Effects of attentional focus on kinematics and muscle activation patterns as a function of expertise

Tiffany L. Zachry
University of Nevada, Las Vegas

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EFFECTS OF ATTENTIONAL FOCUS ON KINEMATICS AND MUSCLE ACTIVATION PATTERNS AS A FUNCTION OF EXPERTISE

by

Tiffany L. Zachry

Bachelor of Arts
Texas Tech University
1999

A thesis submitted in partial fulfillment of the requirements for the

Master of Science Degree in Kinesiology
Division of Health Sciences
Department of Kinesiology
School of Allied Health and Human Performance

Graduate College
University of Nevada, Las Vegas
August 2005

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Thesis Approval
The Graduate College
University of Nevada, Las Vegas

July 13, 2005

The Thesis prepared by

Tiffany L. Zachry

Entitled

Effects of Attentional Focus on Kinematics and Muscle Activation Patterns as a Function of Expertise

is approved in partial fulfillment of the requirements for the degree of

Master of Science in Kinesiology

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Graduate College Faculty Representative
ABSTRACT

Effects of Attentional Focus on Kinematics and Muscle Activation Patterns as a Function of Expertise

by

Tiffany L. Zachry

Dr. Gabriele Wulf, Examination Committee Chair
Professor of Kinesiology
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It has been demonstrated that for motor tasks, an external focus of attention can yield better results than an internal focus of attention. To be more specific, focusing on the effect of the movements seems to be more beneficial to performance and learning than focusing on the movements themselves (for a review, see Wulf & Prinz, 2001). To explain this phenomenon, Wulf, McNevin, and Shea (2001) proposed that an internal focus of attention is less effective because concentrating on the movements interferes with the motor system’s attempt to naturally self-organize, the “constrained-action hypothesis.” The purpose of this study was to find neurophysiological and/or mechanical evidence of this hypothesis using expert and novice American football field goal kickers (place kickers). Four experts and 12 novices (never kicked before) participated; they kicked seven kicks under control (no focus instructions), internal (focus on the part of the foot that would contact the ball), and external (focus on the part of the ball that would be contacted) focus conditions. The kick was divided into three phases: flight (foot-off of kicking leg to heel contact of stance leg), swing (heel contact of stance leg to ball contact of the ball), and follow-through. The study found that the external focus condition resulted in faster and more accurate kicks compared to the internal and control conditions.
contact), and follow-through (ball contact to max hip flexion). Accuracy, hip and knee
kinematic data (flexion/extension and total range of motion), and agonist/antagonist co­
contraction indices (CCI) of the kicking leg (thigh: rectus femoris and biceps femoris,
shank: medial gastrocnemius, tibialis anterior) were recorded. A Chi-Square analysis of
accuracy results showed no difference in the experts, but significantly better performance
in the external condition relative to the other two. ANOVAs revealed no differences
between groups or focus condition in kinematic data, and no differences in experts and
novices in CCI of the thigh. Experts also showed no differences in CCI of the shank;
however, the novices showed significantly higher average CCI during the swing phase of
the kick while using an external focus of attention compared to an internal focus. This
implies the use of a more rigid (stable) ankle joint (Enoka, 1983), which in the case of
striking tasks is presumably desirable for maximum transference of kinetic energy from
the leg segment to the ball. This supports the idea that an external focus of attention
induces a more automatic control of the motor system relative to an internal focus.
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Beyond that, I would like to thank my parents and brothers, who despite our differences, have remained my family and answered my call at the times when only a family would do. Thanks also to Kathleen Zanetti who encouraged me to escape the hell of corporate training and get back into academia where I belong. My most sincere and heartfelt thanks go to those people who have been true friends to me—I hope that I have been generous enough with my gratitude that you all know who you are.
CHAPTER 1

INTRODUCTION

It has been demonstrated in several studies that for motor tasks, an external focus of attention can yield better results than an internal focus of attention. To be more specific, focusing on the effect of the movements seems to be more beneficial to performance and learning than focusing on the movements themselves (e.g., McNevin & Wulf, 2002; Shea & Wulf, 1999; Wulf, Lauterbach, & Toole, 1999; Wulf, McConnel, Gärtnner, & Schwarz, 2002; Wulf & McNevin, 2003; Wulf, McNevin, Fuchs, Ritter, & Toole, 2000; for a review, see Wulf & Prinz, 2001). This concept may seem counterintuitive to many of us because so often in the acquisition of a new skill we are told specifically to concentrate on our form, or the mechanics of the task, with instructions that direct our attention internally. However, the growing body of attentional focus research seems to indicate that this technique may be counterproductive. For example, Wulf and colleagues (Wulf, Höß, & Prinz, 1998, Experiment 1) observed that for a ski simulation task using novice performers, instructions to adopt an external focus of attention were more beneficial in acquisition and retention than both internal focus instructions and a control condition (no instructions). More than that, the internal focus instructions actually degraded performances (compared to control condition) in the acquisition stage and offered no difference from the control condition in retention. Similar results have been seen in
activities like golf pitch shots (Wulf et al., 1999), balance on a stabilometer (e.g., Wulf & McNevin, 2003; Wulf, Weigelt, Poulter, & McNevin, 2003), and lofted soccer kicks (Wulf et al., 2002, Experiment 2). Another study (Wulf et al., 2002, Experiment 1) showed benefits of external focus feedback in both practice and retention, regardless of level of expertise. For “tennis” type volleyball serves, both novices and experts were more accurate when given feedback directed externally (e.g., “...shift your weight toward the target.” p. 174) rather than internally (e.g., “...shift your weight from the back leg to the front leg.” p. 174). So it seems that adopting an external focus of attention enhances both learning and performance relative to internal focus and no focus strategies for a variety of activities.

To explain this phenomenon, Wulf and colleagues proposed the constrained-action hypothesis, which postulates that an internal focus of attention is less effective in learning and/or performing a motor task because concentrating on the movements interferes with the motor system’s attempt to naturally self-organize (McNevin, Shea, & Wulf, 2003; Wulf, McNevin, & Shea, 2001). Support for this hypothesis was found when it was demonstrated that probe reaction times (RTs) were faster while balancing concurrently on a stabilometer using an external focus strategy relative to an internal one (Wulf et al., 2001). This showed that the external focus condition required less attention from the performers, indicating a more automatic control of the movement. If it is true that focusing on our actions hinders the unconscious processes being used to perform them, then there should be some physiological evidence of both the automatic processes and their disruption if one exists. In other words, what is different about the body’s
physiological responses to the mind’s focus of attention for internal versus external conditions?

A recent study (Vance, Wulf, McNevin, & Mercer, 2004) looked at the electromyographic activity of the muscles during bicep curls. They observed that with an external focus (the bar), EMG activity was significantly less than that while using an internal focus (the arms). This may imply that an external focus of attention is not only more effective for performance, but that it may induce a greater economy of movement as well. This conclusion has been further supported in a recent study examining basketball free throws (Zachry, Wulf, Mercer, & Bezodis, in press). Less overall EMG activity was found in a free throw under an external focus condition (focus on the rim) relative to an internal focus condition (focus on the wrist movement of the follow-through) in both the biceps brachii and triceps brachii muscles. This was the first study to examine EMG activity in a task with a clear goal for accuracy (i.e., making the shot) and measurable degrees of success (i.e., how close the shot came to going in).

However, there is currently no research examining how the patterns of muscle activation may change in response to attentional focus conditions. For example, it is possible that co-contractions between agonists and antagonists occur to a greater extent under internal relative to external focus conditions (see Vance et al., 2004). It is common, especially in novice performers, to co-contract opposing muscle groups in order to reduce their susceptibility to perturbations in unfamiliar situations. However, this technique is thought to restrict the joint and reduce degrees of freedom, creating an inefficient and erratic pattern unlike patterns seen in expert performers (Falconer & Winter, 1985; Gentile, 1998). This was shown in an experiment testing experts and
novices during cycling (Chapman, Vicenzino, Blanch, & Hodges, 2004). In addition to more numerous instances of co-contraction, they also observed in novices greater relative EMG amplitudes between primary EMG bursts, indicating that they were not modulating the activity of their muscles to the degree that experts were able to do so.

Conversely, it has also been proposed that some situations warrant a greater degree of co-contraction for improved performance. For instance, highly skilled weight lifters were shown to maintain a high level of muscle coactivation compared to novices (Enoka, 1983), which is considered by many to be an effective method of stabilizing the knee joint (for a review, see Kellis, 1998). Hasan (1986) investigated the significance of joint stiffness on the reduction of effort in the control of movement. A theoretical measure of effort was formulated; it predicted that joint stiffness could be advantageous, and that the increased coactivation, which yields greater joint stiffness, is not necessarily wasteful because it optimizes this joint stiffness. For a striking task, such as an overhand volleyball serve, a forehand in tennis, or in this case, a football place kick, a more restricted, or stiff, joint might be desirable for stability and maximum transference of kinetic energy.

Recent studies have also examined the effects of attentional focus on expert performance. A bit of a controversy exists here, as one study (Wulf, Landers, Mercer, Töllner, & Guadagnoli, 2004) involving world-class elite balance performers from Cirque du Soleil indicated that both internal and external focus conditions were detrimental to performance relative to a control condition in which they were not given specific focus instructions. However, another study (Wulf & Su, 2005) showed performance benefits in elite collegiate golfers similar to those seen in studies involving
novice performers. Therefore, an additional purpose of this study was to shed further light on the effects of attentional focus instructions in expert performers.

