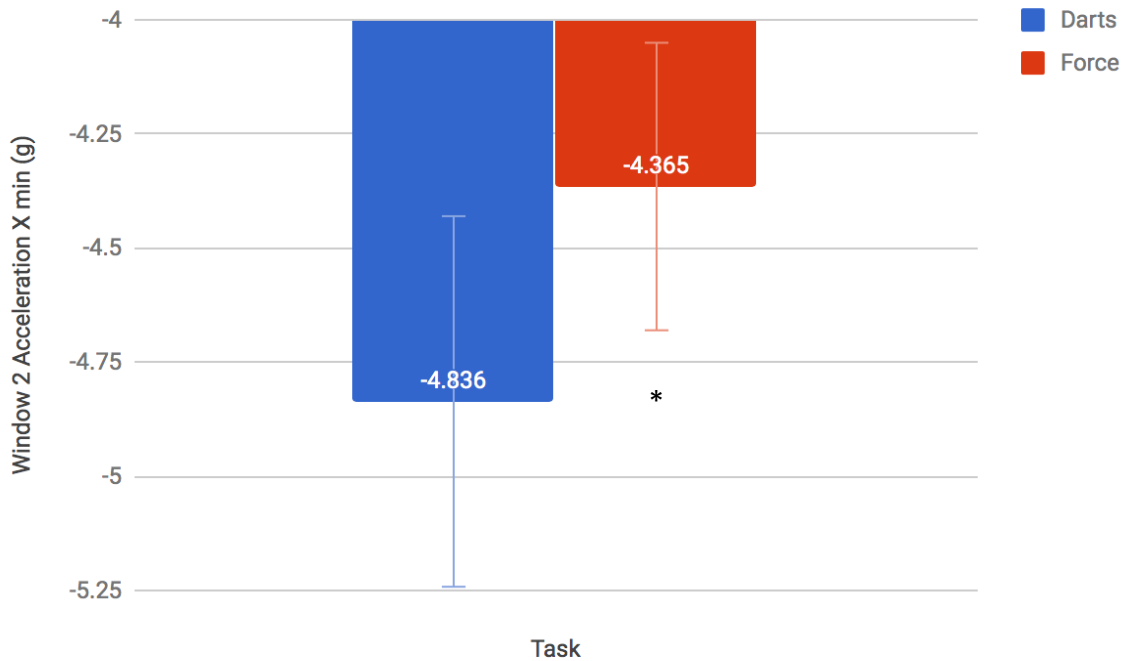

Figure 6. Wrist acceleration in the negative acceleration phase of the X axis in the darts and force production task condition. * p<0.05 indicates significance. Error bars indicate SEMs.

Figure 7. Wrist acceleration in the negative acceleration phase of the X axis in the internal and external focus conditions. Error bars indicate SEMs.
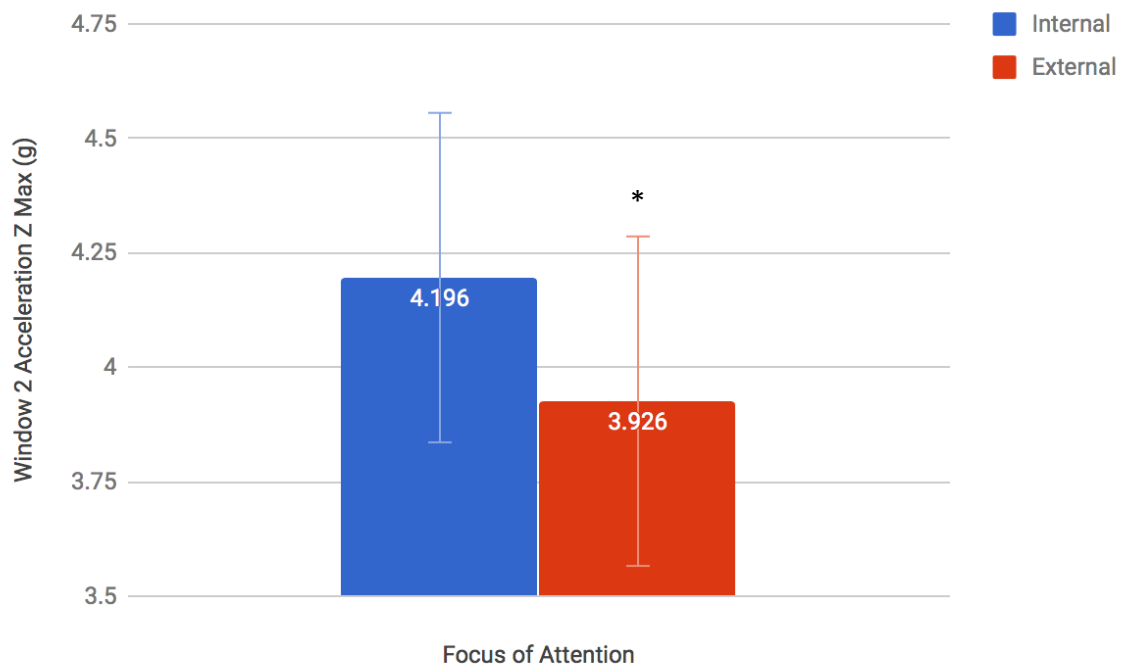

