Improved assessment of focus of attention effects on a balance task

by

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ABSTRACT

Focus of attention (FoA) verbal cues can impact the learning and performance of motor skills. It is common for practitioners in applied settings (coaches, teachers, physical therapists, etc.) to provide their learners with instructions that direct their attention towards their own bodies (limbs, joints, muscles), promoting an internal FoA. However, research has consistently shown that providing learners with external focus of attention instructions, that is directing learners' attentions towards the environment and the effect of their movement, is more beneficial to motor skill performance and learning.

The goals of the present work were threefold. First, we tested the constrained action hypothesis in a balance task. Second, we improved on the quantification of posture data during balance tasks by using measurements of participants' center of pressure collected with a force platform. Third, we explored the potential confound of physical fixation (gaze) vs. mental focus (FoA instructions) by testing participants in vision and no-vision groups. In order to account for both vision and focus effects in our experiment, participants were randomly assigned to four different groups: no vision with external FoA, no vision with internal FoA, vision with external FoA, and vision with internal FoA. The task was to balance on top of a foam surface for 90 seconds. Balance performance was measured during two days of acquisition which was followed by one day with retention and transfer tests.

With vision, participants who were told to focus externally performed slightly better, though not significantly, than participants who were told to focus internally, which is an external advantage that has been seen in many studies. However, without vision, the results were reversed. Participants with an internal focus performed slightly better, though

still not significantly, than participants with an external focus. Both these visible trends were also present in the retention phase of the experiment, which suggests that visual feedback affected motor performance and learning. Vision, therefore, may have a critical interaction between continuous motor tasks, like static balance, and FoA strategies.

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CHAPTER 1

INTRODUCTION

The process of learning motor skills is complex and involves multiple factors, such as modeling, distribution of practice, feedback, etc. The present work focuses on one of these factors: verbal cues. In motor learning, verbal cues are any verbally transmitted information or instruction given to learners with the intent of explaining – or teaching how to execute – a movement or motor task. Learners are usually provided with a set of instructions before attempting a motor task for the first time. More importantly, verbal cues can positively or negatively impact one's ability to learn a motor skill, facilitating or hindering the process, which is the reason why instructors should be cognizant of the instructions they provide their learners. It is common for practitioners in applied settings (coaches, teachers, physical therapists, etc.) to provide their learners with instructions that direct their attention towards their own bodies (limbs, joints, muscles), promoting an internal focus of attention (FoA; Porter et al., 2010). However, research has consistently shown that providing learners with external FoA instructions, that is directing learners' attentions towards the environment and the effect of their movement, is more beneficial to motor skill performance and learning (reviewed by Wulf, 2013).

The goals of the present work were threefold. First, we tested the constrained action hypothesis put forth by Wulf et al. (2001a) regarding FoA. This hypothesis suggests that internal FoA instructions induce a more conscious type of motor control that interferes with automatic and efficient motor control processes. On the other hand, external FoA instructions, focusing on the effect of the movement in the environment, directs participants towards more automatic, unconscious, and reflexive motor control processes, allowing the motor system to self-organize with fewer constraints, resulting in more effective performance and learning (Wulf et al., 2001a). According to Wulf and Lewthwaite (2010), even one or two different words in the instructions can direct participants to an internal FoA and be sufficient to trigger these inefficient conscious control processes that override efficient and automatic control, which impairs performance and learning. The way we approached testing this hypothesis was by comparing the frequency of postural corrections between groups that received different FoA instructions, as more frequent adjustments of participants' postures would indicate less constrained and more automatic processes, so we expected to find higher frequencies for the external FoA groups. Second, we improved on the quantification of posture data during balance tasks by using measurements of participants' center of pressure collected with a force platform. Third, we explored the potential confound of physical fixation (gaze) vs. mental focus (FoA instructions) by testing participants in vision and no-vision groups.

1.1 Foundational FoA Research

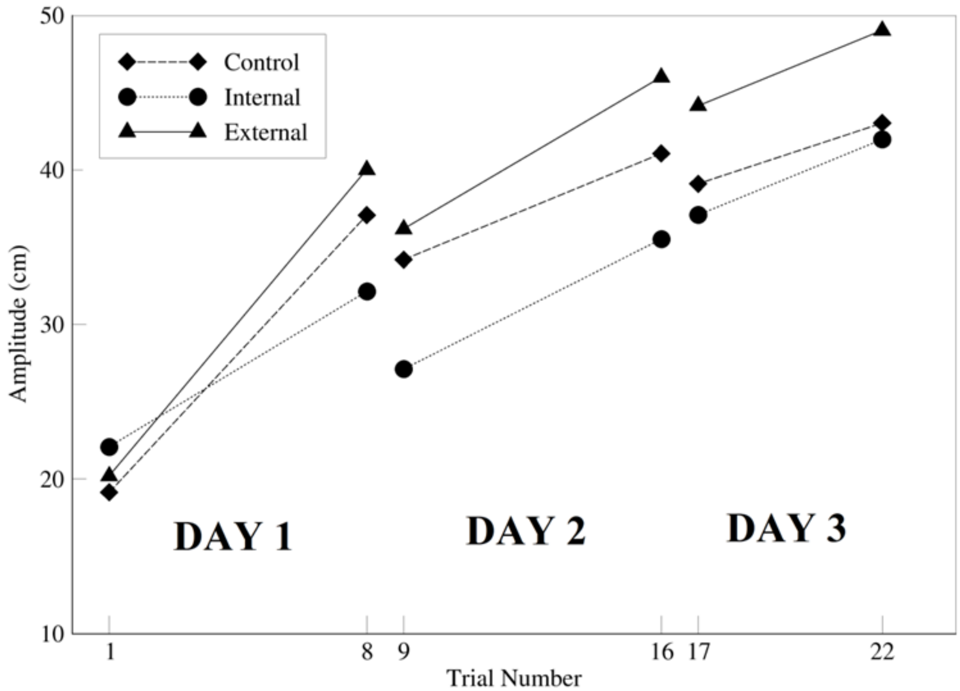
The study that gave life to the body of research on the FoA was conducted by Wulf et al. (1998) on the effect of FoA instructions on complex motor skill learning. In that study, the authors ran two experiments. In the first experiment, participants had to reproduce slalom-type movements with maximum amplitude on top of a ski-simulating platform. They were assigned to three different groups, and each group received different instructions. The internal focus group was instructed to exert force on the outer foot, the external focus group was instructed to exert force on the outer wheels (of the ski-simulating platform), and the control group did not receive any "focus" instructions. Participants practiced the slalom task for two days. Each day consisted of eight trials that were 90 seconds long. FoA instructions were given before every odd-numbered trial for the internal and external focus groups. A third day with six trials was included as a retention test; no instructions were given on that day. The amplitudes of the slalom movements were used as measures of performance and learning during acquisition and retention, respectively. Larger amplitudes of movement suggested better performance or learning as the instructions emphasized the importance of maximizing the amplitude of the movements.

The results of the practice phase showed that the three groups were comparable on the first trial of day 1 (Figure 1). Also, all groups improved with practice throughout the first two days. Overall, the external group had the largest amplitudes and they were significantly larger than the internal group. The control group was visually different from both groups and had intermediate performance compared to the other two groups. These results of the acquisition phase suggested that first, performance is better with an external focus than an internal focus and, second, performance is moderate with no FoA instructions. The results of the retention test on the third day suggested that the external focus group had the largest amplitudes and that the internal focus and control groups were comparable to each other. These results suggested that motor learning is better with an external FoA than either an internal focus or no FoA instructions. The authors concluded that directing learners' attentions away from their own bodies and towards the environmental effects of their movements was beneficial for performance and learning.