On a broader scale, the purpose of this study was to expand on the neurophysiological results seen in previous studies (e.g., Vance et al., 2004; Zachry et al., in press) and to try to achieve a better understanding of the inner mechanisms responsible for the benefits typically seen when adopting an external focus of attention. In contrast to prior research, this is the first study to examine neurophysiological and kinematic factors, not just as a function of focus of attention, but also as a function of expertise. Such an examination could provide a more meaningful analysis of novice performance because it could be contrasted with a so-called “gold standard” (the expert performers).

The task chosen for this study was soccer-style American football place kicking (field goal kicking), and it was selected specifically for its level of difficulty for novice performers. It examined both professional and collegiate kickers (experts) and inexperienced performers who had never before attempted this type of kick (novices). Kinematics, electromyographic activity of the muscles, and accuracy were analyzed for internal and external focus conditions and for a control condition. It was expected that an external focus of attention would result in performance benefits (accuracy scores) similar to those seen in previous studies, and that an external focus might also result in a movement pattern, as exhibited by kinematics and muscle coactivation (or co-contraction) levels, in novices that more closely resembled that of experts relative to an internal focus of attention or a control condition.
CHAPTER 2

METHODS

Participants

Sixteen male volunteers (4 experts, 12 novices) were recruited to participate in the study. Participant ages ranged from 18 to 39 years. Participants with no previous football kicking experience (novices) were recruited from the UNLV student population. Expert soccer-style field goal kickers were recruited from the UNLV football team, the local Arena Football League team (the Las Vegas Gladiators), and the local community. To be considered an expert, the volunteer must have kicked on a high school varsity squad, a college or university squad, or at a professional level within the last two years. Participants were physically active at the time of testing, and were free from any injury or condition that would interfere with his ability to kick a football. Informed consent was obtained from all participants, and they were not aware of the specific purpose of the study.

Apparatus and task

Kinematic data were recorded with Vicon™ Motion Analysis system software (v. 4.6, Oxford Metrics, Oxford, UK). Electromyographic (EMG) data were recorded using Noraxon™ MyoResearch 2 software (v. 2.02, Noraxon USA, Scottsdale, AZ). Kinematic data (3-dimensional position) were collected at 120 Hz, while and EMG data were
collected at 1000 Hz. Kinematic data were captured with a 12-camera Vicon™ Motion Analysis system. The 3-dimensional reference frame was established as Z in the vertical direction and X and Y horizontal. EMG data were captured using a Noraxon™ Telemyo unit (Noraxon USA, Scottsdale, AZ). The motion capture and EMG systems were calibrated as per the manufacturers’ instructions, and the two systems were synchronized using a low-voltage square wave.

Participants were fitted with Blue Sensor™ juvenile Ag/AgCl EMG electrodes (Ambu Inc., Glen Burnie, MD, model N-00-S). EMG electrodes were placed on the surface of the skin in pairs directly over the rectus femoris (RF), biceps femoris (BF), tibialis anterior (TA), and medial gastrocnemius (MG) of each participant’s kicking leg (as per Delagi & Perotto, 1981; see Figure 1). Distance between electrodes in each pair was 2 cm. A ninth electrode was mounted to the acromion process to serve as an “electrical common” for data recording. Athletic pre-wrap and strips of athletic tape were used to secure the electrodes and minimize extraneous movement while not impeding muscular function or movement about the knee joint. Participants also wore 25-mm diameter Vicon™ Motion Systems reflective markers positioned at the anterior superior iliac spines (ASIS), posterior superior iliac spines (PSIS), lateral femoral and tibial shanks, knee joint center approximations, and lateral malleoli of both legs. This marker configuration was taken from the lower body portion of Vicon’s Plug-in Gait model. The model was used to extract flexion/extension data.
Procedure

One static trial was recorded in accordance with the procedure for using the Plug-in Gait model. Participants were then given instructions and a demonstration by the experimenter of a soccer-style American football place kick (field goal kick) adapted from Gogolak's *Kicking the Football Soccer Style* (1972) and Taylor and Nunez-Bentz (1992; see Appendix 3). They were allowed to practice one kick at a self-selected level of effort and testing did not begin until they verbally indicated that they were comfortable with the equipment and technique. Participants performed football field goal style kicks into a full length net (floor-to-ceiling and about 4 m across). A 2.1 by 2 meter square was marked in the center of the net to measure accuracy. In the center of the square was a 10 cm by 10 cm yellow square; the goal for each trial was to kick the ball as close to the yellow square as possible (see Figure 2). A digital video recorder (Sony HandyCam®,
Model DCR HC30, 30 Hz) was set up perpendicular to the center circle in order to record where the ball struck the grid. A coordinate (x, y) was identified for each trial by playing the video and overlaying a grid on which the point of contact was marked. The 2.1 by 2 meter square when viewed on the screen resulted in a 9 x 8 cm grid that was divided into increments of 0.5 cm. The target was not of regulation distance or height in order offset any strength advantages held by the expert kickers. Rather, the distance was set at 4.9 meters and the height at 1.9 meters. Participants kicked 7 field goals (for a total of 21) under each of the following 3 conditions (see also Appendix 3):

1. Control – no focus instructions given

2. Internal focus – instructed to focus on the part of the foot that strikes the ball

3. External focus – instructed to focus on the part of the ball that would be struck

Figure 2. Illustration of target setup.
Order of conditions was counterbalanced between subjects. Each set of kicks was performed at the participant’s personally selected pace. A rest period of at least one minute, unless additional time was requested, was included between each kick, and a successive set did not start until the participant was rested and reported verbally that he was ready to proceed.

Dependent measures and statistical analysis

This study examined the following dependent variables: muscle activation patterns of the rectus femoris, biceps femoris, medial gastrocnemius, and tibialis anterior muscles to determine co-contraction levels at the thigh and shank, maximum flexion/extension of the hip and knee joints, total range of motion (ROM) at the hip and knee joints, ankle velocity at ball contact, and accuracy scores of the kicks. For flexion/extension data, degree zero was considered to be anatomical position. Three-dimensional position data were used to divide the kicks into three phases and extract EMG data for analysis. A search of pertinent literature did not reveal any previous studies defining the phases of an American football place kick, therefore the phases of each kick for this study were identified and operationally defined as follows: the flight phase (toe off of the kicking leg to heel contact of the stance leg), the swing phase (heel contact of the stance leg to ball contact), and the follow-through (ball contact to maximum hip flexion). Ball contact, for the purposes of this experiment, was identified by placing a 1-inch square piece of reflective tape near the top of the ball; contact was defined as the first frame of data in which that marker’s horizontal position deviated from the static horizontal position before the kick. Because occurrences of peak hip and knee flexion and

* It should be noted that there is a dearth of literature concerning American football kicking, and very little has been done to define kinetic, kinematic, or electromyographic patterns of this skill. However, the present study concentrated only on the attention focus effects, and therefore the resultant definitions of kicking phases, etc. may not be appropriate for a biomechanical analysis of the American place kick.

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extension were temporally consistent across subjects (i.e., peak hip flexion always occurred in the follow-through, peak knee flexion always occurred in the swing phase, etc.), kinematic data were analyzed for the total period between the beginning of the flight phase and the end of the follow-through. However, EMG data did not appear to be temporally consistent across subjects, and were therefore analyzed per each phase (flight, swing, and follow-through).

For all conditions, EMG data were used to identify incidents of co-contraction of antagonist groups (i.e. RF v. BF and TA v. MG) using a co-contraction index. For all extracted data sets, EMG data were removed of DC bias and full-wave rectified. They were also smoothed using a low-pass 4th order Butterworth filter (cutoff frequency = 7 Hz) to bring to prominence the on/off patterns over the time-course of each data set. The smoothed data for each muscle were normalized to the peak amplitude of that muscle for that trial. The normalized EMG amplitudes of the RF and BF and MG and TA respectively were used to calculate two co-contraction indices (CCIs) for each trial. The method for determining CCI was an amalgamation of that established by Bowsher, Damiano, and Vaughan (1992) and modified by Kellis, Arabatzi, and Papadopoulos (2003). The following equations were applied:

\[ X_i = 1 - |EMG_{BF,TA} - EMG_{RF,MG}| \]

and

\[ CCI_{thigh,shank} = 0.5(X_i + EMG_{ant}(X_i)) \]

where:

\[ EMG_{BF,TA} = \text{normalized amplitude of either BF for } CCI_{thigh} \text{ or TA for } CCI_{shank} \]

\[ EMG_{RF,MG} = \text{normalized amplitude of either RF for } CCI_{thigh} \text{ or MG for } CCI_{shank} \]
EMG_{ant} = magnitude of the lowest of the two muscles (RF and BF or MG and TA) at any moment "t" in time

CCI_{thigh} = co-contraction index of the RF and BF muscles

CCI_{shank} = co-contraction index of the MG and TA muscles

For this method of calculating a co-contraction index, a CCI of 1 indicates a maximum level of co-contraction and 0 is the minimum. This method is unique in that it generates a CCI for every point in time of the data set and in that it allows the designation of the antagonist muscle to change over the course of the movement. The resultant data sets of CCI_{thigh} and CCI_{shank} were averaged for the course of each phase of the kick (see Figure 3).
Figure 3. Example Co-Contraction Index (CCI) and normalized EMG data of the shank and thigh for a novice kicker. CCI was averaged for flight, swing, and follow-through phases.
Three-dimensional position data were processed using the Plug-in Gait model (formerly Vicon Clinical Manager) to identify angles of flexion/extension about the hip and knee joints. In order to run this model, the raw position data were first applied with the Woltring quintic spline filter written into the Plug-in Gait model (predicted MSE value = 15, as recommended by the manufacturer for the type of activity and camera configuration). Then the required anthropometric information (leg length, knee width, ankle width, and mass) for each subject was entered into the software so that the static model could be run on the static trial that was recorded. The static model stores subject measurements for use with the dynamic model, which was run subsequently on the kicking trials. The dynamic model generates "virtual" hip, knee, and ankle joint center trajectories, and then calculates kinematic and kinetic quantities such as angles and moments. More information on this modeling technique can be obtained directly from Oxford Metrics (www.vicon.com).

