ABSTRACT

THE EFFECT OF UNCERTAINTY ABOUT BALL WEIGHT ON ANTICIPATORY MUSCLE ACTIVITY IN A ONE-HANDED CATCHING TASK

by Jason J. Eckerle

To determine the effect of uncertainty about ball weight on anticipatory muscle activity in catching, anticipatory postural adjustments (APAs) in one-handed catching of balls of known and unknown weights were compared. Twenty-nine (N = 29) male college students participated in the study. Each participant’s muscle activity in the biceps brachii, triceps brachii, wrist flexor group, and bilateral erector spinae (L4-L5) was measured using EMG while he caught visually identical balls of four different weights (1.1, 2.9, 4.8 and 6.6 lb). EMG integrals were computed for the one second prior to ball drop (pre-drop period), and the time between ball drop and catch (drop period). Uncertainty about ball weight had no effect on APA activity during the pre-drop period. During the drop period, however, uncertainty about ball weight did influence APA activity in the biceps and wrist flexors, but the effect depended on the weight of the ball. In the known ball weight condition for both the biceps and wrist flexors, participants exhibited significantly stronger APAs with each increase in ball weight. In contrast, under unknown ball weight condition, APA strength was high and did not change with each increase in ball weight. For the biceps and wrist flexors, the hypothesis that when the weight of the ball was unknown, the CNS would prepare for the ‘worst case scenario’, i.e., the heaviest ball, was confirmed.
THE EFFECT OF UNCERTAINTY ABOUT BALL WEIGHT ON ANTICIPATORY MUSCLE ACTIVITY IN A ONE-HANDED CATCHING TASK

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# Table of Contents

List of Tables .................................................................................................................. iii
List of Figures ................................................................................................................... iv
Introduction ..................................................................................................................... 1

Methods .......................................................................................................................... 4
  Participants ..................................................................................................................... 4
  Procedures ..................................................................................................................... 5
  Catching Task ............................................................................................................... 5
  Measurement ............................................................................................................... 7
  Experimental Design ................................................................................................... 7
  Statistical Analyses ..................................................................................................... 8

Results ............................................................................................................................ 8
  Biceps Brachii: Pre-Drop Period ............................................................................... 8
  Biceps Brachii: Drop Period ..................................................................................... 8
  Triceps Brachii: Pre-Drop Period .............................................................................. 10
  Triceps Brachii: Drop Period .................................................................................... 10
  Wrist Flexor Group: Pre-Drop Period ...................................................................... 12
  Wrist Flexor Group: Drop Period ............................................................................. 12
  Catching Side Lumbar Spine: Pre-Drop Period ....................................................... 14
  Catching Side Lumbar Spine: Drop Period ............................................................... 15
  Non-Catching Side Lumbar Erector Spinae: Pre-Drop Period ............................... 17
  Non-Catching Side Lumbar Erector Spinae: Drop Period ....................................... 17

Discussion ...................................................................................................................... 19
  Pre-Drop Period .......................................................................................................... 20
  Drop Period .................................................................................................................. 20
  Limitations and Conclusion ....................................................................................... 21

References ...................................................................................................................... 23
List of Tables

Table 1: Mean EMG integrals for the pre-drop period in the biceps brachii for the known ball weight (K) and unknown ball weight (U) conditions......................................................... 9

Table 2. Mean EMG integrals for the drop period in the biceps brachii for the known ball weight (K) and unknown ball weight (U) conditions................................................. 9

Table 3: Mean EMG integrals for the pre-drop period in the triceps brachii for the known ball weight (K) and unknown ball weight (U) conditions.............................................. 11

Table 4. Mean EMG integrals for the drop period in the biceps brachii for the known ball weight (K) and unknown ball weight (U) conditions......................................................... 11

Table 5: Mean EMG integrals for the pre-drop period in the wrist flexor group for the known ball weight (K) and unknown ball weight (U) conditions.............................................. 13

Table 6. Mean EMG integrals for the drop period in the wrist flexor group for the known ball weight (K) and unknown ball weight (U) conditions......................................................... 14

Table 7: Mean EMG integrals for the pre-drop period in the erector spinae at the L4-L5 level on the catching side for the known ball weight (K) and unknown ball weight (U) conditions. 15

Table 8: Mean EMG integrals for the drop period in the erector spinae at the L4-L5 level on the catching side for the known ball weight (K) and unknown ball weight (U) conditions..... 16

Table 9: Mean EMG integrals for the pre-drop period in the erector spinae at the L4-L5 level on the non-catching side for the known ball weight (K) and unknown ball weight (U) conditions .............................................................. 18

Table 10. Mean EMG integrals for the drop period in the erector spinae at the L4-L5 level on the non-catching side for the known ball weight (K) and unknown ball weight (U) conditions..19
List of Figures

Figure 1: Diagram of starting position of participant ............................................ 6

Figure 2: Mean EMG integrals for the pre-drop period in the biceps brachii for the known ball
weight (K) and unknown ball weight (U) conditions. ........................................... 9

Figure 3: Mean EMG integrals for the drop period in the biceps brachii for the known ball
weight (K) and unknown ball weight (U) conditions........................................... 10

Figure 4: Mean EMG integrals for the pre-drop period in the triceps brachii for the known ball
weight (K) and unknown ball weight (U) conditions........................................... 11

Figure 5: Mean EMG integrals for the drop period in the triceps brachii for the known ball
weight (K) and unknown ball weight (U) conditions........................................... 12