The second experiment attempted to reproduce the benefits of an external FoA with a new task. This task involved balancing on a stability platform, which has become one of the most common tasks in FoA experiments. There were three changes to the method from the first experiment.

Figure 1

Mean Amplitude in the First and Last Trials of Each Day with the Slalom Task



Note. Created from the data reported by Wulf et al. (1998).

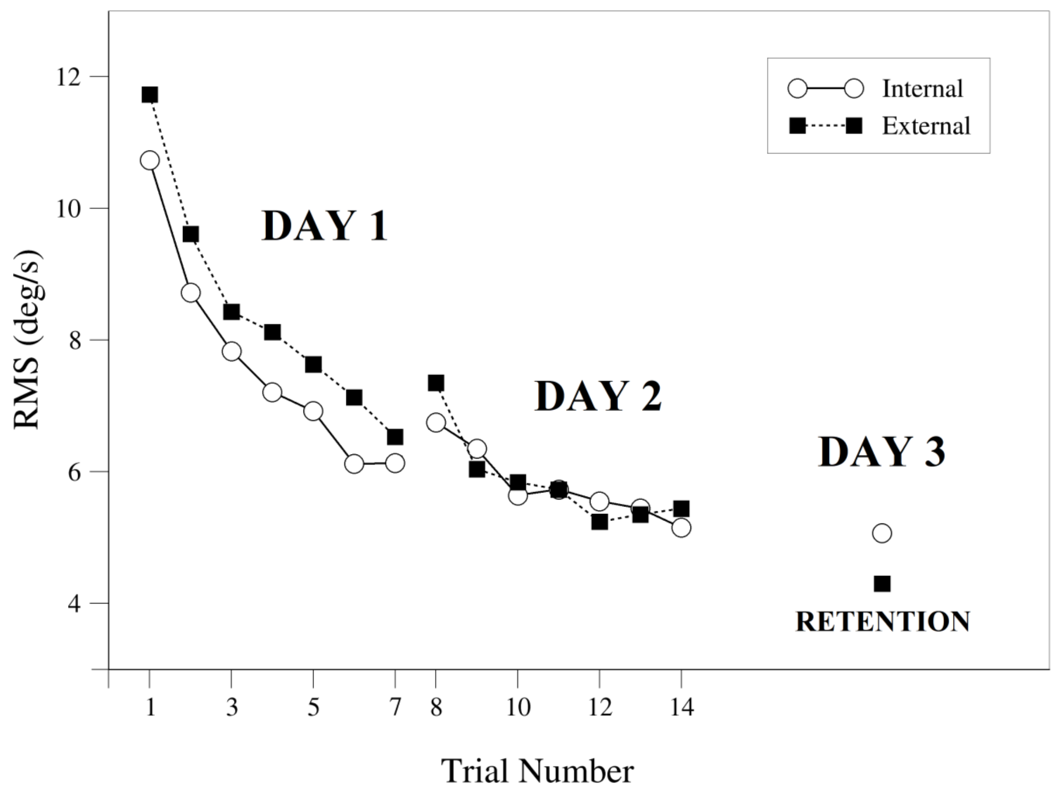
First, the FoA instructions were adapted to the new task. In the internal group, participants were instructed to focus on their feet and to try to keep them at the same height. In the external group, participants were instructed to focus on the red markers on the stability platform and to try to keep them at the same height. The red makers were located in front of the tip of each foot. Second, the control group was dropped. Third, there were seven trials on each day (instead of 8, 8, and 6).

Unlike in Experiment 1, smaller amplitude deviations from horizontal on the stability platform suggested better performance or learning. Performance was quantified by the root-mean-square error (RMSE) of the position time series signal of the platform.

As in Experiment 1, both groups improved with practice throughout the first two days (Figure 2). Interestingly, the authors did not replicate the performance advantage with an external focus in the first experiment; performance in both groups was comparable. Perhaps most importantly, the retention test suggested a benefit to motor learning with an external FoA. Therefore, both experiments showed that ***motor learning*** was facilitated with an external FoA.

Figure 2

Root Mean Square Error Across Practice and Retention of the Stability Platform Task



Note. Created from the data reported by Wulf et al. (1998). RMS = Root Mean Square.

Many studies followed the work of Wulf et al. (1998) and investigated the effect of external FoA instructions in different tasks, contexts, and populations, but the stability platform paradigm has been used consistently. Shea and Wulf (1999), for example, used the same three-day design, with two days of practice and the third day for retention, each day consisting of seven trials that lasted for 90 s. The main difference between this and previous studies was that one more variable – augmented feedback – was investigated, which we will not focus on. All groups improved with practice. The external learning advantage was verified in the retention test for both the external groups (with and without augmented feedback) when compared to their internal counterparts.

Later, Wulf et al. (2001a) added a dependent variable to the stability platform task by also measuring the mean power frequency (MPF) of the stability platform. The authors argued that the MPF is determined by the frequency of postural corrections. They predicted that participants in the external group would have an increased MPF, suggesting more automatic and efficient motor control. Participants in the internal group would have a decreased MPF, indicative of more cognitive and inefficient motor control.

The results of the practice phase revealed a tendency for the external FoA group to have lower RMSE values, but not significantly different when compared to the internal FoA group. During the retention phase, the external group had lower RMSE than the internal group, which replicated the external learning advantage. More importantly, the authors' predictions about MPF were confirmed. The external group had significantly higher MPF ($M = 0.329$, $SE = 0.011$) than the internal group ($M = 0.268$, $SE = 0.011$) during retention. The external group had faster postural corrections, as suggested by MPF, which were smaller in magnitude, as suggested by RMSE.

It is important to mention that the authors could not reliably measure MPF during the practice phase. This was because balancing on the stability platform was difficult, and most participants would occasionally slam the platform into the base. These contacts introduced noise into the position signal of the platform that caused a mischaracterization of the MPF. The number of contacts between the platform and the base decreased with practice, and they did not occur during the retention phase. The result of this was that the progression of MPF during the practice phase could not be quantified. We plan to address this issue by changing the balance task from using a stability platform to quiet standing on an unstable surface (balance foam). MPF during quiet standing can be quantified during practice and retention phases (except when the participant loses their balance and takes a step).

A second study by Wulf et al. (2001b, experiment 2) measured the same dependent variables - RMSE and MPF - on a stability platform. The main difference was that participants were able to try both FoA strategies during acquisition and later choose which of the two they felt was more efficient. Once they decided, they were instructed to use that strategy during the retention phase. Out of 20 participants, 16 decided that an external FoA was more efficient. This difference in preference was significant and may suggest that even naïve participants are able to perceive an advantage with an external FoA. As expected, the advantage was confirmed by the retention test results. The external group had significantly smaller RMSE than the internal group and MPF analysis from the platform revealed that, once again, the external group made significantly more frequent adjustments (M = 0.30, SE = 0.005) than the internal group (M = 0.24, SE = 0.012).

1.2 Origin of the Constrained Action Hypothesis

The “constrained action hypothesis” (Wulf et al., 2001a) suggests that internal focus of attention instructions induce a more conscious type of motor control that causes individuals to constrain automatic control processes that are more efficient. This inefficient conscious control overrides efficient automatic control and impairs performance and learning. External focus of attention instructions direct participants towards this more automatic, unconscious, and reflexive motor control. The collective RMSE and MPF results from the aforementioned stability platform studies support the constrained action hypothesis. What seems to explain these advantages are, according to McNevin et al. (2003), the increased frequencies (higher MPF) of small amplitude responses (lower RMSE) that have been found when participants adopt external FoA strategies. The authors claim that human posture is inherently unstable, and balancing requires a series of small and rapid patterns of muscle activation. Therefore, maintaining the stability platform at level involves an automatic coordination of central processes and peripheral reflexes occurring rapidly. Wulf et al. (2001a) argue that attempts to consciously interfere with this fast and automatic control would result in fewer postural adjustments (lower MPF) with larger amplitudes (higher RMSE), hindering the automatic, faster, and more efficient motor control. The results of the previously mentioned studies suggest that focusing internally leads to fewer postural adjustments with larger amplitudes, which is indicative of a more conscious, slower, and overall inefficient mode of control. The result is worse performance and learning with an internal FoA.