Figure 8. Wrist acceleration in the negative acceleration phase on the Z axis in internal and external focus of attention. * $p < 0.05$ indicates significance. Error bars indicate SEMs.
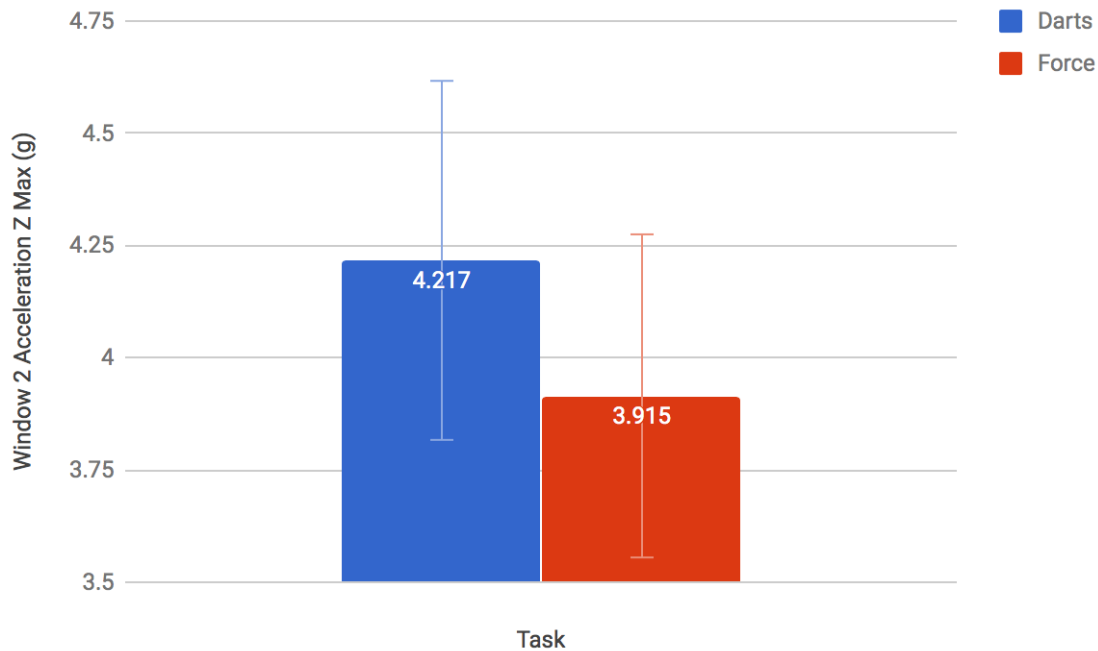
Figure 9. Wrist acceleration in the negative acceleration phase on the Z axis in the darts and force production task condition. Error bars indicate SEMs.