Figure 6: Mean EMG integrals for the pre-drop period in the wrist flexor group for the known
ball weight (K) and unknown ball weight (U) conditions.................................... 13

Figure 7: Mean EMG integrals for the drop period in the wrist flexor group for the known ball
weight (K) and unknown ball weight (U) conditions........................................... 14

Figure 8: Mean EMG integrals for the pre-drop period in the erector spinae at the L4-L5 level on
the catching side for the known ball weight (K) and unknown ball weight (U) conditions. 16

Figure 9: Mean EMG integrals for the drop period in the erector spinae at the L4-L5 level on the
catching side for the known ball weight (K) and unknown ball weight (U) conditions… 17

Figure 10: Mean EMG integrals for the pre-drop period in the erector spinae at the L4-L5 level on
the non-catching side for the known ball weight (K) and unknown ball weight (U) conditions. 18
Figure 11: Mean EMG integrals for the drop period in the erector spinae at the L4-L5 level on the non-catching side for the known ball weight (K) and unknown ball weight (U) conditions. 19
Thesis: The Effect of Uncertainty About Ball Weight on Anticipatory Muscle Activity in a One-Handed Catching Task

Introduction

Postural stability is critical to the execution of almost any voluntary movement, and the central nervous system (CNS) utilizes several sophisticated mechanisms to maintain postural stability under a wide range of task constraints. For example, when you reach for something such as a book on a shelf, muscles in your trunk and legs typically activate in advance of any muscle activity in your shoulder or arm. These muscle contractions in the trunk and legs are referred to as anticipatory postural adjustments (APAs) because they precede the principal movement of the arm. APAs have generally been viewed as postural adjustments to self-induced stability perturbations, such as those generated by voluntary movements. It is thought that the functional roles of APAs are to predict the stability perturbing forces to be generated by an imminent voluntary movement, and produce a preemptive muscular contraction (i.e., APA) in order to stabilize the body in advance of the voluntary movement (Aruin & Latash, 1995a; Zattara & Bouisset, 1988).

Research has demonstrated that APAs are tailored to specific characteristics of voluntary movements, such as the direction (Aruin & Latash, 1995a), load (Aruin & Latash, 1995b; Aruin, Shiratori & Latash, 2001), acceleration (Lee, Buchanan & Rogers, 1987; Zattara & Bouisset, 1988), and velocity (Hodges & Richardson, 1999). APAs are also influenced by conditions such as Parkinson’s disease (Aruin, Neyman, Nicholas & Latash, 1996), stroke (Dickstein, Shefi, Marcovitz & Villa, 2004), low back injury (Hodges 2001; Hodges, Moseley, Gabrielsson & Gandevia, 2003; Hodges & Richardson 1996; Hodges & Richardson 1999), and muscle fatigue (Allison & Henry, 2002; Strang & Berg, 2007; Strang, Berg & Hieronymus, 2009; Strang, Choi & Berg, 2008; Vuillerme, Nougier & Teasdale, 2002).

Compared to the role of APAs in self-induced stability perturbations, the role of APAs in externally-induced stability perturbations, such as those that potentially occur when catching an object, has received much less attention. There is evidence, however, that APAs can occur in conjunction with catching an object, even though the stability perturbation is not self-induced. Lacquaniti and Maioli (1989a & b) observed APAs in research participants when a ball was dropped from different heights both by an experimenter and by a ball-drop apparatus. The first study (Lacquaniti & Maioli, 1989a) focused on APAs and reflex responses in catching. Balls
were dropped from an apparatus using different impact parameters, which included the height from which the ball was dropped and the weight of the ball. Electromyography (EMG) was used to measure muscle activity in the catching arm. Lacquaniti and Maioli (1989a) found that APAs were present in catching and are apparently intended to prepare the limb for impact of the ball and to stabilize the limb after impact. Moreover, Lacquaniti and Maioli (1989a) reported that during catching, the magnitude of APAs in arm muscles correlated linearly with the momentum \((m\times v)\) of the ball at impact. In other words, the heavier the ball and/or the longer the drop, the greater the APA magnitude.

Lacquaniti and Maioli (1989b) subsequently examined APAs while having research participants catch balls with their eyes closed. Visual information was replaced with an audible cue to let the participant know when the ball was dropped. With eyes closed and relying only on an audible cue, research subjects did not show APAs, even when the release height and weight of the ball was known in advance. The work of Lacquaniti and Maioli (1989 a & b) suggested that when sufficient visual information for accurate prediction of the time-to-contact is available, APAs could be generated even when a stability perturbation is externally induced.

Shiratori and Latash (2001) studied differences in the generation of APAs in arm, trunk and leg muscles prior to catching a ball dropped by either the research participant or by the experimenter. Shiratori and Latash also studied the importance of different mechanical characteristics of the ball at impact for the generation of APAs. Participants caught a ball dropped into the left hand by releasing the ball from the right hand at different heights. APAs were quantified as the EMG integral for a 100 ms period prior to ball impact with the limb. The results of the study suggested that kinetic energy, the energy possessed by the ball due to its motion, was more strongly correlated with APA magnitude than momentum \((m\times v)\) was, but this was true only when the experimenter released the ball, and not when the participant released the ball. In other words, when the ball release was self-initiated, the APA magnitude was scaled to the momentum of the ball at impact, while when the experimenter released the ball the APA magnitude was not scaled to the momentum at impact. This means that when the body is in control of the momentum at impact, it uses that information to prepare. When an external source is controlling the impact momentum, the CNS prepares the body differently. More importantly, Shiratori and Latash found that APAs were generated in leg, trunk and arm muscles for both a
self-induced and externally-induced postural perturbations, which is consistent with the findings of Lacquaniti and Maioli (1989 a & b).