1.3 Force Platform Studies

After many studies that established the consistency of the FoA manipulation effect in stability platform experiments, researchers aimed to investigate FoA instructions effects in different balancing tasks and contexts. Some tasks have been performed on top of force platforms, which allows the experimenters to track participants' instantaneous centers of pressure. The first experiment of a study by Wulf et al. (2007) had healthy young adults standing on a force platform with or without a foam balance pad to manipulate stability. Each participant performed these two tasks in three conditions: external focus, internal focus, and control. For the internal condition, participants were told to focus on their feet and to try and put an equal amount of pressure on each foot (force platform only) or to move their feet as little as possible (force platform plus foam). In the external condition, participants were told to focus on the rectangles on which they stood, putting an equal amount of pressure on each rectangle (force platform only) or to move the rectangles as little as possible (force platform plus foam). In the control condition, regardless of what they stood on, participants were told to stand as still as possible. The authors then analyzed center of pressure data collected from the force platform. The center of pressure data were filtered, centered on the means in the anterior-posterior and medial-lateral axes, and converted to the resultant distance. A dependent variable was then extracted from the resultant distance; specifically, RMSE of the resultant distance.

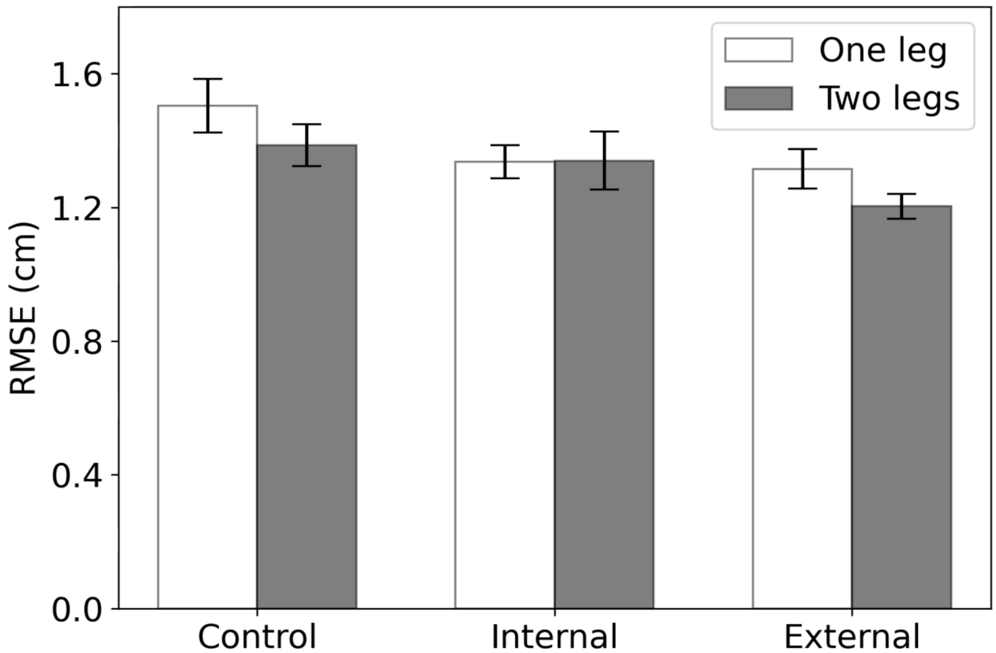
It is worth mentioning a few key differences in terms of methods and design when comparing this experiment to previous experiments. First, instead of testing motor learning with two days of acquisition and one day of retention, these force platform studies tested motor performance on a single day. Second, instead of a between-participant design where different groups of participants were given different FoA instructions, these studies used a within-participant design where the participants were given the different FoA instructions in a counterbalanced order. Third, the trial duration was decreased from 90 to 15 s and there were only three trials in each of the FoA conditions.

As for the results of the study by Wulf et al. (2007), RMSE of the resultant distance was lower on the solid surface than on the foam across all three FoA conditions. Interestingly, the authors did not find significant RMSE differences between internal, external, and control conditions for these two tasks. One explanation for the lack of an advantage with an external FoA was that the static balance tasks, even with the foam, were too easy. The static balance tasks may need to be more difficult, more akin to the difficulty of the dynamic balance task on the stability platform, for the FoA effect to manifest. Therefore, in the second experiment, the authors increased the difficulty of the static balance tasks.

In the second experiment, participants stood upon an inflated rubber disk with a diameter of 33.02 cm (Disc'O'Sit, Gymnic) that was placed on the force platform. There were two tasks, either standing on both feet or on one foot, which further increased the difficulty of the task. The same three FoA conditions were repeated from the first experiment: external focus, internal focus, and control. In the external condition, participants were told to focus on moving the disk as little as possible, while in the internal condition, they were told to focus on moving their feet (or foot) as little as possible. In the control condition, they were only told to "stand still." RMSE of the resultant distance (Figure 3) suggested that balancing on the inflated disk was more difficult than standing on the foam and that balancing on one foot was more difficult than balancing on both feet. Most importantly, performance with external FoA instructions was better than with internal or control instructions. Based on the results of both experiments, the authors concluded that the advantage with external FoA instructions only emerges when the static balance task is difficult.

Figure 3

Root Mean Square Error Across All Conditions with the Rubber Disk in Experiment 2



Note. Created from the data reported by Wulf et al. (2007). RMSE = Root Mean Square Error.

Another study by Wulf (2008) followed a similar protocol that involved participants standing on an inflated rubber disk. This time, however, professional acrobats from Cirque du Soleil were tested. The disk was placed upon a force platform that recorded center of pressure data. The acrobats had to stand on the rubber disk under three different conditions: external focus, internal focus, and control. This study also did not involve a learning paradigm and consisted of a total of only 12 trials (four 15 s trials in each condition). The resultant distance was, again, calculated from the center of pressure time-series data. It was used to calculate two dependent variables: RMSE and MPF. Participants had similar RMSE results in all conditions. However, MPF was significantly higher for the control condition when compared to both external and internal foci, which were not significantly different from one another. These somewhat unexpected results are likely due to the nature of the sample population that consisted of professional acrobats. Wulf (2008) argued that it is likely that requesting these professional acrobats to focus on anything other than what they are used to, internal or external, disrupted their finely tuned reflexive motor control mechanisms. This could explain why balance in the control condition was more automatic than in the internal and external conditions.

The goals of the present work were threefold. First, we tested the constrained action hypothesis put forth by Wulf et al. (2001a). The way we approached testing this hypothesis was by comparing the frequency of postural corrections between groups that received different FoA instructions, as more frequent adjustments on participants' postures would indicate less constrained and more automatic processes, so we expected to find higher frequencies for the external FoA group. As another aspect of the constrained action hypothesis, we also predicted we would find better performance with external focus, more specifically, with smaller postural adjustments. Second, we measured motor performance and learning of a static balance task on an unstable surface and performance was quantified with traditional measurements based on center of pressure. Third, we explored the potential confound of physical fixation (gaze) vs. mental focus (FoA instructions) by including groups with and without visual feedback during the balance task.