For this study, the Plug-in Gait data were used to identify maximum flexion and extension and total range of motion of the hip and knee for the kick, and compared between focus conditions and between novices and experts. Ankle angle data were not recorded because the required markers would have interfered with the kicking task. However, the velocity of the ankle marker was used to estimate foot speed at the time of ball contact, as this has been shown to be a reasonable estimate of ball velocity, and by virtue thereof, success of the kick (e.g., Dörge, Andersen, Sørensen, & Simonsen, 2002).

Finally, the coordinates assigned to the trials as the location where the ball struck the net were analyzed for accuracy by calculating the distance of each of coordinate \((x, y)\) from the origin \((0, 0)\) as outlined by Hancock, Butler, and Fischman (1995). The
intention was to analyze the distance scores using a standard repeated measures ANOVA. However, an unusual and unexpected phenomenon emerged, especially given the size of the square surrounding the yellow target (about 2 m square) and the distance to the target (a little less than 5 m)—there were several trials in which participants were not even able to get the ball into the square so that a coordinate could be assigned. Therefore, the data sets were uneven, and an ANOVA was not possible, so a Chi-Square Test of Association was run instead. In addition, one expert participant’s accuracy data recordings were lost due to a technical issue; therefore only 3 expert participants were analyzed for accuracy.

The dependent measures of maximum hip flexion, minimum hip flexion (max extension), maximum knee flexion, minimum knee flexion (max extension), total hip ROM, total knee ROM, and ankle velocity at ball contact were analyzed in 2 (Level of expertise: Novices, experts) x 3 (Attentional focus: External, internal, control) x 7 (Trials) analyses of variance with repeated measures on the last two factors. The average CCI of the thigh (RF v. BF) and shank (MG v. TA) were analyzed in a 2 (Level of expertise: Novices, experts) x 3 (Phase: Flight, swing, follow-through) x 3 (Attentional focus: External, internal, control) x 7 (Trials) analyses of variance with repeated measures on the last two factors. As a measure of accuracy, the number of makes to misses (i.e., the number of kicks that made it into the accuracy grid as opposed to those that did not) was analyzed using a double-summation chi-square analysis where:

$$X^2 = \sum_{\text{EXPERT}} \sum_{\text{NOVICE}} \left( \frac{\text{Observed} - \text{Expected}}{\text{Expected}} \right)^2$$
CHAPTER 3

RESULTS

Accuracy

The percentage of made kicks per group and condition is illustrated in Figure 4. The Chi-Square Test of Association revealed that attentional focus and expertise were not independent, $X^2 (2, 252) = 22.881, p < .05$ (see Table 1). The novice group performed significantly better while using an external focus of attention relative to an internal focus and the control (no focus) condition.

![Figure 4](image)

Figure 4. Illustrative representation of percent of kicks made by experts and novices for each focus condition (control, internal focus, and external focus).
Table 1. Chi-Square Test of Association results. Observed values represent “makes,” while expected values represent the number of possible “makes” per condition.

<table>
<thead>
<tr>
<th></th>
<th>ObsCTRL</th>
<th>ObsINT</th>
<th>ObsEXT</th>
<th>Expected</th>
<th>$X^2_{CTRL}$</th>
<th>$X^2_{INT}$</th>
<th>$X^2_{EXT}$</th>
<th>$\chi^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experts</td>
<td>19</td>
<td>16</td>
<td>20</td>
<td>21</td>
<td>0.190</td>
<td>1.190</td>
<td>0.048</td>
<td>1.429</td>
</tr>
<tr>
<td>df = 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$X^2_{CRITICAL}$ = 5.991</td>
<td>22.881</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Kinematics

**Maximum hip flexion.** The main effect of attentional focus was not significant, $F(2, 28) = .52, p > .05$ (see Table 2). The main effect of trial was significant, $F(6, 84) = 4.07, p < .05$. This is most likely due to the stretching effect of repeating the kicks over time. The main effect of group was not significant, $F(1, 14) = 2.39, p > .05$. No interaction effects were significant.

**Minimum hip flexion (max extension).** The main effects of focus, trial, and group were not significant, $F(2, 28) = .11, p > .05$, $F(6, 84) = .22, p > .05$, and $F(1, 14) = 1.90, p > .05$ respectively (see Table 2). There were also no significant interaction effects.

**Maximum knee flexion.** The main effects of focus, trial, and group were again not significant, $F(2, 28) = 1.77, p > .05$, $F(6, 84) = .85, p > .05$, and $F(1, 14) = .05, p > .05$ respectively (see Table 2). There were no significant interaction effects.

**Minimum knee flexion (max extension).** The main effects of focus, trial, and group did not reach significance, $F(2, 28) = 1.48, p > .05$, $F(6, 84) = 1.38, p > .05$, and $F(1, 14) = 1.14, p > .05$ respectively (see Table 2). No interaction effects were significant.

**Total hip ROM.** Experts and novices tended to show the greatest hip and knee ROMs in the external focus condition. However, only the main effect of trial reached
significance, \( F(6, 84) = 2.76, p < .05 \), again most likely due to the stretching affect of kicking repeatedly. The main effects of focus and group were not significant, \( F(2, 28) = 1.21, p > .05 \) and \( F(1, 14) = .50, p > .05 \) (see Table 2). There were no interaction effects.

**Total knee ROM.** The main effects of focus, trial, and group did not reach significance, \( F(2, 28) = 1.59, p > .05, F(6, 84) = .47, p > .05, \) and \( F(1, 14) = .12, p > .05 \) respectively (see Table 2). None of the interaction effects were significant.

**Ankle velocity at ball contact.** Even though novices tended to achieve higher ankle velocities in the external focus condition, followed by the control and then the internal focus condition, the main effects of focus, trial, and group were not significant, \( F(2, 28) = .70, p > .05, F(6, 84) = 1.63, p > .05, \) and \( F(1, 14) = 2.93, p > .05 \) respectively (see Table 2). No interaction effects were significant.

**Table 2. Mean values of kinematic data (standard deviation in parentheses).**

<table>
<thead>
<tr>
<th></th>
<th>Experts</th>
<th></th>
<th>Novices</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Internal</td>
<td>External</td>
<td>Control</td>
</tr>
<tr>
<td>Max Hip Flex (deg)</td>
<td>97.60 (21.25)</td>
<td>100.20 (17.86)</td>
<td>100.15</td>
<td>96.03 (12.27)</td>
</tr>
<tr>
<td>Min Hip Flex (deg)</td>
<td>-7.49 (11.56)</td>
<td>-8.58 (10.82)</td>
<td>-9.08 (10.76)</td>
<td>-14.96 (6.68)</td>
</tr>
<tr>
<td>Max Knee Flex (deg)</td>
<td>100.06 (14.91)</td>
<td>99.84 (14.28)</td>
<td>101.78</td>
<td>98.26 (8.61)</td>
</tr>
<tr>
<td>Min Knee Flex (deg)</td>
<td>5.22 (10.23)</td>
<td>2.59 (9.28)</td>
<td>3.85 (9.71)</td>
<td>-0.15 (5.91)</td>
</tr>
<tr>
<td>Hip ROM (deg)</td>
<td>105.08 (23.09)</td>
<td>108.78 (20.31)</td>
<td>109.23</td>
<td>100.98 (13.33)</td>
</tr>
<tr>
<td>Knee ROM (deg)</td>
<td>94.84 (23.33)</td>
<td>97.25 (20.95)</td>
<td>97.93 (19.71)</td>
<td>98.40 (13.47)</td>
</tr>
<tr>
<td>Ankle Velocity (m/s)</td>
<td>13.35 (1.67)</td>
<td>13.80 (1.89)</td>
<td>13.71 (1.74)</td>
<td>12.36 (0.97)</td>
</tr>
</tbody>
</table>

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EMG co-contraction indices

**Average thigh CCI.** The CCIs were averaged for each phase of the kick (see Methods). In both groups across all phases except the novice flight phase, average thigh CCI tended to be lowest while using an external focus of attention. Nonetheless, the main effects of phase, focus, trial, and group were not significant, \( F(2, 28) = .81, p > .05, F(2, 28) = 2.78, p > .05, F(6, 84) = .92, p > .05, \) and \( F(1, 14) = .10, p > .05 \) respectively (see Table 3).