The strength of an APA is, by definition, based on the predicted magnitude of an expected postural perturbation, regardless of whether the perturbation is self- or externally-induced. In catching, the magnitude of the postural perturbation depends on the weight and velocity of the object to be caught. We know that individuals use knowledge about object properties such as weight in combination with visual information about object motion prior to the catch to predict the impact parameters such as time-to-contact and force at contact (Ashford, Bennett, Elliott & Rioja, 2004). This information is used by the CNS to prepare the neuromuscular system to successfully complete the catching task (Lacquanti & Maioli, 1989 a & b). However, an object’s weight is not always known or predictable, yet it is generally possible to catch objects of an unknown weight. It is unclear how the CNS copes with an unknown weight in terms of the generation of APAs in catching.

A pilot study involving 6 participants was conducted to compare APAs in four muscles (i.e., anterior deltoid, biceps brachii, triceps brachii and L4-L5 erector spinae) in the performance of a simple one-handed ball-catching task with known and unknown ball weights (Eckerle, Gadzey & Murdock, 2005). All participants were exposed to both the known and unknown ball weight conditions, and caught balls of 2, 4 and 6 lb under each condition. In the unknown ball weight condition, participants were aware that the ball could weigh 2, 4, or 6 lb, but did not know which ball weight would be used on each trial. All of the balls used in the study were visually identical. The dependent variable was the magnitude of the APA, quantified as the EMG integral over the 1 s prior to the catch, in each of the four muscles evaluated.

Data from the pilot study indicated that for each of the muscles evaluated and at every ball weight, the magnitude of APAs in the unknown weight condition exceeded those in the known weight condition. In fact, for all muscles, the smallest APA recorded in the unknown condition exceeded the largest APA in the known condition. The results of the pilot study suggested that the CNS coped differently with the known and unknown ball weight conditions. Specifically, under the unknown ball weight condition, the CNS appeared to prepare for the ‘worst case scenario’, that is, a ball that weighed at least as much as the heaviest ball weight possible (6 lb), if not more.
The results of the pilot study indicated that a full-blown study of the effect of uncertainty of ball weight on APAs in catching had the potential to teach us something new about human postural control. Therefore, the purpose of this experiment was to compare APAs in one-handed catching of balls of known and unknown weights. A ball-drop apparatus was constructed and balls were prepared so as to be visually identical regardless of the weight. Half of the trials were performed with the participant knowing the weight of the ball to be dropped, and the other half of the trials were performed without the participant knowing the weight of the ball to be dropped. The EMG integral was measured in six muscles/groups over two time periods, a) one second prior to ball drop, and b) the time from ball drop to catch. It is hypothesized that APA activity would be greater under the unknown ball weight condition for both time periods, and that the APA magnitude at each weight in the unknown ball weight condition would be equal to or greater the APA magnitude for the heaviest ball under the known ball weight condition. In other words, when the ball weight was not known, the CNS would prepare for the worst-case scenario, the heaviest possible ball.

Methods

Participants

The experiment included 30 healthy adult males who were students at a Midwestern university. The participants were recruited using flyers posted in classroom buildings as well as asking for volunteers in undergraduate and graduate classes. One participant had to be eliminated from the study following data collection because of corrupted EMG data. The remaining 29 participants had a mean age of 21.1 ± 1.4 years. The group’s mean height, body weight and BMI were 180.7 ± 7.5 cm, 84.7 ± 9.7 kg and 26.0 ± 3.0, respectively. All participants were free of cardiovascular and neurological diseases, as well as musculoskeletal injuries. All participants preferred catching with their right hand. All participants had previously engaged in some form of sport activity that required hand-eye coordination, such as baseball, ice hockey, basketball, lacrosse, softball, tennis, and volleyball. Twenty-six of the 29 participants reported that they currently participated in organized intramural or intercollegiate sports involving hand-eye coordination. Our Institutional Review Board approved the study, and all participants provided informed consent. Each participant was paid $10 for the time devoted to the single laboratory session.
Procedures

After completing a short questionnaire regarding previous and current sport participation, each participant completed a single session of data collection. Participants were first outfitted with the bipolar surface EMG electrodes (Ag/AgCl disposable electrodes [Ambu Inc., Maryland, USA]) that would be used to measure activity in six muscles, the catching arm anterior deltoid, biceps brachii, triceps brachii, wrist flexor group (palmaris longus, flexor carpi radialis, flexor carpi ulnaris), and bilateral erector spinae at lumbar vertebrae 4-5. Two electrodes were placed 20 mm apart over each muscle, in alignment with the muscle fibers. Electrode placement for the anterior deltoid required the participants to actively horizontally flex the shoulder at 90 degrees of forward flexion against resistance, at which time the electrodes were placed over the belly of the muscle. For the biceps brachii and triceps brachii, the participant flexed and extended the elbow, respectively, against resistance. The electrodes where placed on the palpable belly of each muscle. For the wrist flexor group, the electrodes were placed halfway between the cuboid fossa and the radial styloid process. To place electrodes over the erector spinae, the 4th and 5th lumbar vertebrae were palpated and the electrodes were placed bilaterally, approximately 2.5 cm from the vertebral midline. Finally, a reference electrode was placed on the iliac crest, superior to the anterior superior iliac spine (ASIS).