CHAPTER 2

METHOD

2.1 Participants

Data was collected from 58 participants. The sample was composed of Texas Tech University students between the ages of 18 and 39 years old who were free of any condition or injury that would impair standing balance. Participants were recruited from undergraduate classes and the vast majority were offered extra credit as reward. All were naïve to the purpose of the experiment and provided informed consent. The Institutional Review Board at Texas Tech University approved the study.

2.2 Design

Participants were separated into four groups: two groups with vision (internal [n = 12] and external foci [n = 12]) and two groups without vision (internal [n = 17] and external foci [n = 17]), in a counterbalanced fashion. Data was collected across three days, two days of acquisition and one final day for retention and transfer tests. The maximum interval between testing days tolerated was 3 days. Every experimental trial lasted 90 seconds; the rest interval between trials was standardized to 90 seconds. There were eight trials on the first day, seven trials on the second day, and ten trials on the third day. On the first day, the first trial was a baseline pre-test without FoA instructions. The remaining seven trials were acquisition with FoA instructions. The second day had another seven acquisition trials with FoA instructions. The third day began with seven retention trials without FoA instructions, which is the norm in FoA research, and the last three trials were transfer, where the participant repeated the same balance task but on a different foam pad.

2.3 Apparatus

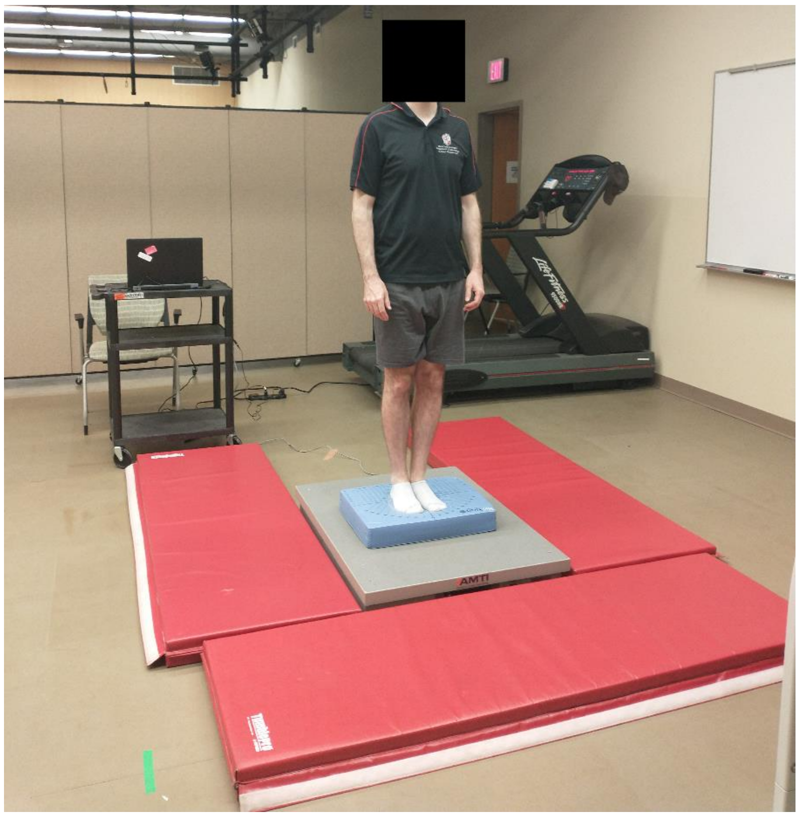
Center of pressure time-series data was initially recorded by a force platform (AMTI OPT464508, 46.4 by 50.8 cm) at a sampling frequency of 1,000 Hz. The force platform was connected to a computer with the Vicon Nexus v2.8 recording the data. Due to technical difficulties, data collection was switched to an AMTI AccuPower force platform, maintaining the same sampling rate of 1,000 Hz, but using the AMTI NetForce software. Two different foam balance pads were used: one for acquisition and retention (foam pad from the Biodex Biosway, 39.4 by 50.8 by 8.0 cm) and one for transfer (Airex balance pad, 38.1 by 47.6 by 6.4 cm). The Biosway foam pad is softer than the Airex, which made balancing more difficult.

2.4 Procedures

On each trial, the participant was instructed to step onto the foam pad, assume a narrow stance with their feet touching each other, and then close their eyes or look straight ahead; depending on whether they were in the no vision or vision groups. On all trials, the participant was instructed to "stand as still as possible" (Zok et al., 2008). Data collection began when the participant had stepped onto the foam, closed their eyes or was looking straight ahead, and was relatively stable (Figure 4). For the acquisition trials on the first and second days, both external groups were also instructed to "focus on minimizing movements of the foam", whereas both internal groups were told to "focus on minimizing movements of your feet". At the end of each acquisition trial, the participant was asked, "How much of the trial, from 0 to 100%, were you able to maintain your focus on minimizing movements of [your feet (internal focus group) OR the foam (external focus group)]?” FoA instructions and the post-trial questionnaire were not given for the pretest (day 1, trial 1), retention (day 3, trials 1 to 7), and transfer (day 3, trials 8 to 10).

Figure 4

A Photo of a Pilot Participant (advisor JB)



2.5 Data Analysis

Center of pressure time series data was filtered with a low-pass Butterworth filter (dual pass, fourth order) with a cutoff frequency of 10 Hz (the order and cutoff frequency were after the two passes). This cutoff frequency was selected to achieve visibly comparable frequency spectrums in data collected from the two different force platforms. The mean center of pressure in the anterior-posterior and medial-lateral directions was subtracted from the time series data. The anterior-posterior and medial-lateral center of pressure were combined into the resultant distance (Prieto et al., 1996).

$$Resultant\ distance = \sqrt{CoP_{AP}^2 + CoP_{ML}^2}$$

Four dependent variables were extracted from the resultant distance: root mean square error (RMSE; Wulf et al., 2004), standard deviation, velocity (Prieto et al., 1996), and MPF (Wulf et al., 2001a). A fifth dependent variable, 95% confidence ellipse area (Prieto et al., 1996), was extracted from the center of pressure data. RMSE and MPF were included as they are commonly used in FoA studies. The other three dependent variables, 95% confidence ellipse area, standard deviation, and velocity, were included because they are commonly used in force platform studies that analyze center of pressure.

Each dependent variable was statistically analyzed in the four stages of the experiment: pretest, acquisition, retention, and transfer. Performance during the pretest was analyzed with 2 Focus of Attention (internal, external) by 2 Vision (vision, no vision) ANOVAs. This was done to ensure that both vision groups were equivalent before practicing the task with different FoA instructions, as well as both no-vision groups Evidently, we expected both vision groups to have a better baseline pretest performance than both no-vision groups, due to the intrinsic increase in the difficulty of the task with eyes closed. Performance during acquisition was analyzed with 2 Focus of Attention (internal, external) by 2 Vision (vision, no vision) by 2 Day (1, 2) by 2 Trial (1, 7) mixed ANOVA, with focus of attention and vision as between-participant factors. Motor learning was assessed with retention and transfer tasks. Retention performance was analyzed with 2 Focus of Attention by 2 Vision by 2 Trial mixed ANOVA. The mean of the three transfer trials was calculated, and then transfer performance was analyzed with a 2 Focus of Attention by 2 Vision ANOVA. Significant interactions were analyzed with simple main effects (two-way interactions) or simple interaction effects (higher-order interactions). The

Bonferroni correction was used to control the familywise error rate. Reported values are means and 95% confidence intervals.