**Average Shank CCI.** The main effect of phase was significant, \( F(2, 28) = 9.34, p < .05. \) The swing phase showed the highest level of CCI (mean = .475) and was significantly greater than average CCI in the follow-through (mean = .389). It was also higher than average CCI in the flight phase (mean = .439), though not significantly so. The main effect of focus across both groups and all phases was also significant, \( F(2, 28) = 6.41, p < .05, \) where both internal and external focus conditions were greater than the control condition (means = .445, .452, and .406, respectively). The main effects of trials and group were not significant, \( F(6, 84) = 1.50, p > .05 \) and \( F(1, 14) = .0001, p > .05 \) respectively (see Table 3). There was one significant interaction, that of focus and group, \( F(2, 28) = 3.44, p < .05. \)

The finding that CCI was always highest in the swing phase, regardless of focus condition or level of expertise, confirmed the thought that a rigid ankle joint would be most desirable in that phase, relative to the other two, as preparation was made for ball contact. Also, because the interaction of focus and group was significant, it was confirmed that experts and novices were reacting differently to the attentional focus conditions. For these reasons, separate 3 (focus: control, internal, external) x 7 (trials)
ANOVAs were run for each group’s swing phase data. In the expert group, there were no significant main effects of focus or trials, $F(2, 6) = 1.60, p > .05$ and $F(6, 18) = .76, p > .05$, respectively (see Figure 5). There was also no interaction of focus and trials. The novices, on the other hand, did show a significant main effect of focus, $F(2, 22) = 3.63, p < .05$ (see Figure 6). An LSD comparison of main effects revealed that the external focus condition had significantly higher average CCI than the internal focus condition ($p = .02$). The external condition CCI was also very close to being significantly higher than the control condition ($p = .07$). The internal and control conditions were not significantly different from one another ($p = .62$). The main effect of trial was not significant, $F(6, 66) = .87, p > .05$, and the interaction of focus and trials was not significant.

Table 3. Mean values of thigh and shank EMG CCI data (standard deviation in parentheses).

<table>
<thead>
<tr>
<th>Thigh CCI</th>
<th>Flight</th>
<th>Swing</th>
<th>Follow-through</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Internal</td>
<td>External</td>
</tr>
<tr>
<td>Experts</td>
<td>.375</td>
<td>.352</td>
<td>.348</td>
</tr>
<tr>
<td></td>
<td>(.090)</td>
<td>(.111)</td>
<td>(.096)</td>
</tr>
<tr>
<td></td>
<td>(.053)</td>
<td>(.063)</td>
<td>(.056)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Shank CCI</th>
<th>Flight</th>
<th>Swing</th>
<th>Follow-through</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Control</td>
<td>Internal</td>
<td>External</td>
</tr>
<tr>
<td>Experts</td>
<td>.423</td>
<td>.449</td>
<td>.420</td>
</tr>
<tr>
<td></td>
<td>(.067)</td>
<td>(.071)</td>
<td>(.067)</td>
</tr>
<tr>
<td>Novices</td>
<td>.426</td>
<td>.454</td>
<td>.462</td>
</tr>
<tr>
<td></td>
<td>(.040)</td>
<td>(.042)</td>
<td>(.040)</td>
</tr>
</tbody>
</table>
Figure 5. Mean Co-Contraction Indices of the shank (medial gastrocnemius and tibialis anterior) during the swing phase with standard error bars (Experts).

Figure 6. Mean Co-Contraction Indices of the shank (medial gastrocnemius and tibialis anterior) during the swing phase with standard error bars (Novices).
CHAPTER 4

DISCUSSION

Adopting an external focus of attention (i.e., focusing on the effect or outcome of a movement) has generally been shown to be beneficial to acquisition and performance of motor skills, and the present study supported those findings. Although no focus advantages were shown for the expert group, which is consistent with the findings of Wulf and colleagues (2004), a benefit was seen in the external focus condition for the novice group as in many previous studies (for a review, see Wulf & Prinz, 2001). American football place kicking can now be added to the growing list of motor skills in which adopting an external focus of attention is more effective for acquiring a skill compared to an internal focus or no focus instructions.

The purpose of this study, however, was to investigate the explanations for these effects at the mechanical and neurophysiological levels. Wulf and colleagues (2001) proposed the “constrained action hypothesis,” postulating that focusing on the movement effect is more beneficial because, as opposed to focusing on the movement itself (internal focus), it does not interfere with the body’s own attempts at self-organization and proceduralization. The only studies so far which have provided any physiological evidence of this effect came from Vance and colleagues (2004) and Zachry and colleagues (in press). Both studies showed reduced EMG activity as the result of an

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external focus of attention, which the authors interpreted as signs of a more economical
movement pattern and more effective coordination between agonist and antagonist
muscle groups. The internal focus conditions in these studies, on the other hand, seemed
to lead to a constriction of the motor system, or a “freezing” of the degrees of freedom.

Numerous researchers have discussed the possible reasons for this so-called
“freezing” of the system. It is often seen as an indication of novice performance,
presumably because it yields inefficient movement (Falconer & Winter, 1985; Winter,
1990). Conversely, others have interpreted instances of co-activation as a gauge of
performance expertise. For example, when biceps femoris was acting as an antagonist to
vastus lateralis, skilled weight lifters increased the duration of antagonist muscle activity
as load was increased, while novices did not (Enoka, 1983). In fact, coactivation of the
quadriceps and hamstrings is considered to be largely important in stabilizing the knee
joint, especially in athletic activities (Kellis, 1998). It has even been asserted that in
some cases, muscle coactivation is not inefficient at all, and actually optimizes joint
stiffness. Joint stiffness, in these cases, not only minimizes perturbations, but also
reduces deviations in movement trajectory, consequently reducing the effort required for
the given activity (Hasan, 1986).

The present findings indicate that novices achieved a greater level of joint stiffness
about the ankle when using an external focus of attention (the ball) relative to internal
(the foot) and control (no focus instructions) condition specifically in the swing phase of
the kick, which begins with the plant of the stance leg and concludes with ball contact. It
makes sense that co-contraction in the shank would be most desirable in the swing phase
because the ankle needs to remain in plantar flexion during this phase as it prepares for
the collision with the ball (see Appendix 3). This notion is supported by the fact that across all groups and conditions, average CCI was highest in that phase. It seems logical that increased ankle joint stiffness would allow the kicker to strike the ball with a more rigid, inelastic implement, in this case, the lower limb segment; this would facilitate clean contact with the ball and maximize the amount of kinetic energy transferred from the limb to the ball. Conversely, striking the ball with an elastic segment would dampen the force by absorbing, or attenuating, the force of the kick. This would presumably result in kicks that do not follow the desired trajectory, most likely too low and/or to one side or the other. The results reveal that accuracy was indeed affected by the rigidity of the ankle joint; the focus condition which resulted in the greatest joint stiffness (external focus) also yielded the fewest number of misses in the novice performers. In addition, visual inspection of the accuracy videos confirmed that the novices missed primarily to the side or the bottom of the grid, whereas the experts missed high most commonly, probably as a function of their training to clear the offensive line.

This conclusion should not be interpreted to mean that these results conflict with the claims of previous studies. For a striking (kicking) activity, a stiff joint would be seen as beneficial. This does not hold true for activities like a basketball free throw (Zachry et al., in press), where a greater degree of finesse, or “soft touch,” is required to make the shot. For an activity like biceps curls (Vance et al., 2004), increased stiffness at the wrist joint might be beneficial in stabilizing the bar, but the researchers did not investigate the wrist joint. Increased stiffness at the elbow joint would presumably malign the biceps curl movement, and the results of that study indicated that the participants were using a more elastic elbow joint under an external relative to an internal focus of attention.
Along those same lines, it is possible that no significant differences in CCI were seen for
the thigh in this study because elasticity of the knee joint is desirable for achieving a
sufficient range of motion and rapid extension of the knee to kick the ball.

These findings provide support for the idea that adopting an external focus of
attention aids the motor system in its attempt at self-organization and proceduralization
(Wulf et al., 2001). When concentrating on the ball (external focus), novice participants
struck the ball with a more rigid segment, which led to truer flight trajectories relative to
both control and internal focus conditions. There were no significant differences in ankle
velocity at ball contact, which has been shown to be a reasonable estimate of ball velocity
(Dörge et al., 2002), and consequently, an estimate of the amount of kinetic energy
transferred from the leg to the ball. This might not be surprising given the relatively
short distance of the kick and the emphasis on accuracy rather than power as a measure of
success of the kick.

The effects of attentional focus on expert performance remain somewhat unclear
upon completion of this study. The expert group's accuracy did not differ significantly
across focus conditions, nor did their CCI levels. Additionally, CCIs between experts
and novices were not significantly different. However, due to the unavoidably small
sample of expert kickers available for the study, it is difficult to draw meaningful
conclusions from the expert findings. It would be interesting to further investigate the
effects of attention focus on a large pool of highly skilled kickers.

Also, no significant differences were seen in the kinematic evaluations of peak
flexion/extension or range of motion (ROM) of the hip and knee joints across focus
conditions or as a function of expertise. Nevertheless, the values observed for the knee

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were consistent with those reported by Snowden (1997). No values for ROM at the hip have been reported for American football place kicking, but the present study saw results similar, though not identical, to those observed for rugby drop kicking (Orchard, McIntosh, Landeo, Savage, & Beatty, 2003). The two kicking styles are fairly different, though, so this observation is not unexpected. The similarities between rugby and football kicking were mostly temporal and related to the timing of flexion and extension of the hip and knee joints. In this respect, virtually all kinds of kicking activities are similar.