Catching Task

Using their preferred hand (the right hand, in all cases), participants attempted to catch 4.5 inch diameter balls dropped from a vertical height of 0.75 meters above the participant’s catching hand and elbow (olecranon process). Participants stood in front of a ball drop apparatus with their right arm and hand in the prescribed starting position (FIGURE 1). The starting position required the participant to assume a comfortable stance with the feet approximately shoulder’s width apart, and extend their right hand with the elbow flexed to approximately 110 degrees. The wrist was held in a neutral position with the palm in a supinated position.
A ball-drop apparatus was used to ensure that balls were dropped uniformly on each trial. Participants knew where the ball would emerge from the apparatus when dropped, but could not see the ball when it was loaded into the apparatus. Once the ball was loaded into the apparatus, the participant was instructed to assume the starting position. Laser pointers acted as cues for the participant to position his hand and arm at precisely the same starting position prior to each trial. The participant then provided a verbal cue that he was ready for the ball to be dropped. To ensure that the participant could not temporally anticipate exactly when the ball would be dropped, a variable and random foreperiod of 5-12 seconds passed between the participant’s indication that he was ready to begin a trial and the actual drop of the ball.

Participants were instructed to catch the ball and promptly return the arm/hand to the starting position. Participants performed 20 trials of the catching task under each of two conditions, for a total of 40 trials. Participants caught balls of four different weights, 1.1 lb, 2.9 lb, 4.8 lb and 6.6 lb. Prior to each trial performed under condition K (known ball weight), participants were told the weight of the ball to be caught, and were asked to handle the ball with their right hand for approximately 5 s. Under condition U (unknown ball weight), participants did not know the weight of the ball to be caught, nor did they handle the ball, but participants
were aware that the weight of the ball to be caught would be between 1.1 and 6.6 pounds. In each condition, participants caught 5 balls at each of the four ball weights. The order in which conditions K and U were encountered was randomized across trials, as was the order of ball weight within conditions. Participants were given brief rest between each trial, and two-minutes of seated rest between trials 20 and 21.

All balls were made visually identical by covering each in identical opaque black elastic sleeves. There were two balls for each weight, and the fabric sleeves were regularly rotated among the eight balls. Prior to beginning the experiment, participants handled all of the balls to gain familiarly with the ball size and the different ball weights. Participants also performed practice catches for each ball weight under both conditions K and U. During the practice trials, participants were asked to find a comfortable stance with the feet approximately shoulder’s width apart. After the last practice trial, a participant was asked to assume his ideal stance, after which foot position was marked on the floor to ensure that the participants stood in the same place and with the same general body posture for all trials.

**Measurement**

The EMG (Myosystem 1200, Noraxon, USA) signal was recorded with 12-bit resolution at a bandwidth of 10-500 Hz, and amplified x1000. All trials were sampled at 1000 Hz as well as rectified and smoothed using a 10 Hz low-pass Butterworth filter. The EMG data was analyzed using Myoresearch v2.02 software. The ball-drop apparatus incorporated a series of photo sensors positioned in the plane of ball-drop trajectory that identified the catch event, and the apparatus was able to denote the exact times of ball drop and catch on the EMG record. APA magnitude was quantified as the EMG integral over two separate time intervals, the 1 s period prior to ball drop (pre-drop period), and the period between the ball drop and the catch (drop period). During the data reduction process, an irregularity in the anterior deltoid EMG channel became apparent in the data from many participants. Therefore, the EMG data for the anterior deltoid was excluded, leaving five muscles for the analysis. Also, the triceps EMG data from a single participant contained anomalies that resulted in that data being omitted from the analysis. Therefore, for the triceps data, N = 28.

**Experimental Design**

The experiment employed a repeated measures mixed design. Independent variables included knowledge of ball weight (two levels = known and unknown) and ball weight (4 levels
Dependent variables were measured in all five muscles, and included the EMG integrals during both the pre-drop and drop periods.

Statistical Analyses

The data was analyzed using mixed ANOVA. Specifically, a series of five 2 x 4 (knowledge status by ball weight) ANOVAs, with repeated measures on both factors, were conducted. Post-hoc pairwise comparisons were then performed to analyze any significant main effects for condition and/or ball weight. Post-hoc paired samples t-tests were performed to analyze any significant interaction between knowledge condition and ball weight.

Results

Biceps Brachii: Pre-Drop Period

The mean EMG integrals in the biceps brachii for the pre-drop period are presented in Table 1 and Figure 2. There were no significant main effects for knowledge condition, \( F (1,56) = .01, p = .938 \), or ball weight, \( F (3,56) = .40, p = .529 \), nor was there a significant condition by weight interaction, \( F (4,56) = 1.22, p = .274 \).

Biceps Brachii: Drop Period

The mean EMG integrals in the biceps brachii for the drop period are presented in Table 2 and Figure 3. There was no significant main effect for knowledge condition, \( F (1,56) = .42, p = .52 \). However, there was a significant main effect for ball weight \( F (3,56) = 41.85, p < .001 \), as well as a significant knowledge condition by ball weight interaction \( F (4,56) = 20.21, p < .001 \). Post-hoc pairwise comparisons for ball weight revealed that participants exerted significantly stronger APAs with each increase in ball weight (1.1 lb vs. 2.9 lb, \( p < .001 \); 2.9 lb vs. 4.8 lb, \( p = .028 \); 4.8 lb vs. 6.6 lb, \( p = .02 \)).