EMG Activity

The EMG measurements of triceps and biceps maximum activity is shown in Figure 10 across all conditions. EMG activity was higher in the agonist triceps muscles than the antagonist biceps muscles, $F(1,19) = 45.266$, $p = .001$, $\eta_{p2} = 0.704$. There was a tendency for the internal darts condition to have higher muscle activity when compared to the external dart condition (Figure 11). The opposite was the trend for the force conditions with the external focus on force correlating to higher muscle activity than the internal force focus condition. The Task x FOA interaction was significant, $F(1,19) = 4.541$, $p = .046$, $\eta_{p2} = 0.193$. Overall, the effect of task was not significant, $F(1,19) = 2.228$, $p = .152$, $\eta_{p2} = 0.105$. The effect of FOA was also not significant, $F(1,19) = 1.762$, $p = .200$, $\eta_{p2} = 0.085$.

The mean EMG integral of biceps and triceps activity for the task, $F(1,19) = 2.967$, $p = .101$, $\eta_{p2} = 0.135$ and FOA conditions, $F(1,19) = 3.095$, $p = .095$, $\eta_{p2} = 0.140$ were not significant. This was also true for the co-contraction activity based on the integrals of the biceps and triceps in terms of task, $F(1,19) = 0.574$, $p = .458$, $\eta_{p2} = 0.029$ and FOA, $F(1,19) = 1.536$, $p = .230$, $\eta_{p2} = 0.725$. Maximum co-contraction based on peak EMG of the two muscles was also not significant for task, $F(1,19) = 1.898$, $p = .184$, $\eta_{p2} = 0.091$ and FOA, $F(1,19) = 0.459$, $p = .506$, $\eta_{p2} = 0.024$.
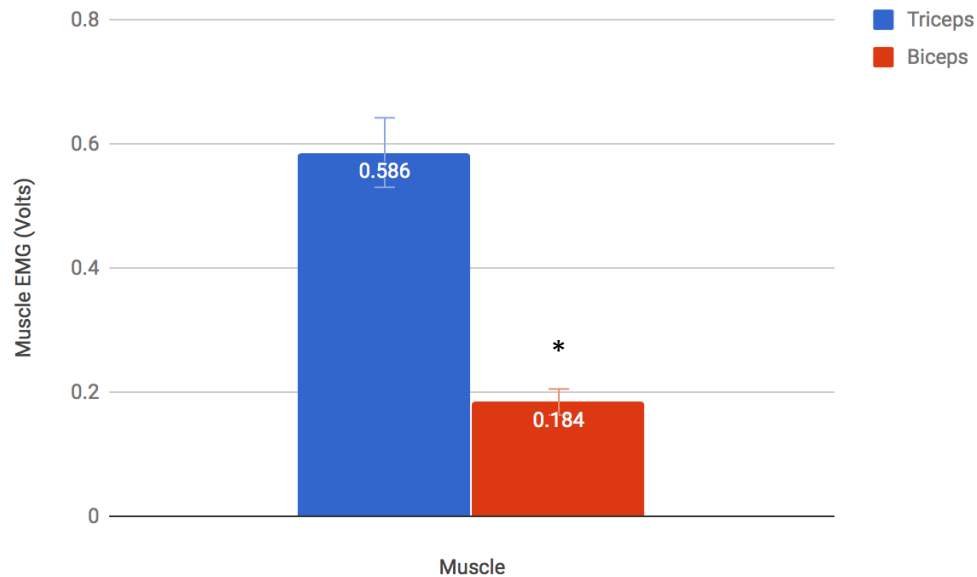