The beneficial result of adopting an external focus of attention, or focusing on the outcome or effect of a movement rather than the movement itself, is proving to be quite robust. The effects have been seen across numerous types of sporting activities (Wulf et al., 1998; Wulf et al., 1999; Wulf et al., 2002; Wulf & Su, 2005; Zachry, Wulf, & Mercer, 2005; Zachry et al., in press), and in tasks like balancing, which have daily applications (McNevin et al., 2003; McNevin & Wulf, 2002; Wulf et al., 2004a; Wulf et al., 2001; Wulf, Mercer, McNevin, & Guadagnoli, 2004b; Wulf et al., 2003). The advantage is not always seen in performers with an elite level of expertise, as in the present study and that of Wulf et al. (2004), but is certainly not limited to beginners. Highly and moderately skilled participants in some cases have responded very similarly to novice performers (Wulf & Su, 2005; Zachry et al., 2005; Zachry et al., in press). Benefits have also been seen in the performance of everyday activities in unique populations, such as those suffering from Parkinson’s disease (Landers, Wulf, Wallmann, & Guadagnoli, in press; Wulf et al., 2004) or cerebrovascular accident (Fasoli, Trombly, Tickle-Degnen, & Verfaellie, 2002).
The primary goal of this study was to extend the findings that have provided support for the constrained action hypothesis (McNevin et al., 2003; Vance et al., 2004; Wulf et al., 2001; Zachry et al., in press), which seeks to explain the benefits of an external focus of attention. By demonstrating that while using an external focus, novice performers devised a more effective movement strategy (increased ankle joint stiffness, resulting in greater joint stability and a more rigid striking implement for maximal transference of kinetic energy and better control of ball trajectory) relative to both internal focus and control conditions, the present study has done just that. These findings provide strong evidence for the constrained action hypothesis and the ways in which it manifests itself.
REFERENCES


APPENDIX I

REVIEW OF LITERATURE

Attentional focus

Attentional focus research is a relatively new line of research; however, the findings are already quite robust. In general, an external focus of attention (i.e., focusing on the outcome or goal of a movement) has been shown to be more effective for learning and performance, and even more economical in some cases, relative to an internal focus and in some cases, no focus (control). The effects have been seen for both expert and novice performers, and also for impaired (Parkinson’s disease, cerebrovascular accident) and non-impaired populations.

Attentional focus instructions. The first study to observe the advantages of an external focus of attention was conducted by Wulf and colleagues in 1998. The experiment consisted of two parts, both providing participants with internal and external focus instructions for the acquisition of a novel skill. Experiment 1 tested the effects on a ski simulator machine that consisted of a wheeled platform that glided along a track. The platform was secured to the track by heavy rubber bands, which caused it to return to center; it could be driven to the edges of the track by exerting force on the platform. As skill level increases, performers on this machine are able to produce large movement amplitudes, and relative to beginners, tend to wait longer to shift weight to their inside.
foot. Participants were divided into three groups. The internal focus group was instructed to focus on their body movement, that is, to exert force on their outer foot. The external focus group was instructed to exert force on the outer wheels of the platform. The control group was not given any specific focus instructions other than to try to produce large amplitudes with the platform. In practice across two days, the external group was superior to both internal and control groups, and the internal group was actually inferior to the control group as well. This suggested that at least during acquisition, focusing on one’s own body seemed to degrade performance. In retention on Day 3, which was tested one day later via a six-trial session with no instructions given to any group, the external group continued to perform superiorly to internal and control groups, while the internal and control groups were very similar to one another.

Experiment 2 (Wulf et al., 1998), sought to generalize the findings of Experiment 1 to a balance task on a stabilometer and to test the effects of focus of attention when the differences between instruction types are very subtle. The stabilometer was a wooden platform which moved in one plane (side to side) and maximum deviation to either side of center (horizontal) was 15°. Participants placed the tip of each foot on two small red markers placed equidistant from the center of the platform. For this portion of the study, there were only internal and external focus groups, and the instructions given to them differed only slightly. The internal group was told to focus on keeping their feet at the same height for as long as possible during each 90-s trial, while the external group was told to focus on keeping the red markers at the same height. Again, participants practiced for two days and then completed a retention test on Day 3 with no focus instructions given. This time there were no significant differences in performance during practice,
however, the external focus group was once again clearly superior in retention, thus reinforcing the learning benefits seen in Experiment 1.

In 1999, Wulf, Lauterbach, and Toole followed up on the results seen by Wulf and colleagues in 1998 with an experiment involving a golf chip shot. The purpose was to test the benefits of an external focus of attention in more field-like conditions. Novices practiced golf pitch shots for 80 trials under either internal (focus on arm swing) or external (focus on club swing) focus conditions. The external focus group performed better in practice and in a retention test consisting of 30 trials one day later. These findings supported those of Wulf and colleagues (1998) and implied that external focus benefits were applicable outside of a laboratory environment.

While the above-mentioned studies showed clear benefits of an external focus of attention, it was unclear what focus strategy performers would choose if left to their own devices, and if advantages or disadvantages of a strategy would be apparent to learners concurrent with performance. Wulf, Shea, and Park (2001) examined this issue. In Experiment 1, they found that after practicing a balance task on a stabilometer under internal and external focus conditions and when allowed to use their preferred strategy in practice on Day 2 and retention on Day 3, most learners chose the external focus condition. For Experiment 2, performers were allowed to use either focus strategy at any point during their two days of practice, and also in retention on Day 3. Again, most of the participants preferred the external focus condition and in both experiments, those who used the external focus strategy performed better in retention relative to those who focused internally. From these findings, it appears that the benefits of an external focus
of attention show themselves early in the acquisition of a new skill, and that the advantages are obvious to learners during performance.

Furthermore, it was observed that for this type of balance activity on a stabilometer, increasing the distance of the external focus of attention so that it was farther from the effects of the movement enhanced the benefits seen in previous studies (McNevin et al., 2003). Similar to aforementioned experiments, participants focused on either their feet (internal) or on markers just in front of their toes (near-external). However, two additional conditions were added in which participants focused on markers on the outer edge (far-outside) or near the midline of the platform (far-inside). In addition to improving balance learning relative to internal and near-external conditions, the far-external conditions also showed more frequent movement adjustments. This suggests that focusing on more distant effects of movements may result greater use of more automatic control processes during the acquisition of a new skill. Other studies have also shown benefits of an external focus of attention. For example, McNevin and Wulf (2002) showed that using an external focus of attention on a supra-postural task yield better static balance responses (i.e., greater frequency of responding) relative to both internal focus and control conditions. In 2003, Wulf and colleagues also examined the effects of focusing on a supra-postural task, this time while learning a balance task on a stabilometer. They found that external focus conditions yielded superior retention and transfer performances in the balance task, and in Experiment 1, performers were more effective on the supra-postural task as well.

Attentional focus feedback. A study by Shea and Wulf (Shea & Wulf, 1999) sought to test whether these attentional focus effects could be generalized to the feedback given
to learners. Again, a balance task was chosen and performed on a stabilometer. In this study participants were divided into four groups as follows: internal focus of attention, external focus of attention, concurrent feedback directed internally, and concurrent feedback directed externally. As before, the internal and external focus groups were instructed to focus on keeping their feet or markers on the platform level during the task. The concurrent feedback groups watched a visualization displaying their deviations from center as they performed the task and were told that the feedback represented either how well their feet were staying horizontal or how well the markers were staying horizontal. After two days of practice, retention without feedback or instructions was assessed on the third day. Both the external focus group and the external feedback group had fewer errors than the internal focus and internal feedback groups respectively. This suggested that external focus effects are generalizable to feedback and that when supplying learners with feedback, inducing an external focus of attention is more effective than directing the feedback to one's body movements. This may seem counterintuitive in a sporting world where athletes are frequently given feedback aimed directly at their form.

Another study which examined actual athletic activities under internal and external focus conditions (Wulf et al., 2002) also observed that external focus benefits seem to be applicable to real-world scenarios. Both novice and advanced volleyball players practiced “tennis” type serves while being given feedback which referred to either their body movements (internal) or the effects of those movements (external). Again, external focus feedback was more beneficial as it resulted in greater accuracy, regardless of skill level of the performers. Experiment 2 tested conventional feedback wisdom by having experienced soccer players shoot lofted passes at a target given internal or external focus
feedback in frequencies of 100% or 33%. It had been shown previously (Weeks & Kordus, 1998; Wulf & Schmidt, 1996) that reduced frequency of feedback (i.e., 33% relative to 100%) was more beneficial for learning. This held true for the internal focus feedback groups of Wulf and colleagues' (2002) Experiment 2. Also, as seen before, both external focus feedback groups of experienced soccer players showed better accuracy relative to the internal focus groups. However, for the external focus feedback groups, both 100% feedback frequency and 33% feedback frequency were equally effective. This suggested that perhaps more than just the frequency, but also the type of feedback, could be responsible for learning effects. This is not in line with the generally accepted idea that frequent feedback interferes with a learner’s ability to focus on their own movements because they become dependent on the informational support and are effectively relegated to the role of passive observers in the learning process. Wulf and colleagues offered an alternative explanation for the detrimental effects of becoming dependent on frequent feedback; they suggest that rather than inhibiting focus on one’s own movements, frequent feedback may actually induce too much focus on body movements, resulting in the detrimental effects seen while adopting an internal focus of attention.