CHAPTER 3

RESULTS

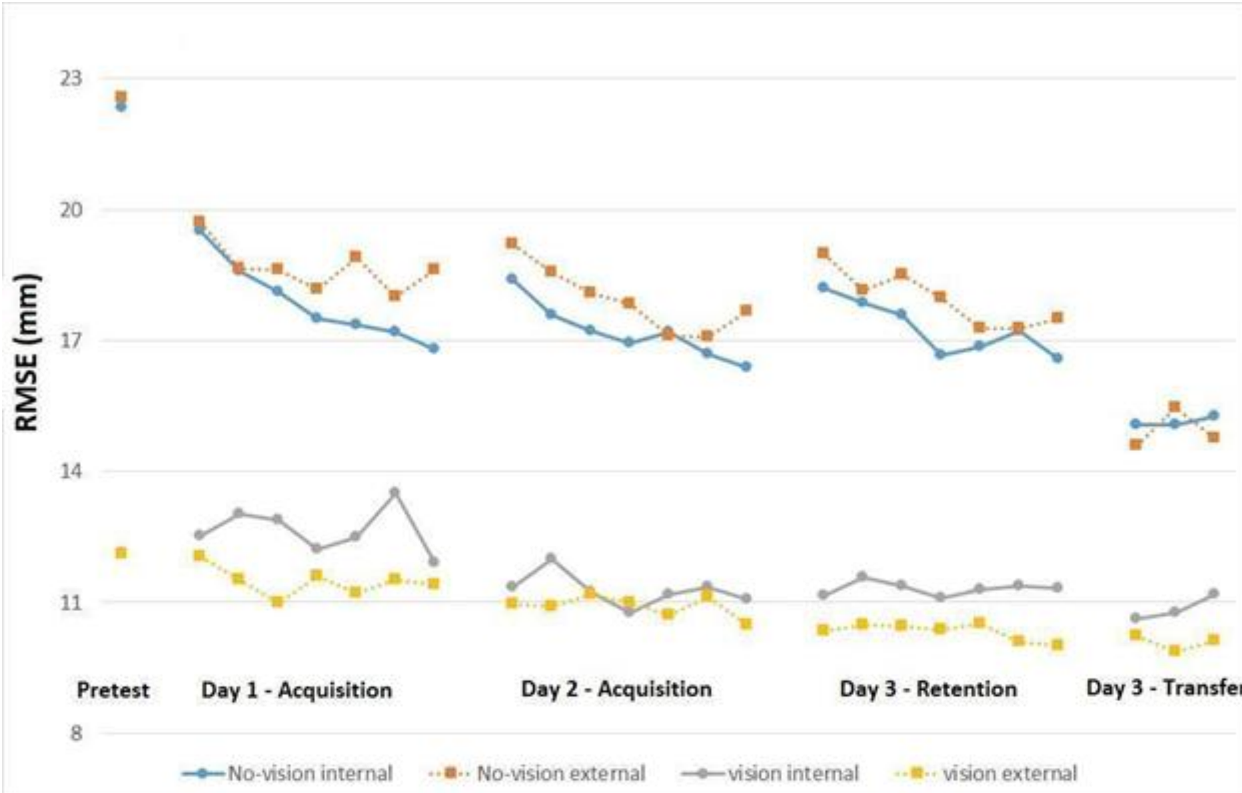
The results of the ANOVAs on the five dependent variables are shown in Tables A1 to A4. Four of the five dependent variables (RMSE, standard deviation, velocity and 95% confidence ellipse area) had similar statistical results. The full analysis of RMSE is presented below; the same pattern of results applies to standard deviation, velocity, and 95% confidence ellipse area (plots can be found in Figures B1 to B3). RMSE is presented because it is the most common dependent variable in focus of attention studies with a balance task. MPF, another common dependent variable, had unique statistical results, and its full analysis is also presented below. Last, we reported the results of the manipulation check, the reported percentages of focus reported by the participants after each acquisition trial.

3.1 RMSE

Figure 5 shows that vision played an important part on participants' abilities to balance. There is a clear advantage (smaller RMSEs) for the groups with vision (vision internal and vision external) compared to the groups without vision (no vision internal and no vision external), which was expected. For the groups with vision, RMSE was slightly lower with an external focus than with an internal focus. For the groups without vision, RMSE was slightly lower with an internal focus than with an external focus. However, these small visible differences were not significantly different (see Tables A1 to A4).

Figure 5

Mean RMSE Scores in Each Trial Across All Experimental Phases and Conditions



Note. RMSE = Root Mean Square Error.

3.1.1 Pretest

There was a significant main effect of Vision during the pretest phase, F(1, 54) = 107.7, p < .01, η_p^2 = .67. As expected, RMSE was significantly smaller with vision than without vision (Figure 5). This suggests that at an initial stage before any practice, balance was easier with vision than without it, which is as expected. The main effect of Focus and the Vision by Focus interaction were not significant, $F(1, 54) < 0.1, p = .92, \eta_p^2 < .01, F(1, 54) < 0.1, p = .90, \eta_p^2 < .01$. This suggests that before introducing focus of attention instructions, the vision internal and vision external groups had comparable balance performance and the no-vision internal and no-vision external groups had comparable balance performance.

3.1.2 Acquisition

During the acquisition phase, there was a significant main effect of Day. RMSE was significantly smaller on day 2 compared to day 1, $F(1, 54) = 10.9$, $p < .01$, $\eta_p^2 = .17$. This suggests that all groups had better performance on day 2 of acquisition compared to day 1. Additionally, there was a significant Trial by Vision interaction, $F(1, 54) = 6.9$, $p < .01$, $\eta_p^2 = .11$. Simple main effects suggested that the groups without vision showed significant improvement from trial 1 to trial 7, $p < .01$, with smaller errors, while the groups with vision had comparable performance on trials 1 and 7, $p = .20$.

3.1.3 Retention

In the retention phase there was, once again, a significant Trial by Vision interaction, $F(1, 54) = 8.7$, $p < .01$, $\boldsymbol{\eta_p^2} = .14$. As in the acquisition phase, simple main effects showed significant improvement from trial 1 to trial 7 without vision, $p < .01$, but no significant differences with vision, $p = .82$.

3.1.4 Transfer

There was a significant main effect of Vision during the transfer phase, $F(1, 54) = 51.2$, $p < .01$, $\boldsymbol{\eta_p^2} = .49$. RMSE with vision was smaller than without vision, which was expected in all phases of the experiment.

3.2 MPF

Our MPF data did not align with previous findings in focus of attention research (Figure B4). We expected to find a higher number of small adjustments (increased MPF) for the external FoA groups compared to their internal counterparts, which did not occur. In fact, there were no significant main effects or interaction with FoA.

3.2.1 Pretest

There was a significant main effect of Vision during the pretest phase, F(1, 54) = 8.0, p < .01, η_p^2 = .13. Participants with vision (0.14 Hz, [0.13, 0.16]) had lower MPFs than participants without vision (0.17 Hz, [0.16, 0.18]). This suggests that, without vision, participants required a larger number of corrective movements to maintain their balance than with vision.

3.2.2 Acquisition

During the acquisition phase, there was a significant Day by Trial interaction, F(1, 54) = 5.4, p = .02, η_p^2 = .09. On Day 1, there were no significant differences from the first (0.14 Hz, [0.13, 0.15]) to the last trial (0.14 Hz, [0.13, 0.15]), p = .73, but on Day 2 there was a significant decrease in MPF, p < .01, suggesting that on the last trial (0.15 Hz, [0.14, 0.16]) participants made fewer adjustments than on the first trial (0.16 Hz, [0.15, 0.17]). This could be attributed to a potential practice effect, with participants learning to maintain themselves steadier on top of the unstable surface with fewer movements of their feet as their familiarity with the task increased. Another possible interpretation is that part of the instructions provided - “focus on minimizing movements- stimulated a more stationary strategy, resulting in lower MPF.