As a follow-up to the significant knowledge condition by ball weight interaction, paired sample t-tests for ball weight within each knowledge condition were conducted. Under condition K, participants exhibited significantly stronger APAs with each increase in ball weight (1.1 lb vs. 2.9 lb, \( p < .001 \); 2.9 lb vs. 4.8 lb, \( p < .001 \); 4.8 lb vs. 6.6 lb, \( p < .001 \)). In contrast, under condition U, there were no differences in the strength of the APAs among the four different weights (1.1 lb vs. 2.9 lb, \( p = .247 \); 1.1 lb vs. 4.8 lb, \( p = .139 \); 1.1 lb vs. 6.6 lb \( p = .089 \); 2.9 lb vs. 4.8 lb, \( p = .930 \); 2.9 lb vs. 6.6 lb, \( p = .271 \); and 4.8 lb vs. 6.6 lb, \( p = .930 \)).
### Table 1
Mean EMG integrals for the pre-drop period in the biceps brachii for the known ball weight (K) and unknown ball weight (U) conditions.

<table>
<thead>
<tr>
<th>Ball weight (lb)</th>
<th>Condition</th>
<th>K (known) µVs</th>
<th>U (unknown) µVs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>1.1</td>
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<tr>
<td>2.9</td>
<td>48.48</td>
<td>±16.67</td>
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<td>4.8</td>
<td>51.02</td>
<td>±19.39</td>
<td>49.16</td>
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<tr>
<td>6.6</td>
<td>49.97</td>
<td>±20.42</td>
<td>50.70</td>
</tr>
</tbody>
</table>

### Figure 2: Mean EMG integrals for the pre-drop period in the biceps brachii for the known ball weight (K) and unknown ball weight (U) conditions.

### Table 2
Mean EMG integrals for the drop period in the biceps brachii for the known ball weight (K) and unknown ball weight (U) conditions.

<table>
<thead>
<tr>
<th>Ball weight (lb)</th>
<th>Condition</th>
<th>K (known) µVs</th>
<th>U (unknown) µVs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>1.1</td>
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<td>170.44</td>
</tr>
<tr>
<td>2.9</td>
<td>158.28</td>
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<td>4.8</td>
<td>172.68</td>
<td>±85.25</td>
<td>175.89</td>
</tr>
<tr>
<td>6.6</td>
<td>186.21</td>
<td>±89.18</td>
<td>181.47</td>
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</table>
Figure 3: Mean EMG integrals for the drop period in the biceps brachii for the known ball weight (K) and unknown ball weight (U) conditions.

**Triceps Brachii: Pre-Drop Period**

The mean EMG integrals in the triceps brachii for the pre-drop period are presented in Table 3 and Figure 4. There were no significant main effects for knowledge condition, $F(1,56) = .000$, $p = .998$, or ball weight, $F(3,56) = .40$, $p = .529$, nor was there a significant knowledge condition by ball weight interaction, $F(4,56) = 1.14$, $p = .291$.

**Triceps Brachii: Drop Period**

The mean EMG integrals in the triceps brachii for the drop period are presented in Table 4 and Figure 5. There was no significant main effect for knowledge condition, $F(1,56) = .16$, $p = .689$, but there was a significant main effect for ball weight $F(3,56) = 13.58$, $p = .001$. There was no significant knowledge condition by ball weight interaction $F(4,56)= .41$, $p = .524$. Post-hoc pairwise comparisons for ball weight revealed significant differences when comparing the lightest weight ball to the heavier balls (1.1 lb vs. 2.9 lb, $p = .002$; 1.1 lb vs. 4.8 lb, $p = .001$; 1.1 lb vs. 6.6 lb, $p < .001$). There were no differences among the other ball weight comparisons (2.9 lb vs. 4.8 lb, $p = .166$; 2.9 lb vs. 6.6 lb, $p = .066$; 4.8 lb vs. 6.6 lb, $p = .245$).
Table 3
Mean EMG integrals for the pre-drop period in the triceps brachii for the known ball weight (K) and unknown ball weight (U) conditions.

<table>
<thead>
<tr>
<th>Ball weight (lb)</th>
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<td>K (known) µVs</td>
<td>U (unknown) µVs</td>
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<tr>
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<td>±6.89</td>
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<td>±7.68</td>
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Figure 4: Mean EMG integrals for the pre-drop period in the triceps brachii for the known ball weight (K) and unknown ball weight (U) conditions.

Table 4
Mean EMG integrals for the drop period in the triceps brachii for the known ball weight (K) and unknown ball weight (U) conditions.

<table>
<thead>
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<td>K (known) µVs</td>
<td>U (unknown) µVs</td>
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<td>24.51</td>
<td>±11.66</td>
<td>26.80</td>
<td>±11.80</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>28.07</td>
<td>±14.88</td>
<td>30.30</td>
<td>±14.45</td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td>29.90</td>
<td>±14.41</td>
<td>30.67</td>
<td>±15.18</td>
<td></td>
</tr>
<tr>
<td>6.6</td>
<td>31.23</td>
<td>±15.47</td>
<td>31.84</td>
<td>±19.46</td>
<td></td>
</tr>
</tbody>
</table>
Figure 5: Mean EMG integrals for the drop period in the triceps brachii for the known ball weight (K) and unknown ball weight (U) conditions.