Attentional focus as a function of expertise. A more recent study sought to view the effects of attention focus on more unique populations than had been used previously (Wulf et al., 2004). In Experiment 1, participants were world-class balance performers from the Cirque du Soleil production of “Mystère” (Las Vegas, NV) and students with no special balance training or skills. Experiment 2 measured postural sway for older adults with Parkinson’s disease, which tends to cause balance problems in its sufferers. For
both experiments, postural sway was measured under internal (minimizing the movements of the feet), external (minimizing the movement of the inflated rubber disk on which they were standing), and control (standing still) conditions. It was observed that both internal and external focus conditions were less effective than the control condition for the elite balance performers who routinely performed such tasks at a presumably high level of automation. In addition, there were no significant differences in postural sway in the students with no special balance skills. However, the participants with Parkinson’s disease did benefit from the use of an external focus of attention as their postural stability was enhanced. Because the task was very easy for elite performers and very difficult for the Parkinson’s group, the researchers concluded that optimal attentional focus effects might be seen as a function of relative task difficulty. In other words, it may be possible to achieve a level of expertise in which a task is so automated that any attempt to control the focus of attention hinders the movement.

These results were replicated when Parkinson’s patients with fall histories were tested under control (no focus instructions), internal focus (focus on keeping and equal amount of force on each foot), and external focus (focus on keeping an equal amount of force on each of two rectangles under the feet) conditions (Landers et al., in press). A Balance Master system was used to administer a Sensory Organization Test (SOT) protocol for these sensory conditions: 1) eyes open, fixed support surface and surround, 2) eyes closed, fixed support surface and surround, and 3) eyes open, sway-referenced support surface and fixed surround. Performance was significantly better in the sway-referenced balance condition when participants used an external focus of attention. Also, the number of “falls” (incidents when a participant completely lost balance and was
supported by a harness or experimenter) was recorded. In the sway-referenced balance condition, there were four falls in the control (no focus instructions) condition, and three in the internal focus condition, but there were no falls in the external focus condition. These observations were important because they broadened the findings of Wulf and colleagues (2004), and most significantly, because of the potential for therapists to enhance training effectiveness by phrasing instructions in a way that would induce an external focus of attention.

Fasoli and colleagues (Fasoli et al., 2002) saw similar results in another unique population, persons with cerebrovascular accident (CVA). The study compared the kinematics of CVA and non-impaired adults in everyday reaching tasks (e.g., taking an apple off a shelf and putting it in a basket, moving a coffee cup from a table to a saucer) under internal and external focus conditions. As before, an external focus was more effective in this experiment, as shorter movement time and greater peak velocity were seen in this condition for both impaired and non-impaired groups. The researchers noted that internally focused instructions in therapy-related tasks could contribute to slower and less forceful reach, and that therapists need to consider their use of instruction when evaluating and treating movement disorders.

To extend the findings of Wulf et al. (1999), another study also examined attention focus effects on expert performers (Wulf & Su, 2005). Golfers from a collegiate squad with an average handicap of 1.3 performed chip shots similar to those in the previous study. A within-subject design was used to test external focus (the club), internal focus (their arms), and control (no focus instructions) conditions. As in several other studies, the external focus condition yielded better accuracy relative to the other two, and there
was no difference between the internal focus and control conditions. Although the
golfers in this study were not elite, or world-class, performers as in the study by Wulf and
colleagues (2004), they were still well above-average golfers, and the results suggest that
the benefits of an external focus are generalizable to a relatively wide range of levels of
expertise.

The constrained action hypothesis. The preceding findings led to the development of
a hypothesis by Wulf, McNevin, and Shea (2001), which was further supported by
McNevin and colleagues (2003), to explain why an external focus of attention has shown
so many advantages for learning and performance. The “constrained action hypothesis”
states that attempting to consciously control a movement, as in an internal focus
condition, constrains the motor system and inhibits the automatic processes that would
otherwise control the movement. Conversely, directing focus away from the movement
and toward the effects of the movement (i.e., an external focus condition) may permit the
system to self-organize more naturally. Support for this hypothesis was found by
measuring probe reaction times (RT) of performers who were concurrently balancing on
a stabilometer (Wulf et al., 2001). Participants balanced on the stabilometer for 90-
second trials and were pseudo-randomly (at least 5 seconds and no more than 16.75
seconds between stimuli) presented with auditory stimuli. The goal of this secondary
task was to respond to the sound as quickly as possible by pressing a button held in the
right hand. As in previous experiments, the external focus group was generally better in
the balance task. More important, though, was the finding that the external focus
participants also showed faster probe RTs than the internal focus participants did. This
type of test is commonly accepted as a measure of the attention demands of a task (i.e.,
lower RTs suggest less attention was required for the concurrent task), therefore the results show strong support for the notion that an external focus of attention allows for a greater degree of automaticity in the control of movement.

Recently work has been done to determine how the constrained action hypothesis might manifest itself at a neurophysiological level. Vance and colleagues (2004) had participants employ internal (focus on the arms) and external (focus on the curl bar) focus conditions during a bicep curl task. In Experiment 1, they found that integrated electromyographic (iEMG) activity was significantly less in the external focus condition relative to the internal focus condition. The curls were also performed faster under the external focus condition than the internal focus condition. Experiment 2 controlled for this effect by having participants perform the bicep curls in time to a metronome. The iEMG activity was still reduced in the external focus condition. The authors surmised that these results supported the constrained action hypothesis because they suggest the use of more automatic control processes. The findings also suggest that adopting an external focus of attention may yield a more economical movement pattern.

To further explore attentional focus effects at the neurophysiological level, Zachry and colleagues recently conducted two studies examining electromyographic (EMG) activity of the muscles in tasks with a specific accuracy and/or performance goal. The first study (Zachry et al., in press) measured root mean square (RMS) EMG activity of the major muscles of the arm involved in shooting a basketball free throw (foul shot) in a within-subject design. As in preceding studies, free throw accuracy was better under an external focus condition, but most importantly, this study also saw the reduced EMG activity observed by Vance and colleagues (2004). Both the biceps and triceps muscles

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showed significantly less activity during the external focus condition (basket) relative to the internal focus condition (wrist motion).

A follow-up study (Zachry et al., 2005) was conducted to determine if the same results would be seen in a skill that was familiar to most any adult, in this case a vertical jump and reach task. In addition to collecting EMG data for the major muscles in the lower extremities, vertical ground reaction force (vGRF) was also measured as a means to estimate the amount of force produced for the jumps (i.e., force generated in take-off should be a predictor of jump height). For this activity, no significant differences were seen in either EMG or vGRF data, however, the reach height was significantly higher for the external focus condition relative to both internal focus and control conditions. Although it was not determined specifically how the effects of attentional focus manifest themselves physiologically, the results did indicate that participants were using a different movement strategy while employing an external focus of attention. The present study sought to further illuminate these differences in strategy in participants performing a novel task by measuring muscle activation patterns and lower extremity kinematics in an American football place kick.

Kicking

Little has been written about American football place kicking (field goal kicking), and the majority of the existing literature mostly concerns the “how-to” of kicking mechanics. There has been a great deal more research done on soccer and rugby kicking, and these skills appear to be at least fundamentally similar to American football kicking. Therefore, the findings are relevant in the context of a biomechanical analysis of American place kicking since the most prevalent style is currently the “soccer-style”
kick. That being said, the body of soccer and rugby kicking literature served as an excellent foundation from which to draw operational definitions of kicking phases, active muscle groups, and comparisons of foot speed data at ball contact.

Due to the nature of the two sports, a soccer kick and a soccer-style American football kick are different (i.e., ball size and shape, necessary ball angle of elevation, etc.). Nevertheless, many of the fundamental components of the two kicks are very similar. For instance, a characteristic of soccer kicking is that players tend to take an angled approach to kick a stationary ball. Isokawa and Lees (1988) observed that maximum velocity of the shank occurred with an approach angle of approximately 30°, while maximum ball speed took place with a 45° approach angle, suggesting that the optimum angle was somewhere in that range and noting that these values are in agreement with what players choose to do. For American place kicking, Taylor and Nunez-Bentz (1992) compiled writings from numerous authors in a review of kicking mechanics and found the suggested angle of approach for this type of kick to generally be about 45°. In an observational study of 42 kickers (Snowden, 1997), approach angle values for American football were shown to have a range of 20° to 35°. It seems that common coaching wisdom and actual performance by kickers concerning approach angle do not necessarily agree in American football kicking, however, the pool of literature is quite small, and the ranges do appear to be in line with values seen for soccer kicking.

Only modest attention has been paid to placement of the stance foot in soccer and football kicking, but the observed values look to be fairly similar. For soccer, the reported range of values for lateral distance from ball center anywhere from 5 to 37 cm (Lees & Nolan, 1998); for American football it is suggested that the stance foot be
planted a distance of 15.2 to 20.3 cm from ball center (Taylor & Nunez-Bentz, 1992). Depending on the desired trajectory of the ball, it is suggested for football place kicking that the anterior-posterior distance of stance foot from ball center should be from 0 to about 10 cm (Taylor & Nunez-Bentz, 1992), while for soccer an larger range of 5 to 38 cm has been suggested (Lees & Nolan, 1998).