Figure 10. Triceps and biceps muscle activation across all conditions. * p<0.05 indicates significance. Error bars indicate SEMs.
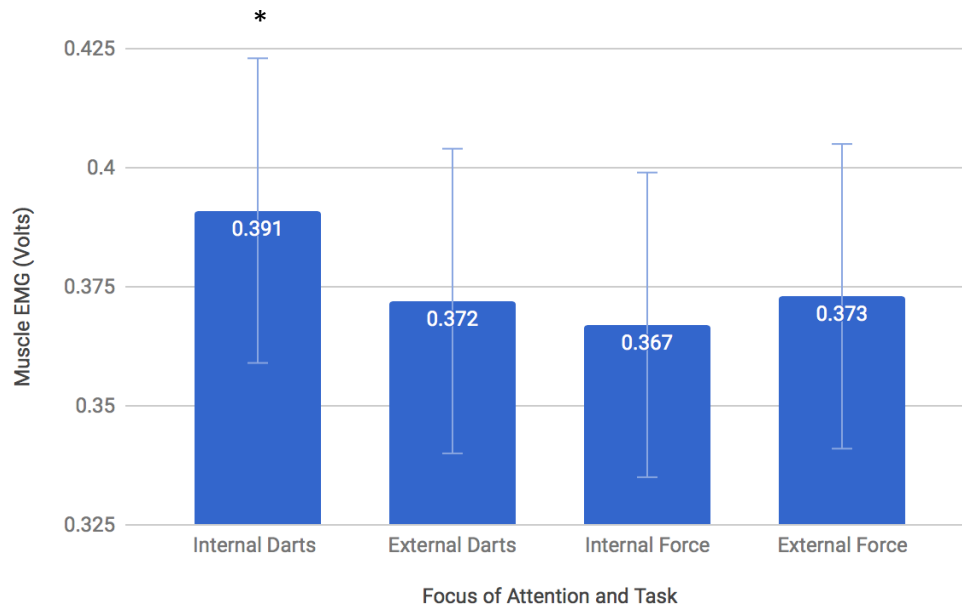
Figure 11. Muscle activation in the focus of attention and different task conditions. Muscle activation was higher when focusing internally on the darts task and when focusing externally on the force task. * p<0.05 indicates significance. Error bars indicate SEMs.

Force Production

The average means in force production for the darts and force conditions are shown in Figure 12. There was higher force production in the force task conditions than the darts conditions $F(1,19) = 5.457$, $p = .031$, $\eta_{p2} = 0.223$, but there was no effect of FOA, $F(1,19) = 2.57$, $p = .125$, $\eta_{p2} = 0.12$. The standard deviations of the mean forces are shown in Figure 13 with higher standard deviation in the force production task than the dart task $F(1,19) = 5.043$, $p = .037$, $\eta_{p2} = 0.210$, but no effect of FOA, $F(1,19) = 0.27$, $p = .61$, $\eta_{p2} = 0.014$. The interaction between task and FOA was not significant for peak force, $F(1,19) = 2.75$, $p = .11$, $\eta_{p2} = 0.13$, or for the standard deviation in force, $F(1,19) = 0.12$, $p = .738$, $\eta_{p2} = 0.006$. The accuracy in force production was also an important aspect examined and there was no effect of task $F(1,19) = 0.013$, $p = .909$, $\eta_{p2} = 0.001$ (Figure 14) or FOA $F(1,19) = 0.770$, $p = .391$, $\eta_{p2} = 0.039$ (Figure

15). Also, the interaction between task and FOA was not significant, $F(1,19) = 0.22$, $p = .642$, η_{p2}
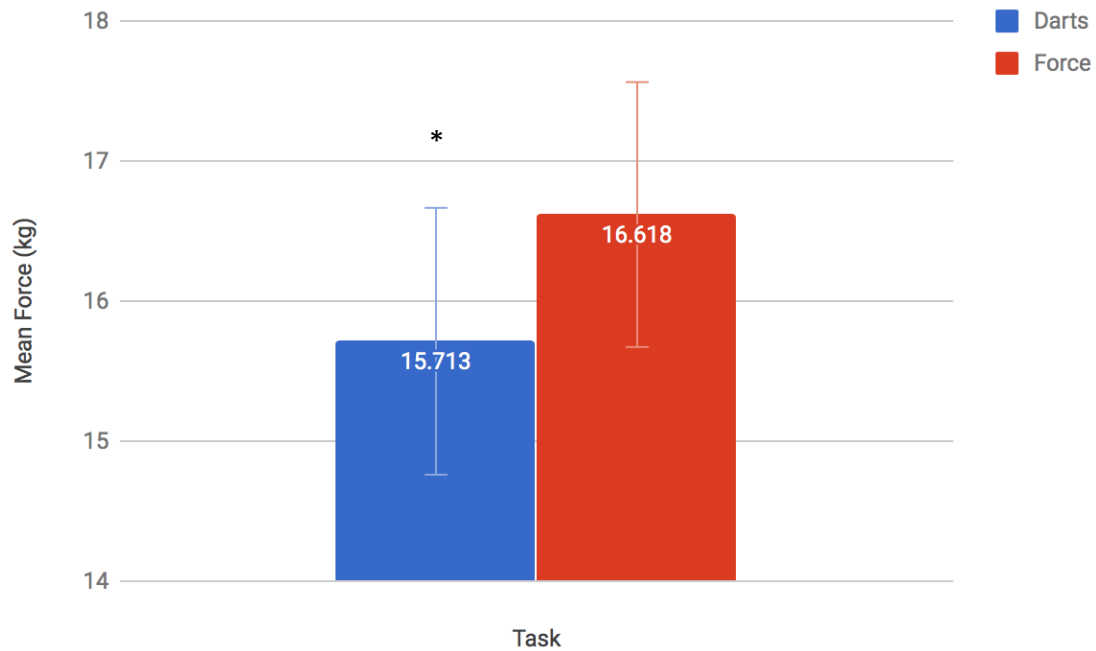
$= 0.012$.