3.2.3 Retention

There was a significant main effect of Trial during the retention phase on Day3, F(1, 54) = 16.9, p < .01, $\boldsymbol{\eta_p^2}$ = .24. MPF significantly decreased from trial 1 (0.16 Hz, [0.15, 0.17]) to trial 7 (0.15 Hz, [0.14, 0.16]), possibly reinforcing the interpretation of the Day by Trial interaction during the acquisition phase.

3.2.4 Transfer

There were no significant effects or interactions for MPF during the transfer phase (0.14 Hz, [0.13, 0.15]).

3.3 Manipulation Check

There were no significant differences between groups in the focus percentages reported by the participants after acquisition trials. The grand mean was 82.7% [79.2, 86.2]. This means that regardless of focus strategy or presence of vision, most participants claimed to be highly focused on following the instructions.

CHAPTER 4

DISCUSSION

In this study, we aimed to replicate previous findings concerning FoA effects in balance tasks while improving on the assessment of task performance by measuring some more traditional balance variables - resultant distance, standard deviation, velocity, and center of pressure 95% confidence interval ellipse area (Prieto et al, 1996) - that have not been used before in FoA research but are often found in sway studies (van der Kooij et al., 2011). Notably, velocity and standard deviation are relative to the resultant distance. Additionally, we wanted to explore a potential confound from previous studies: visual feedback, which has often been overlooked in previous FoA research, despite that it is the dominant sense used during static balance. In order to account for both vision and focus effects in our experiment, participants were randomly assigned to four different groups: no vision with external FoA, no vision with internal FoA, vision with external FoA, and vision with internal FoA. The task was to balance on top of a foam surface for 90 seconds. Balance performance was measured during two days of acquisition which was followed by one day with retention and transfer tests.

4.1 FoA Effects with Vision

We predicted there would be performance and motor learning advantages for the vision external FoA group compared to the vision internal FoA group because such advantages have been reported in many stability platform experiments (e.g., Wulf et al., 1998; Wulf et al., 2001; McNevin et al., 2003). However, the balance performance of both vision groups was comparable. This was true of all dependent variables and experimental phases: acquisition, retention, and transfer. There is some FoA research with similar results. Wulf et al. (2007, Experiment 1) had young adults performing a similar task, in which participants either stood on a force platform or on a foam pad on top of a force platform. They found that balance performance (RMSE) was comparable for the internal and external FoA groups on both the force platform and the foam pad. Wulf and colleagues argued that these tasks were too easy for young adults and that is why no significant differences between FoA strategies were found. Considering how similar the tasks were between our and Wulf et al. (2007) experiments, our task was likely too easy for the population tested as well, and our results would corroborate the hypothesis that a certain degree of task difficulty is required for attentional focus manipulations to be effective. One source of support that our task with vision was likely too easy is that there was no significant improvement from the first to the last trial on all three days for the groups with vision. There was evidence for some minor improvements in performance, as day 2 had better balance performance than day 1.

Considering Wulf et al.'s (2017) findings on task difficulty, why did we not make our balance task more difficult? Wulf et al. (2017) tested a more difficult static balance task in Experiment 2 by replacing the foam pad with an inflated rubber disk, and this challenging task did elicit an external advantage (Figure 3). We did try using a rubber disk, which made the task more difficult. The problem was that the balance task was now too difficult for the groups without vision. To preserve internal validity, we used the same balance task for all four groups. The difficulty of this task, standing on a foam pad, was constrained by the groups without vision.

4.2 FoA Effects without Vision

Contrary to our initial hypothesis and akin to our results with vision, balance performance was comparable for the internal and external FoA groups without vision. However, we also hypothesized that vision played a bigger part in balance tasks, potentially confounding the results while it has rarely been considered within the FoA body of research. Indeed, for four out of five dependent variables (excluding MPF), balance performance was better with vision than without vision. These results emphasize how the groups with vision had better balance performance than the groups without vision in all four phases of the experiment (Figure 5). Additionally, the groups without vision significantly improved from the first to last trial on each day. This suggests that the task was difficult and that there were large increases in performance. If the task was not too easy without vision, then what can account for a lack of an external advantage? We hypothesize that performing a static balance task without vision fundamentally changes the task and the influence of focus of attention instructions. We discuss this hypothesis in the next section.

4.3 The Role of Vision in Balance and FoA

Of even more interest to us was the effect vision had in potentially reversing the relationship between focus of attention strategies, creating an “advantage inversion” of sorts. With vision, participants who were told to focus externally performed slightly better, though not significantly, than participants who were told to focus internally, which is an external advantage that has been seen in many studies (reviewed by Wulf, 2013). However, without vision, the results were reversed. Participants with an internal focus performed slightly better, though still not significantly, than participants with an external focus. Both these visible trends were also present in the retention phase of the experiment, which suggests that visual feedback affected motor performance and learning. Vision, therefore, may have a critical interaction between continuous motor tasks, like static balance, and FoA strategies.

This is an important finding for FoA research and for the constrained action hypothesis (Wulf et al., 2001). There is very little research that examines the interaction between visual feedback and FoA strategies. Sherwood et al. (2014) found an external advantage in a study where all the participants were blindfolded. However, it was a discrete task, dart throwing, and participants removed the blindfold at the end of each trial to see how close their dart was to the bullseye. Vision is likely more important during a continuous balance task, which could be why we did not replicate the typical advantage for an external focus of attention.

4.4 Limitations and Future Directions

Three potential limitations of our study are the proximity of both FoA focal points, the MPF assessment, and the relevance of the instructions to task performance. In terms of proximity of FoA focal points, research has shown there is a distance effect to the external focal point; specifically, that the size of the external advantage increases with further focal points (McNevin et al., 2003). An example of this distance effect in a standing balance task was the work of Richer et al. (2017). They had participants perform a standing balance task on a flat surface (a force platform) with control, internal, and external focus of attention instructions. They measured similar variables to our present study (except for velocity and MPF), though they separated the center of pressure data into anteroposterior and mediolateral directions. In the internal condition, participants focused on their ankles, and in the external condition, they focused on a set of motion-capture markers that were attached to their ankles, but floating 9 cm away, connected to their joints by pieces of plastic. Interestingly, they found a significant reduction in postural sway in the external focus condition compared to the internal condition, an external advantage. Those results suggest that, even on a flat surface, an increased distance of 9 cm away from their bodies could be enough to evince an external focus advantage. Recall that our external groups focused on minimizing movements of the foam pad. Perhaps a more distal external focus of attention would have elicited an external advantage. Our participants were not in contact with anything else during the trials, so the effects their movements could elicit on the environment were limited to the foam pad itself, and that is why our instructions were to minimize these movements.

Our MPF results exhibited erratic patterns, and were inconclusive, in general. Because we were tracking the center of pressure data in our experiment, our participants had more degrees of freedom for their movements, so we assessed MPF across two axes while previous research, especially stability platform studies, were only concerned with one axis (as stability platforms can only move in the mediolateral plane). The addition of an extra axis in our experiment could have caused our measurements to be noisier than usual and, thus, inconclusive.

As for the relevance of the instructions, telling participants to “stand as still as possible and minimize movements” might not improve performance and could hinder performance. Wulf et al. (1998, Experiment 1) showed that the internal group had worse performance than the control group on the last trial of each day of acquisition. To investigate this possibility in our task, we would need to run an additional control group without FoA instructions.

Future research should consider the potential interaction between vision and FoA instructions, especially for continuous tasks. Also, a more difficult balance task, that is still feasible without vision, might help to find an external advantage with vision and, possibly, an internal advantage without vision. It is possible that discrete tasks might also be affected by the removal of visual feedback. Either way, determining how visual feedback interacts with FoA instructions seems to be a promising and challenging avenue for future research.