After placement of the stance leg, soccer kicking is characterized by extension at the hip and flexion at the knee of the kicking leg for the backswing. The pelvis is then rotated around the stance leg and the thigh is brought forward while the knee continues to flex. From this point, the thigh begins to decelerate until it is almost motionless at ball contact. However, the knee is vigorously extended to almost full extension at ball contact and remains straight into the beginning of the follow-through. It then flexes slightly again as follow-through is completed, and the foot usually reaches above hip level (Lees & Nolan, 1998). Taylor and Nunez-Bentz’s (1992) cumulative instructions for appropriate American football soccer-style kicking technique is very similar. From the plant of the stance foot, the kicking leg is described as being involved in a combination of extension at the hip, flexion at the knee, and plantar flexion at the ankle. It then moves from extension to flexion of the hip, bringing the leg forward. For right side dominant kickers, it then follows that: “As the right knee passes over the ball, the lower leg is forcefully extended at the knee; the right foot remains in plantar flexion throughout the movement. The distal portion of the anterio-medial aspect of the first metatarsal (top of the foot, along the line of the shoelaces) should be the body’s impact point with the ball (p. 217-18).” The follow-through is completed as the kicker’s leg follows the intended
path of the ball, and the foot should always end up well above the hip and often level with or above the head.

Because of these similarities between American place kicking and soccer and rugby kicking, it was reasonable to assume that kinematic values identified for soccer and rugby kicking would be relatively realistic expectations for American football kicking as well. For example, Orchard and colleagues (Orchard et al., 2003) observed in rugby drop kicking hip extension up to approximately -20° and hip flexion up to about 60°. Average knee angles were seen to be around 140° of flexion and up to about 20° of extension. No reports of hip flexion/extension data were found for American kicking, but Snowden (1997) reported knee flexion in 42 field goal kickers to range from 50° to 110° and knee extension to range from 5° to -5°. For all of the above values, 0° equals full extension. We expected the values observed in the present study to be reflective of these ranges.

The similarities between rugby and soccer kicking and soccer-style football kicking also allowed for a borrowing of methodological procedures from which an American football place kick could be similarly quantified. For example, Orchard, Walt, McIntosh, and Garlick (1999) attempted to quantify muscle activity of a drop punt kick in rugby. In doing so, they extensively delineated the phases of the kicking motion. The rugby drop kick was determined to consist of the following phases: 1) run-up/approach, 2) backswing, 3) wind-up, 4) forward swing, 5) follow through, and 6) recovery. Lees and Nolan (1998) noted that the soccer kick has been divided into four phases: 1) withdrawal of the thigh and shank during the backswing, 2) rotation of the thigh and shank forward, which occurs as a result of hip flexion, 3) when the thigh angular velocity reduces, there is a corresponding increase in shank angular velocity up to impact with the ball, and 4)
the follow-through. For the present study, an amalgam of these approaches was created resulting in the following break-down of the phases of an American football place kick: 1) flight phase (toe off of the kicking leg to heel contact of the stance leg), 2) swing phase (heel contact of stance leg to ball contact), and 3) follow-through (ball contact to maximum hip flexion).

Additionally, the study of a rugby drop kick (Orchard, Walt, McIntosh, & Garlick, 1999) offered insight into EMG lead placement and expectations for flexion/extension data. Electromyograms of the quadriceps, hamstrings, and gluteals of both legs as well as rectus abdominus were recorded. The hamstrings of the kicking leg were found to be the most active muscle group in the kicking motion, involved eccentrically (muscle actively lengthening) in the wind-up and concentrically (muscle actively shortening) in the forward swing. This information aided in the selection of muscles for EMG analysis (rectus femoris, biceps femoris, medial gastrocnemius, and tibialis anterior). Orchard and colleagues (1999) also observed maximum hip extension shortly after toe-off of the kicking leg, maximum knee flexion in the swing phase, maximum knee extension just after ball contact, and maximum hip flexion at the end of the follow-through. Consequently, it seemed reasonable to expect similar occurrences in American place kicking.

For calculations of foot speed at ball contact, which has been shown to be a reasonable predictor of ball velocity (a measure of the success of the kick, Dörge et al., 2002; Lees & Nolan, 1998), the velocity of the ankle was used, similar to the method employed by Barfield and colleagues (Barfield, Kirkendall, & Yu, 2002). In that experiment, ankle velocity was calculated as the velocity of the centroid of the lateral
malleolus of the kicking foot, and was therefore the technique used in the present study as well. From the amassed values of foot speed in soccer kicking (Lees & Nolan, 1998), it was expected that results ranging from about 18 to 28 m/s would be seen.

Instrumentation

**Surface electromyography.** When a muscle contracts an electrical impulse is produced which is known as an electromyogram. The study of these impulses is therefore called electromyography or EMG for short. While a muscle is contracted, EMG signal magnitude increases as tension is developed. The ability of a muscle to conduct electrical impulses as a result of motor unit recruitment is referred to as a motor unit action potential (m.u.a.p.). These m.u.a.p.s can be recorded using surface-mounted or intra-muscular (inserted directly into the muscle tissue) electrodes. Silver/silver chloride (Ag/AgCl) bipolar surface electrodes were used for the present study. This type of electrode detects average activity of superficial muscles, but it is susceptible to impedance from things like epidermal and adipose tissue. This is a limitation of surface electromyography (sEMG), however, sEMG tends to yield more consistent results than intra-muscular EMG (Winter, 1990).

The standards used in this study (see Methods) for reporting specifications for electrodes, EMG detection, rectification, sampling into the computer, and amplitude processing were in accordance with the International Society of Electromyography and Kinesiology (Merletti, 1999). Electrode placement was determined with the assistance of Delagi and Perotto’s *Anatomic Guide for the Electromyographer: The Limbs* (1981), and additional insight into the proper recording of the “seductive muse” of EMG activity was drawn from Carlo De Luca’s 1997 article titled “The Use of Surface

Motion capture. While a handful of soccer studies have examined three-dimensional kinematics (see Lees & Nolan, 1998), the same does not appear to be true for American place kicking. Through the use of a Vicon motion capture system, the present study was able to do just that. Three-dimensional position data were processed using the Plug-in Gait model (formerly Vicon Clinical Manager) to identify angles of flexion/extension about the hip and knee joints. In order to run this model, the raw position data were first applied with the Woltring quintic spline filter written into the Plug-in Gait model. Then the required anthropometric information (leg length, knee width, ankle width, and mass) for each subject was entered into the software so that the static model could be run on the static trial that was recorded. The static model stores subject measurements for use with the dynamic model, which was run subsequently on the kicking trials. The dynamic model generates "virtual" hip, knee, and ankle joint center trajectories, and then calculates kinematic and kinetic quantities such as angles and moments ("Plug in gait model details", Accessed 3/14/2005).

Analysis of accuracy scores. Accuracy and consistency within subjects and between groups were analyzed via the methods described by Hancock and colleagues (Hancock et al., 1995). A coordinate value (x, y) was assigned to the point where each kick struck the net, and the distance formula was used to calculate its distance from the origin.
References


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Appendix II

HYPOTHESES AND LIMITATIONS

Hypotheses

Hypothesis 1. Accuracy scores, foot speed at ball contact, kinematics, and muscle activation patterns will differ between experts and novices. Specifically, experts will show greater accuracy and foot speed relative to novices, and kinematics and muscle firing patterns in experts will show signs of a more automatic and well-learned movement (e.g., less variability of muscles recruited and lesser instances of co-contraction; see Chapman et al., 2004).

Hypothesis 2. An external focus condition will yield greater accuracy scores and foot speed at ball contact in novices. Kinematics and muscle activation patterns in novices are also hypothesized to more closely resemble those of experts relative to internal focus and control conditions, though no previous research has yet shown as such.

Limitations of the study

One limitation of this study is a generally recognized limitation of all studies recording electromyographic (EMG) activity. This study will use surface EMG, but both surface and intra-muscular EMG are unable to capture all of the motor unit action potentials (m.u.a.p.) being transmitted through a muscle fiber at any given time. However, surface EMG is able to detect average activity of superficial muscles with
greater consistency than intra-muscular electrodes. Despite that, surface EMG is subject to crosstalk (muscles sliding past one another) from other muscles and impedance (i.e. skin, fat tissue, etc.) weakening the signal (Winter, 1990). To offset these effects, EMG data will be captured in accordance with accepted standards in the field (De Luca, 1997; Delagi & Perotto, 1981).

The number of muscles for which EMG activity can be recorded is also a limiting factor of this study. Four muscles can be sampled using one main cable with four sets of dual leads. While multiple cables can be used, they are quite cumbersome when fitted on a participant, and when used in combination with the Vicon markers, the participant’s kicking leg will be heavily weighted (in comparison to normal, non-instrumented conditions). Because of the difficulty of this activity and the importance of reducing distraction from the prescribed focus conditions, using any more than four channels of EMG is not practical.