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Figure 12. The mean force production of the darts (left) and force (right) conditions. * p<0.05 indicates significance.

Error bars indicate SEMs.
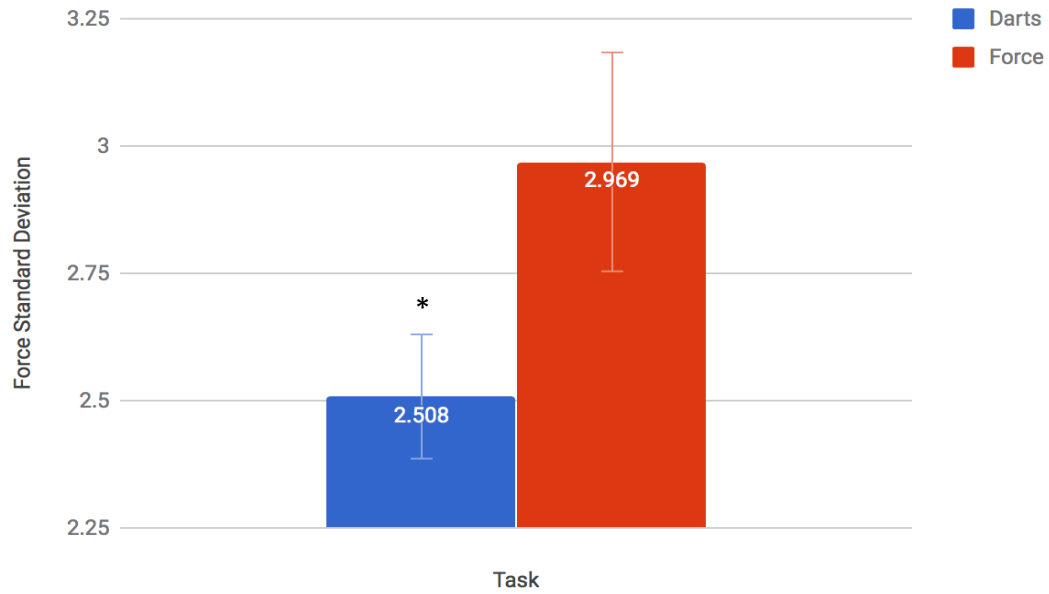
Figure 13. The standard deviations of the mean force production of the darts and force tasks. * p<0.05 indicates