Wrist Flexors: Pre-Drop Period

The mean EMG integrals in the wrist flexor group for the pre-drop period are presented in Table 5 and Figure 6. There were no significant main effects for knowledge condition, $F(1,56) = .01, p = .927$, or ball weight, $F(3,56) = .37, p = .546$, nor was there a significant knowledge condition by ball weight interaction, $F(4,56) = .06, p = .816$.

Wrist Flexors: Drop Period

The mean EMG integrals in the wrist flexor group for the drop period are presented in Table 6 and Figure 7. There was no significant main effect for knowledge condition, $F(1,56) = .76, p = .389$. However, there was a significant main effect for ball weight, $F(3,56) = 58.63, p < .001$, and a significant knowledge condition by ball weight interaction $F(4,56) = 30.51, p < .001$. Pairwise comparisons for ball weight revealed that participants exerted significantly stronger APAs at the 2.9 lb ball weight than the 1.1 lb weight ($p < .001$), and stronger APAs at the 6.6 lb weight than the 4.8 lb weight ($p = .031$). The APA magnitudes at the ball weights of 2.9 lb and 4.8 lb did not differ ($p = .079$).

As a follow-up to the significant knowledge condition by ball weight interaction, paired sample t-tests for ball weight within each knowledge condition were evaluated. Under condition K, participants exhibited significantly stronger APAs with each increase in ball weight (1.1 lb vs. 2.9 lb, $p < .001$; 2.9 lb vs. 4.8 lb, $p = .010$; 4.8 lb vs. 6.6 lb, $p < .001$). In contrast, under
condition U, participants exhibited significantly stronger APAs for the 6.6 lb. ball weight than the 1.1 lb. ball weight only \( (p = .047) \). There were no other significant differences under condition U (1.1 lb vs. 2.9 lb, \( p = .256 \); 1.1 lb vs. 4.8 lb, \( p = .388 \); 2.9 lb vs. 4.8 lb, \( p = .760 \); 2.9 lb vs. 6.6 lb, \( p = .417 \); and 4.8 lb vs. 6.6 lb, \( p = .281 \).

<table>
<thead>
<tr>
<th>Ball weight (lb)</th>
<th>Condition</th>
<th>Mean (µVs)</th>
<th>SD</th>
<th>Mean (µVs)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K (known)</td>
<td>14.59 ± 7.82</td>
<td></td>
<td>14.75 ± 7.24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>U (unknown)</td>
<td>14.75 ± 7.24</td>
<td></td>
<td>15.36 ± 8.22</td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td></td>
<td>15.53 ± 7.58</td>
<td></td>
<td>15.34 ± 7.55</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td></td>
<td>14.74 ± 7.34</td>
<td></td>
<td>15.34 ± 7.55</td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td></td>
<td>15.03 ± 7.26</td>
<td></td>
<td>15.14 ± 7.40</td>
<td></td>
</tr>
<tr>
<td>6.6</td>
<td></td>
<td>15.03 ± 7.26</td>
<td></td>
<td>15.14 ± 7.40</td>
<td></td>
</tr>
</tbody>
</table>

Table 5
Mean EMG integrals for the pre-drop period in the wrist flexor group for the known ball weight (K) and unknown ball weight (U) conditions.

Figure 6: Mean EMG integrals for the pre-drop period in the wrist flexor group for the known ball weight (K) and unknown ball weight (U) conditions.
Table 6
Mean EMG integrals for the drop period in the wrist flexor group for the known ball weight (K) and unknown ball weight (U) conditions.

<table>
<thead>
<tr>
<th>Ball weight (lb)</th>
<th>K (known) µVs</th>
<th>U (unknown) µVs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>1.1</td>
<td>54.42 ±24.23</td>
<td>77.11 ±31.95</td>
</tr>
<tr>
<td>2.9</td>
<td>71.98 ±34.63</td>
<td>80.45 ±38.22</td>
</tr>
<tr>
<td>4.8</td>
<td>78.89 ±35.88</td>
<td>79.71 ±36.15</td>
</tr>
<tr>
<td>6.6</td>
<td>85.11 ±33.36</td>
<td>82.70 ±34.92</td>
</tr>
</tbody>
</table>

Figure 7: Mean EMG integrals for the drop period in the wrist flexor group for the known ball weight (K) and unknown ball weight (U) conditions.

Catching Side Lumbar Erector Spinae: Pre-Drop Period

The mean EMG integrals in the erector spinae at the L4-L5 level on the catching side (right) for the pre-drop period are presented in Table 7 and Figure 8. There were no significant main effects for knowledge condition, $F(1,56) = .03$, $p = .855$, or ball weight, $F(3,56) = .43$, $p = .516$, nor was there a significant knowledge condition by ball weight interaction, $F(4,56) = .12$, $p = .729$. 
Catching Side Lumbar Erector Spinae: Drop Period

The mean EMG integrals in the erector spinae at the L4-L5 level on the catching side (right) for the drop period are presented in Table 8 and Figure 9. There was no significant main effect for knowledge condition, $F(1, 56) = .42, p = .520$, but there was a significant main effect for ball weight, $F(3, 56) = 6.11, p = .017$. There was no significant knowledge condition by ball weight interaction, $F(4, 56) = 1.49, p = .227$. Post-hoc pairwise comparisons for ball weight revealed significant differences when comparing the lightest weight ball to the two heaviest ball weights (1.1 lb vs. 4.8 lb, $p = .036$, and 1.1 lb vs. 6.6 lb, $p = .007$). There were no other differences among ball weights (1.1 lb vs. 2.9 lb, $p = .057$; 2.9 lb vs. 4.8 lb, $p = .753$; 2.9 lb vs. 6.6 lb, $p = .640$; 4.8 lb vs. 6.6 lb, $p = .201$).