Another limitation of this study is the inability to measure foot/ankle kinematics due to the constructs of the Plug-in Gait™ marker set used with the Vicon motion capture system (Oxford Metrics, Oxford, UK). This marker set can be used to model such kinematic variables as joint flexion/extension, joint rotation, and joint moments. However, to gain such information about the foot, a toe marker must be attached. That marker would interfere with the flight of the ball and would most likely be destroyed after a few trials as well. It would also be obstructed from view by the cameras during ball contact; therefore, attempting to use the toe marker is both impractical and counterproductive.
KICKING INSTRUCTIONS

General kicking instructions

Start from a position two steps behind and two steps to the left of the ball, forming a 45° degree angle with the ball. The left foot should be slightly ahead of the right foot, and the waist should be slightly bent with arms relaxed. Step first with the right foot and cover approximately half the distance to the ball. The second step with the left foot should plant even with the ball and about 6-8 inches to the side of it; the toes of the left foot should point at the target. During this step, the right leg should be brought back for the backswing with the knee flexed. When the left foot is planted, bring the right leg forward; the knee should lead the leg to the ball. As the right knee starts to pass over the ball, extend the knee so that the right foot contacts the ball. The toes of the right foot should be pointed during this entire movement. Contact the ball with the top part of the right foot along the line of the shoelaces about an inch below the center of the ball. Follow through by continuing to bring the leg along the desired path of the ball and extending the toes high into the air for greater power (Gogolak, 1972; Taylor & Nunez-Bentz, 1992).* The goal is to kick the ball so that it hits the yellow circle in the center of the net.

* Instructions reversed in the instance of a left side dominant participant.
Attention focus instructions

**Control condition.** “Focus your attention the way you would if no one was giving you any outside instruction.”

**Internal focus condition.** “Focus on the part of your foot that will be contacting the ball, the top of your foot along the line of your shoelaces.”

**External focus condition.** “Focus on the part of the ball that you will be contacting with your foot, the spot approximately one inch below the center of the ball.”

For all conditions, the participants were informed that “focus” in this study meant on what they should be concentrating, not at what they should specifically be looking. Also, it was expressed that in all trials and conditions the goal was always to kick the ball as closely as possible to the target in the center of the net.
APPENDIX IV

ADDITIONAL MATERIALS

Informed consent document

INFORMED CONSENT

TITLE OF STUDY: Muscle recruitment patterns of expert and novice football field goal kickers in response to internal versus external focus of attention.

INVESTIGATOR/S: Gabriele Wulf, Tiffany Zachry, Janet Griffin, Tina Lindquist, Amanda Tritsch, David DeLion, Kathleen Orzechowski, Jana Padilla

PROTOCOL NUMBER: 0502 - 1534

CONTACT INFORMATION
If you have any questions or concerns about the study, please contact:

Gabriele Wulf 895-0938 Janet Griffin 895-4494
Tiffany Zachry 895-3419 Tina Lindquist 895-1241

For questions regarding the rights of research participants, any complaints or comments regarding the manner in which the study is being conducted you may contact the UNLV Office for the Protection of Research Subjects at 895-2794.

Purpose of the Study
You are invited to participate in a research study. The purpose of this study is to determine biomechanical differences between expert and novice football field goal kickers in response to different attentional focus conditions.

Participants
You are being asked to participate in the study because you have no condition that interferes with the ability to kick a football off of a tee and you are between the ages of 18-40 years.

Procedures
If you volunteer to participate in this study, the kinematics of your kicking technique will be recorded using a motion capture system. You will be fitted with small reflective markers at key anatomical locations on your legs in order for the system to capture your movement. No video record of you or the ball will be recorded, only a three-dimensional “stick figure”
representation of the ball. You will also wear small electrodes placed on the surface of your skin over the major muscles of your kicking leg. These electrodes record the electrical activity of your muscles during the kick, but do not put any current into your muscles.

You will be asked to kick three (3) sets of seven (7) field goals in an indoor environment (into a large net) using an official size college football. For each set you will be given specific instructions about how to focus your attention for the kick.

**Risks of Participation**
The main risk of participating is muscle soreness. To minimize muscle soreness, you should be sure to warm up as you feel appropriate for this type of activity and to communicate with the researchers if you are experiencing any discomfort.

**Benefits of Participation**
Although there may be no direct benefits to you as a participant in this study, you will have the knowledge of how you performed during all conditions. The results of this study will help us better refine techniques used to acquire field goal kicking skills.

**Cost /Compensation**
There will be no financial cost to you to participate in this study. This study will take between one and two hours of your time. You will not be compensated for your time. The University of Nevada, Las Vegas may not provide compensation or free medical care for an unanticipated injury sustained as a result of participating in this research study.

**Voluntary Participation**
Your participation in this study is voluntary. You may refuse to participate in this study or in any part of this study. You may withdraw at any time without prejudice to your relations with the university. You are encouraged to ask questions about this study at the beginning or any time during the research study.

**Confidentiality**
All information gathered in this study will be kept completely confidential. No reference will be made in written or oral materials that could link you to this study. All personal information about you will be stored for a minimum of three (3) years in a locked cabinet accessible only by the research staff.

**Participant Consent:**
I have read the above information and agree to participate in this study. A copy of this form has been given to me.

_____________________________          ____________________
Signature of Participant                  Date

_____________________________
Participant Name (Please Print)
### Biomechanics Laboratory Project Organization Form

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Recruiting statement document for expert kickers

**UNLV**
UNIVERSITY OF NEVADA LAS VEGAS

**Principal Investigator:** Gabriele Wulf, PhD.
**Co-Investigator:** Tiffany Zachry
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**Department:** Kinesiology

**Title:** EFFECTS OF ATTENTIONAL FOCUS ON KINEMATICS AND MUSCLE ACTIVATION PATTERNS AS A FUNCTION OF EXPERTISE

**METHODS, PROCEDURES:**

*Instrumentation*

Muscle activity of the lower extremities will be recorded (1000 Hz) using an electromyography (EMG) system (Noraxon, Inc.). To measure muscle activity, sensors will be placed on the surface of the skin in pairs over the bellies of the major muscles involved in kicking. The locations for the sensors will be shaved of any hair and cleaned. A ground sensor will be placed on a bony landmark such as the acromion process (i.e., shoulder).

Participants will also wear 25-mm diameter Vicon Motion Systems (Oxford Metrics) reflective markers positioned at the hip, knee, and ankle joints, as well as other key body locations if needed (e.g. torso or upper extremities to gain a better sense of the overall movement). This system will allow identification of the phases of the kick for synchronization with EMG data and will be sampled at 120 Hz. The markers are non-invasive, and the system does not record a video image of the participants, only a “stick figure” three-dimensional representation of the movement. However, a video image will be recorded using a standard VHS camcorder for the purpose of determining accuracy. All cassettes and/or digital movie files will be stored in a locked or password-secure location to protect the participants’ anonymity.

*Procedures*

Participants will perform football field goal style kicks into a full length net (floor-to-ceiling and wall-to-wall) in the Biomechanics Lab located in the Sports Injury Research Center on the UNLV campus. A target will be placed on the net to measure accuracy. The target will not be of regulation distance or height in order offset any strength advantages held by the expert kickers. Rather, the distance will be set at about 5 meters and the height at about 2 meters. Participants will kick about 15-20 field goals under three focus conditions, which will not be revealed until the time of testing in order to maintain the integrity of the data. Sufficient rest will be provided between conditions and between trials, however, the kicking exercises will not be very strenuous. Also, no volunteers with current or recent injuries (within the last 6 months) will be allowed to
participate in this study, and testing will cease immediately if a participant reports any pain or discomfort either before or during the trials.

RISKS:
Soreness and/or fatigue in lower extremities tested - Minimal
Psychological – Minimal; it is possible that a subject will become upset with his or her performance testing. It will be stressed that performance is non-competitive with other participants and they will not be able to view one another’s performances.

Precautions taken to minimize risks
Only individuals capable of completing a soccer-style football field goal kick will be recruited for the study. All participants will be given ample rest between each condition to minimize the effect of fatigue as well as potential muscle soreness. Warm up will be allowed, and testing will not begin until the participant feels physically prepared to begin the activity. If at any time a participant becomes fatigued, injured, or uncomfortable with the instrumentation and is in any manner unwilling and/or unable to continue the activity, the subject will by no means be required to continue. If an injury were to occur, standard First Aid procedures would be administered as necessary, and Campus Security would be notified immediately and the IRB will be notified. Only the principal investigators will have access to the confidential subject-code information.

COST TO PARTICIPANTS:
There will be no cost to the subject other than their time.

INFORMED CONSENT:
Potential participants will have the testing protocol explained by the Principal Investigator or a member of the Research Team. Individuals who contact the investigators as potential participants will be asked to identify if they have any condition that would inhibit their ability to perform the kicking task. If the individual qualifies to participate, the test procedures will be explained as well as the risks involved with participation. The individuals will be asked to read the informed consent form and any questions regarding the study will be discussed at that time. If the individual agrees to participate, they will be asked to sign the informed consent.

CONFIDENTIALITY:
The names of all participants will be held in strict confidence and will not be revealed in any publications or reports resulting from the study. All references to participants will be made solely on the basis of a subject number assigned for the study. The code information relating subject names to subject numbers will be retained in a confidential locked file located in the laboratory and accessible only to the principal investigators. Data will be archived in the Motor Behavior Laboratory (BHS 215).
VITA

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