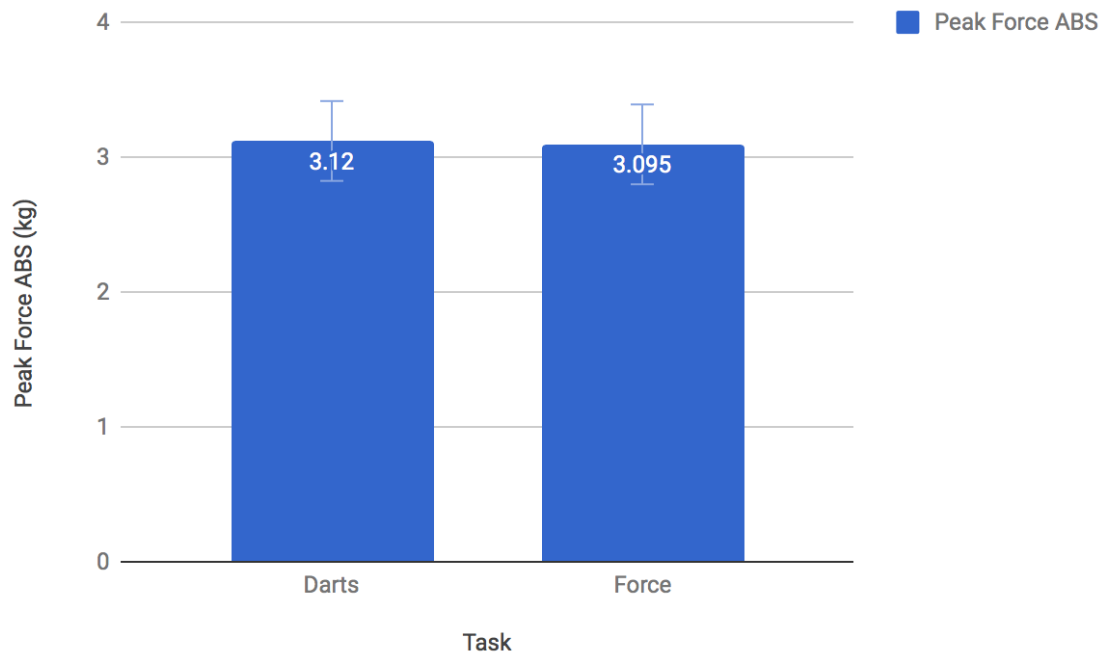significance. Error bars indicate SEMs.

Figure 14. The absolute peak force produced in the two tasks. Error bars indicate SEMs.
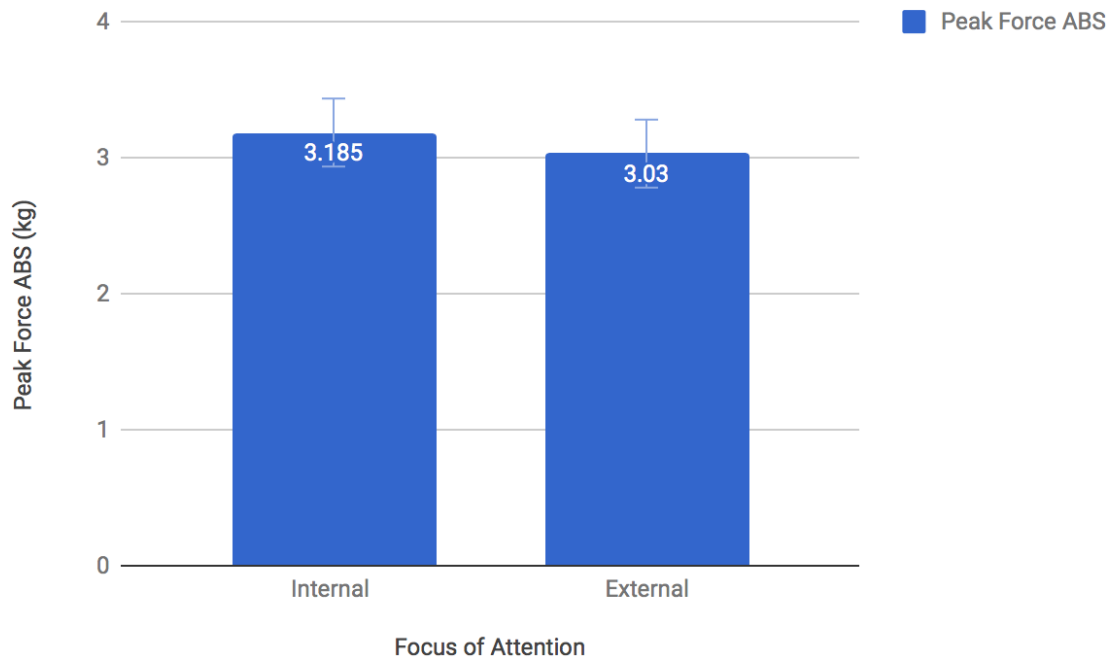
Figure 15. The absolute peak force produced in the two-different focus of attention conditions. Error bars indicate SEMs.