<table>
<thead>
<tr>
<th>Ball weight (lb)</th>
<th>Condition</th>
<th>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K (known)</td>
<td>µV</td>
<td></td>
<td>U (unknown)</td>
<td>µV</td>
</tr>
<tr>
<td>1.1</td>
<td></td>
<td>13.47</td>
<td>±6.96</td>
<td>13.59</td>
<td>±6.60</td>
</tr>
<tr>
<td>2.9</td>
<td></td>
<td>14.42</td>
<td>±7.07</td>
<td>14.72</td>
<td>±7.57</td>
</tr>
<tr>
<td>6.6</td>
<td></td>
<td>13.74</td>
<td>±6.23</td>
<td>14.06</td>
<td>±6.87</td>
</tr>
</tbody>
</table>
Figure 8: Mean EMG integrals for the pre-drop period in the erector spinae at the L4-L5 level on the catching side for the known ball weight (K) and unknown ball weight (U) conditions.

Table 8:
Mean EMG integrals for the drop period in the erector spinae at the L4-L5 level on the catching side for the known ball weight (K) and unknown ball weight (U) conditions.

<table>
<thead>
<tr>
<th>Ball weight (lb)</th>
<th>Condition</th>
<th>K (known) µVs</th>
<th>SD</th>
<th>U (unknown) µVs</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Mean</td>
<td>15.53</td>
<td>±6.51</td>
<td>17.18</td>
<td>±7.36</td>
</tr>
<tr>
<td>2.9</td>
<td>Mean</td>
<td>16.78</td>
<td>±6.98</td>
<td>18.13</td>
<td>±7.34</td>
</tr>
<tr>
<td>4.8</td>
<td>Mean</td>
<td>16.83</td>
<td>±6.61</td>
<td>17.77</td>
<td>±7.01</td>
</tr>
<tr>
<td>6.6</td>
<td>Mean</td>
<td>17.44</td>
<td>±6.63</td>
<td>17.95</td>
<td>±6.79</td>
</tr>
</tbody>
</table>
Non-Catching Side Lumbar Erector Spinae: Pre-Drop Period

The mean EMG integrals in the erector spinae at the L4-L5 level on the non-catching side (left) for the pre-drop period are presented in Table 9 and Figure 10. There were no significant main effects for knowledge condition, $F(1,56) = .05, p = .821$, or ball weight, $F(3,56) = 1.10, p = .299$, nor was there a significant knowledge condition by ball weight interaction, $F(4,56) = .18, p = .674$.

Non-Catching Side Lumbar Erector Spinae: Drop Period

The mean EMG integrals in the erector spinae at the L4-L5 level on the non-catching side (left) for the drop period are presented in Table 10 and Figure 11. There was no significant main effect for knowledge condition, $F(1,56) = .13, p = .721$, but there was a main effect for ball weight $F(3,56) = 9.10, p = .004$. There was no significant knowledge condition by ball weight interaction $F(4,56)= 1.58, p = .215$. Post-hoc pairwise comparisons for ball weight revealed significant differences when comparing the lightest ball to the two heaviest balls (1.1 lb vs. 4.8 lb, $p = .020$, and 1.1 lb vs. 6.6 lb, $p = .002$). There were no differences among the other ball weights (1.1 lb vs. 2.9 lb., $p = .064$; 2.9 lb vs. 4.8 lb, $p = .804$; 2.9 lb vs. 6.6 lb, $p = .268$; 4.8 lb vs. 6.6 lb, $p = .274$).
Table 9
Mean EMG integrals for the pre-drop period in the erector spinae at the L4-L5 level on the non-catching side for the known ball weight (K) and unknown ball weight (U) conditions.

<table>
<thead>
<tr>
<th>Ball weight (lb)</th>
<th>Condition</th>
<th>K (known) µVs</th>
<th>U (unknown) µVs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>1.1</td>
<td>17.69 ± 8.44</td>
<td>17.96 ± 8.92</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>17.89 ± 8.77</td>
<td>18.53 ± 8.63</td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td>18.08 ± 8.76</td>
<td>18.61 ± 9.08</td>
<td></td>
</tr>
<tr>
<td>6.6</td>
<td>17.85 ± 8.49</td>
<td>18.46 ± 8.99</td>
<td></td>
</tr>
</tbody>
</table>

Figure 10. Mean EMG integrals for the pre-drop period in the erector spinae at the L4-L5 level on the non-catching side for the known ball weight (K) and unknown ball weight (U) conditions.
### Table 10
Mean EMG integrals for the drop period in the erector spinae at the L4-L5 level on the non-catching side for the known ball weight (K) and unknown ball weight (U) conditions.