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APPENDICES

APPENDIX A
TABLES

Table A1
Pretest ANOVA results

	$F(1, 54)$	p	η_p^2
RMS			
Vision	107.7	<.01	.67
Focus	<0.1	.92	<.01
Vision by Focus	<0.1	.90	<.01
Ellipse			
Vision	74.4	<.01	.58
Focus	<0.1	.86	<.01
Vision by Focus	.14	.71	<.01
Std			
Vision	109.0	<.01	.67
Focus	<0.1	.88	<.01
Vision by Focus	<0.1	.80	<.01
Velocity			
Vision	75.5	<.01	.58
Focus	.17	.68	<.01
Vision by Focus	<0.1	.79	<.01
MPF			
Vision	8.0	<.01	.13
Focus	1.4	.24	.03
Vision by Focus	1.2	.29	.02

Note. RMS = Root mean square error; Ellipse = 95% confidence interval center of pressure area ellipse; Std = standard deviation of resultant distance; Velocity = velocity of resultant distance; MPF = mean power frequency; η_p^2 = partial eta squared.

Table A2

Acquisition ANOVA results

	***F*(1, 54)**	***p***	η_p^2
RMS			
Day	10.9	<.01	.17
Day by Vision	0.2	.63	<.01
Day by Focus	<0.1	.95	<.01
Day by Vision by Focus	<0.1	.96	<.01
Trial	21.1	<.01	.28
Trial by Vision	6.9	.01	.11
Trial by Focus	0.8	.38	.02
Trial by Vision by Focus	1.3	.27	.02
Day by Trial	0.2	.64	<.01
Day by Trial by Vision	<0.1	.87	<.01
Day by Trial by Focus	0.8	.39	.01
Day by Trial by Vision by Focus	0.4	.51	.01
Vision	88.1	<.01	.62
Focus	0.1	.71	<.01
Vision by Focus	1.1	.30	.02
Ellipse			
Day	8.9	<.01	.14
Day by Vision	0.1	.72	<.01
Day by Focus	<0.1	.85	<.01
Day by Vision by Focus	<0.1	.78	<.01
Trial	16.7	<.01	.23
Trial by Vision	8.4	<.01	.13
Trial by Focus	0.9	.36	.02
Trial by Vision by Focus	1.2	.29	.02
Day by Trial	0.5	.48	<.01
Day by Trial by Vision	<0.1	.78	<.01
Day by Trial by Focus	0.4	.53	<.01
Day by Trial by Vision by Focus	0.4	.53	<.01
Vision	65.7	<.01	.54
Focus	0.3	.58	<.01
Vision by Focus	1.2	.28	.02
Std			
Day	10.5	<.01	.16
Day by Vision	0.2	.69	<.01
Day by Focus	<0.1	.88	<.01
Day by Vision by Focus	<0.1	.88	<.01

Trial	17.9	<.01	.25
Trial by Vision	8.8	<.01	.14
Trial by Focus	0.6	.44	.01
Trial by Vision by Focus	0.5	.47	.01
Day by Trial	<0.1	.80	<.01
Day by Trial by Vision	0.4	.51	<.01
Day by Trial by Focus	<0.1	.93	<.01
Day by Trial by Vision by Focus	0.2	.62	<.01
Vision	92.5	<.01	.63
Focus	0.2	.70	<.01
Vision by Focus	1.1	.29	.02
Velocity			
Day	<0.1	.96	<.01
Day by Vision	0.2	.68	<.01
Day by Focus	0.3	.57	<.01
Day by Vision by Focus	0.3	.60	<.01
Trial	76.0	<.01	.59
Trial by Vision	32.6	<.01	.38
Trial by Focus	0.8	.38	.01
Trial by Vision by Focus	3.9	.05	.07
Day by Trial	2.4	.13	.04
Day by Trial by Vision	0.2	.64	<.01
Day by Trial by Focus	1.0	.31	.02
Day by Trial by Vision by Focus	0.6	.46	.01
Vision	62.5	<.01	.54
Focus	<0.1	.84	<.01
Vision by Focus	1.3	.27	.02
MPF			
Day	10.8	<.01	.17
Day by Vision	3.4	.07	.06
Day by Focus	3.5	.06	.06
Day by Vision by Focus	0.6	.43	.01
Trial	6.9	.01	.11
Trial by Vision	8.1	<.01	.13
Trial by Focus	<0.1	.90	<.01
Trial by Vision by Focus	0.4	.55	<.01
Day by Trial	5.4	.02	.09
Day by Trial by Vision	0.7	.42	.01
Day by Trial by Focus	1.0	.31	.02
Day by Trial by Vision by Focus	0.2	.69	<.01
Vision	3.9	.06	.07

Focus	0.2	.63	<.01
Vision by Focus	0.1	.72	<.01

Note. RMS = Root mean square error; Ellipse = 95% confidence interval center of pressure area ellipse; Std = standard deviation of resultant distance; Velocity = velocity of resultant distance; MPF = mean power frequency; η_p^2 = partial eta squared.

Table A3

Retention ANOVA results

	$\boldsymbol{F}$**(1, 54)**	$\boldsymbol{p}$	η_p^2
RMS			
Trial	11.0	<.01	.17
Trial by Vision	8.7	<.01	.14
Trial by Focus	0.1	.75	<.01
Trial by Vision by Focus	0.4	.52	<.01
Vision	87.5	<.01	.62
Focus	<0.1	.89	<.01
Vision by Focus	1.6	.22	.03
Ellipse			
Trial	10.3	<.01	.16
Trial by Vision	9.5	<.01	.15
Trial by Focus	<0.1	.97	<.01
Trail by Vision by Focus	0.5	.49	<.01
Vision	59.2	<.01	.52
Focus	<0.1	.87	<.01
Vision by Focus	1.5	.23	.03
Std			
Trial	16.7	<.01	.24
Trial by Vision	10.2	<.01	.16
Trial by Focus	0.1	.71	<.01
Trail by Vision by Focus	0.3	.59	<.01
Vision	82.5	<.01	.60
Focus	<0.1	.94	<.01
Vision by Focus	2.3	.14	.04
Velocity			
Trial	56.5	<.01	.51
Trial by Vision	16.1	<.01	.23
Trial by Focus	1.3	.25	.02

Trail by Vision by Focus	1.1	.31	.02
Vision	57.7	<.01	.52
Focus	<0.1	.83	<.01
Vision by Focus	1.6	.20	.03
MPF			
Trial	16.9	<.01	.24
Trial by Vision	0.1	.74	<.01
Trial by Focus	2.7	.11	.05
Trail by Vision by Focus	<0.1	.93	<.01
Vision	0.6	.46	.01
Focus	<0.1	.92	<.01
Vision by Focus	0.6	.45	.01

Note. RMS = Root mean square error; Ellipse = 95% confidence interval center of pressure area ellipse; Std = standard deviation of resultant distance; Velocity = velocity of resultant distance; MPF = mean power frequency; η_p^2 = partial eta squared.

Table A4

Transfer ANOVA results

	$F(1, 54)$	p	η_p^2
RMS			
Vision	51.2	<.01	.49
Focus	0.6	.45	.01
Vision by Focus	0.2	.65	<.01
Ellipse			
Vision	37.2	<.01	.41
Focus	0.5	.47	.01
Vision by Focus	0.2	.65	<.01
Std			
Vision	53.3	<.01	.50
Focus	0.6	.46	.01
Vision by Focus	0.1	.72	<.01
Velocity			
Vision	39.3	<.01	.42
Focus	<0.1	.87	<0.1
Vision by Focus	1.7	.20	.03

MPF			
Vision	0.1	.32	.02
Focus	<0.1	.84	<.01
Vision by Focus	1.6	.22	.03

Note. RMS = Root mean square error; Ellipse = 95% confidence interval center of pressure area ellipse; Std = standard deviation of resultant distance; Velocity = velocity of resultant distance; MPF = mean power frequency; η_p^2 = partial eta squared.