Discussion

The main goal of this experiment was to determine how different focuses of attention affect dart throwing muscle activity and wrist acceleration. During the positive acceleration phase of the movement, when the upper arm accelerated towards the dart board, maximum wrist acceleration in the Y axis was higher in the external focus conditions. EMG activity of the agonist triceps was also higher than the antagonist biceps. These findings were expected as an internal focus was suspected to result in a reduction in some aspect of the throwing acceleration due to a focus shift to the internal kinematics. However, maximum co-contraction and co-contractions of the antagonist muscles were not significantly different between the task and FOA conditions. During the negative acceleration phase, when the upper arm decelerated towards the dart board, minimum X acceleration was greater in the darts and internal FOA conditions. The

was also true with the maximum Z acceleration with the darts and internal FOA having greater acceleration. The differences in the dart task were expected, but the difference in the internal FOA conditions were not expected. Across all force measurements, peak force was not significantly different, but the mean force produced in the force task was significantly higher than the force produced in the darts task. This finding was expected as shifting focus towards the force production task could have led to more flexor muscle activation. As expected, accuracy in the darts external focus conditions was better than the internal focus conditions. However unexpectedly, subjects were also more accurate when focusing externally on the force task as well. This could mean that less attention is required when using an external focus of attention as compared to an internal focus of attention.

The findings of this study suggest that there is better throwing accuracy with an external focus of attention when compared to an internal focus due to lower radial and bivariate error in the external conditions. This is consistent with other studies such as Hitchcock and Sherwood (in press), Lohse et al. (2010) and Sherwood et al. (2016), for example. The results match the predicted outcomes of the constrained-action hypothesis, self-invoking trigger hypothesis, and OPTIMAL theory. A possible explanation could be that an internal focus of attention induces more higher-level cognitive processes than and external focus. These higher cognitive processes could negatively influence the automatic, unconscious processes described by the constrained-action hypothesis. Another possible explanation could be that any internal reflections on the part of the subject has the ability to disrupt motor performance described by the self-invoking trigger hypothesis. According to the OPTIMAL theory, an external focus of attention could increase motivation and attention and improve performance and learning by directing attention to the task goal which could also explain the better accuracy seen in the external focus conditions.

Regardless of the explanation, an internal focus of attention resulted in larger errors in dart

throwing than an external focus, but in terms of force accuracy there was no differences in

accuracy between the task and FOA conditions.

       This study was an extension of the work by Hitchcock and Sherwood (in press), but with

a force production secondary task added. The addition of the force production task added another

set of internal and external focus conditions along with the FOA condition in elbow and dart

release angles. The effects of the force conditions were also monitored with wrist acceleration

and EMG muscle activity. This task also served as a separate focus of attention condition that is

different from the focus of the dart throwing arm which allowed us to examine the two separate

FOA aspects of motor performance.

       The results of this study and the works of previous studies agree that different foci of

attention have significant effects on motor control. For example, there was a significantly greater

muscle activation in the internal darts condition as compared to the external darts condition such

as that shown in works such as Lohse et al. (2010). The tendency for less EMG activity under an

external focus of attention in the darts task leads us to believe that the reduced muscular activity

improved performance by increasing neuromuscular efficiency. However, there tended to be

greater muscular activation in the external force condition than the internal force condition, but

this was not significant. This could suggest that focusing externally on a force producing task

leads to higher force production than focusing internally. Co-contraction was found to be not

significantly different between the task and focus conditions which is different from findings

such as Hitchcock and Sherwood (in press) that found that there was reduced co-contraction

between the agonist and antagonist muscles during the first half of the dart throwing movement

when focusing externally. Therefore, the findings suggest that there was no difference in the

muscle stiffness or co-contraction, but when task and FOA are factored in, there were differences in muscle activity between the internal and external darts task as compared to muscle activity with the force task.