APPENDIX B
FIGURES

Figure B1

Standard Deviation of Resultant Distance

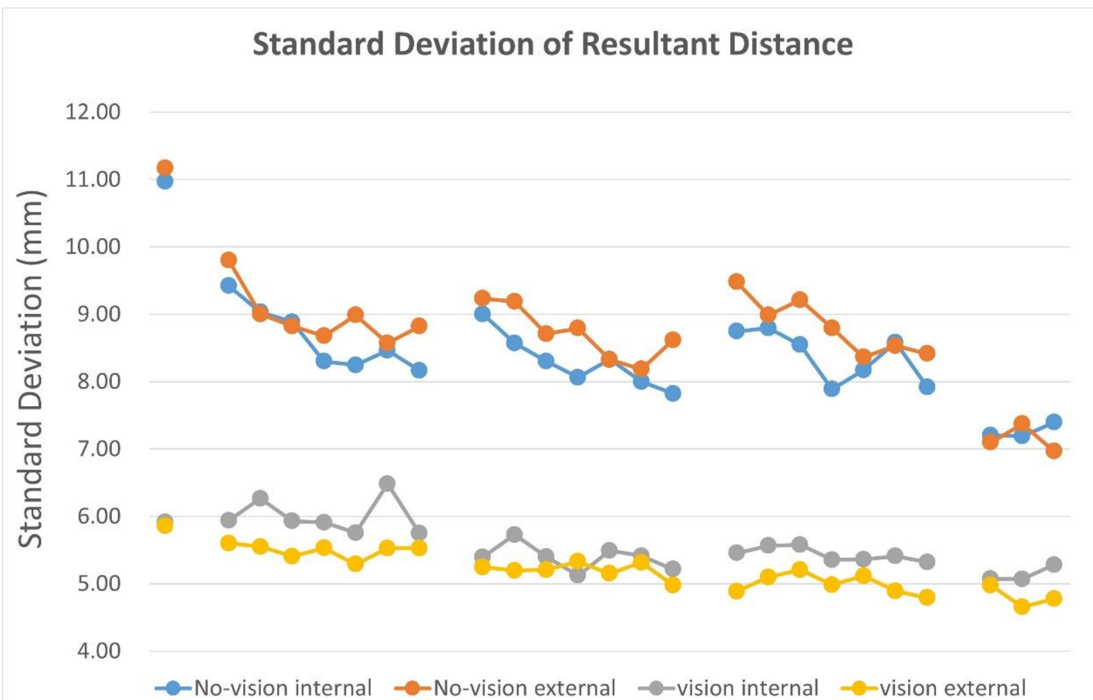

Figure B2

Velocity of Resultant Distance

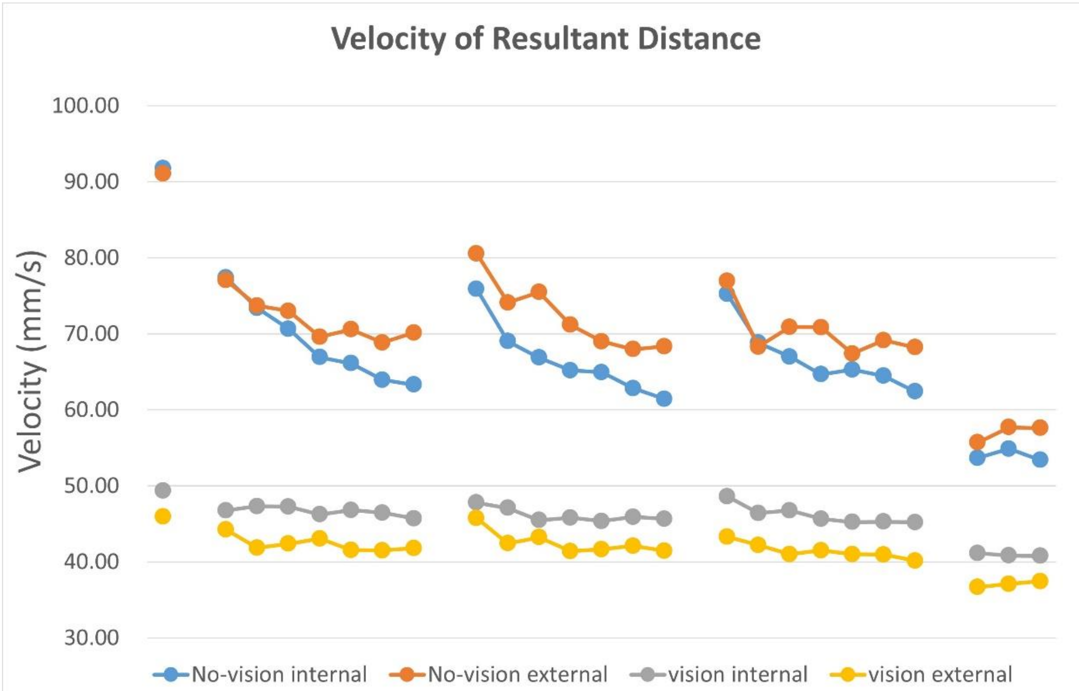

Figure B3

Center of pressure 95% confidence interval ellipse area

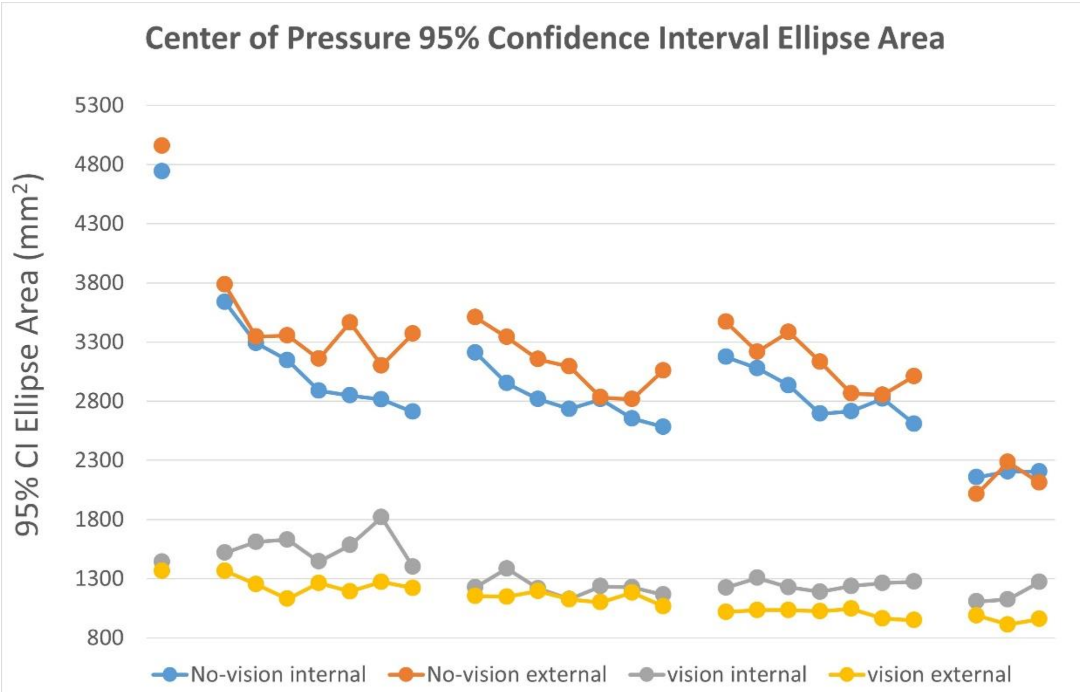

Figure B4

Mean power frequency