Although accuracy and EMG findings mostly match the results of other published literature, the new findings suggest differences in wrist acceleration. In Hitchcock and Sherwood (in press) it was found that there was higher acceleration in the Y and Z axes during the deceleration half of the movement when focusing externally. However, in the present study, the results of some parts of acceleration in the X and Z axes during the deceleration half of the movement was found to be slightly higher in the internal focus conditions and in the dart tasks. This increased acceleration could have been due to the incorporation of a secondary force task that affected the cognitive processes between the FOA conditions. The secondary task could have reduced cognitive load in the internal conditions, of the second phase of the throw, resulting in the increased acceleration in the internal conditions. On the other hand, it was found that maximum Y acceleration in the positive acceleration phase was higher in the external focus conditions as compared to the internal focus condition. This could be that focusing externally, whether on the flight of the dart, or the pointer on the force gauge reduced cognitive load and allowed for more autonomic processes. The greater maximum Y acceleration could have been a result of this more automatic throwing mechanism.

The results from the force production showed that there was greater mean force produced in the force task than the darts task. This finding was expected as shifting focus from dart throwing to the gripping task would increase neural activation towards the force task and subsequently produce more force. However, unlike the dart task, focusing externally on the force production task did not result in greater accuracy as compared to an internal focus. This could

have been due to the external focus task being hard to mentally visualize as compared to something such as focusing externally on the flight of the dart. Also, the measurements of the hand dynamometer could have not been accurate enough to measure precise values during each squeeze.

Muscular activation of the dart throwing arm was indeed higher in the darts task, as expected, but when focusing on the force production task, there was a higher muscular activity in the external focus condition. In the darts task, an internal focus of attention resulted in higher muscle activation than an external focus. This finding suggests that externally focusing on force production led to higher muscular activation of the throwing arm. This result may still be consistent with hypotheses such as the constrained-action hypothesis that focusing externally results in a decrease of conscious processes since this focus of attention was different than that in the dart throwing task itself. The results of dart task did match findings such as Hitchcock and Sherwood (in press) where an external focus on dart throwing resulted in lower EMG activity.

All in all, accuracy was best in the external focus conditions regardless of the task, but kinematic and EMG data showed that there was greater acceleration in the positive phase and EMG activity in the internal focus conditions with the darts task. EMG data were lower in the force production tasks suggesting that it could play a role in increasing the automaticity of the dart throws. The decreased EMG activity could indicate a decrease in muscle stiffness allowing for less disruption of intramuscular movements. This could support the idea that more automatic movements consistent with the constrained action hypothesis lead to better performance. Greater Y acceleration during the positive phase might improve accuracy by decreasing muscle stiffness. However greater X and Z acceleration in the negative phase might hinder performance by generating lower levels of throwing control as compared to an external focus which was found to

have lower X and Z acceleration. The lack of a relationship between co-contraction, muscle activity and peak force could have been due to several reasons. Co-contraction and muscle activity was measured in terms of the biceps and triceps in this experiment, but other muscles such as the brachioradialis, brachialis and anconius could have played an important role. Also, each participant could have differed in throwing styles and motor control involving different levels of muscular activity and co-contraction. Peak force was measured as a singular value with a hand dynamometer and we were unable to access the changes in force production over the course of the dart throw. Timing of the throws, elbow angle at release and flight curvature were not accessed in this experiment. This likely did not show some throwing discrepancies that might have been important in comparing the ratings the subjects gave to the actual values of the throws. The findings of this research suggest that there is no relationship between co-contraction and peak force to accuracy. Future experiments could expand this work by measuring EMG activity with more muscles of the upper arm, measure force with a grip force transducer to study the ranges of force produced and conduct high-speed video recording of throwing techniques and dart angles. All these improvements would provide a more complete analysis of dart throwing and force production under different focuses of attention conditions.

In conclusion, this study succeeded in replicating some findings in other works on focus of attention and accuracy in dart throwing. This work extended the literature by analyzing how a force producing task with different focuses of attention affected muscle activity and accuracy. Further research on force production with different focuses of attention on motor behavior must be conducted to continue analysis on its effects on kinematics and accuracy.

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