<table>
<thead>
<tr>
<th>Ball weight (lb)</th>
<th>Condition</th>
<th>Mean (K)</th>
<th>SD (K)</th>
<th>Mean (U)</th>
<th>SD (U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>K (known) µV</td>
<td>20.33 ± 8.06</td>
<td>21.79 ± 9.48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>U (unknown) µV</td>
<td>21.47 ± 6.99</td>
<td>22.67 ± 9.88</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.8</td>
<td>K (known) µV</td>
<td>22.00 ± 9.41</td>
<td>22.41 ± 9.61</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.6</td>
<td>U (unknown) µV</td>
<td>22.42 ± 9.59</td>
<td>22.82 ± 9.98</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Figure 11: Mean EMG integrals for the drop period in the erector spinae at the L4-L5 level on the non-catching side for the known ball weight (K) and unknown ball weight (U) conditions.

### Discussion

The nature of APAs in self-induced perturbations of postural stability is well understood. However, the role of APAs in externally-induced perturbations, such as those that could occur in catching, have not been studied extensively. Previous research has demonstrated that APAs can occur in ball catching when the catcher knows the weight of the ball to be caught and has visual information about time-to-contact (Lacquaniti & Maioli, 1989 a & b; Shiratori & Latash, 2001). In this context, the role of an APA is to predict the stability perturbing forces to be imposed by the ball on the catcher, and produce a defensive muscular contraction (i.e., APA) in order to
stabilize the body in advance of the actual catch. However, ball weight is not always known or predictable, yet it is generally possible to catch balls of unknown weights. It is unclear how the CNS copes with an unknown weight in terms of the generation of APAs in catching. The purpose of this experiment was to determine the effect of the knowledge of ball weight on APAs in a one-handed catching task. My goal was to better understand how the CNS copes with uncertainty about ball weight, in terms of its use of APAs. I hypothesized that APA magnitude would be greater under an unknown ball weight condition than a known ball weight condition, and that the APA magnitude at each weight in the unknown ball weight condition would be equal to or greater than the APA magnitude for the heaviest ball under a known ball weight condition.

**Pre-Drop Period**

During the 1 s prior to ball drop, whether participants had knowledge of the weight of the ball to be caught had no effect on the magnitude of the APAs generated in all five muscles evaluated. In other words, in advance of the drop of the ball, the CNS did not prepare the musculature differently when the ball weight was unknown compared to when the ball weight was known. Not only were there no main effects for knowledge condition, neither were there any main effects for ball weight or knowledge condition by ball weight interactions. In short, the CNS seems to behave similarly in the period just prior to ball drop regardless of the knowledge status concerning the weight of the ball, and regardless of the actual weight of the ball, at least for the range of ball weights used in the present study (1.1 - 6.6 lbs.). It would be interesting to find out if ball weights heavier than 6.6 lb. would provoke a differential response by the CNS prior to ball drop.

It is noteworthy that the present experiment used a random and variable foreperiod of between 5 and 12 seconds to prevent participants from being able to temporally anticipate the precise time of ball drop. Future research will investigate whether the CNS behaves differently when a constant foreperiod is employed. That is, if the participant knows precisely when the ball will be dropped, will muscle activity ramp-up as the drop time approaches, and if so, will muscle activity ramp-up differently for known and unknown ball weight conditions?

**Drop Period**

During the drop period, as in the pre-drop period, whether or not participants had knowledge of the weight of the ball to be caught had no statistically significant effect on the magnitude of the APAs generated in all five muscles evaluated. However, in all five muscles,
the mean APA integral in the unknown weight condition exceeded that of the known weight condition. This trend suggests that uncertainty about ball weight may indeed result in a small increase in APA activity during the drop period.

There were main effects for ball weight in all muscles. That is, when data were collapsed across knowledge condition, ball weight had an effect on the APAs during the drop period, with heavier balls producing APAs of greater magnitude. One would expect heavier balls to elicit greater APA activity in order to counteract the more profound stability perturbations likely when catching heavier balls. What is most interesting, however, were the significant knowledge condition by ball weight interactions revealed for the biceps and wrist flexor muscles. The biceps brachii and wrist flexor muscles are prime movers of the elbow and wrist, respectively, in this catching task. In the known condition for both the biceps and wrist flexors, participants exhibited significantly stronger APAs with each increase in ball weight. In contrast, under unknown condition, there were no differences in APA strength among the four different weights in the biceps muscle, and only a single difference between the 1.1 lb ball and the 6.6 lb ball in the wrist flexors. During the drop period in both muscles, the APA magnitudes for all ball weights in the unknown condition, were similar to the APA magnitudes for the two heaviest ball weights in the known condition.

At least in the biceps and wrist flexors, my hypothesis that when the weight of the ball is not known, the CNS will prepare the musculature to catch the heaviest ball, is confirmed. It makes sense that the CNS prepare this way in order to complete the catching action. If the CNS produces weaker APAs than needed to complete the catch, the ball will simply hit the hand and fall to the ground because there was not enough muscle activity to stabilize the hand, arm and body and complete the catch. If the CNS produces stronger APAs than needed, the catch can still occur, albeit not very efficiently.

Limitations and Conclusions.

This research study had two primary limitations. The first concerned the focus on college aged male participants, who were considered to be athletic as well, which prevents us from generalizing our finding to not only college age females and non-athletic college aged males, but also to middle aged and older individuals. Secondly, the EMG signal for anterior deltoid was corrupt. This would be useful information to have and should be considered for future research to determine if all the agonist muscles, involved in catching, act differently than the antagonist.
muscles. It is also important to point out that the majority of the subjects were athletic individuals, meaning they regularly participated in some sort of sport involving hand-eye coordination. It is possible that these individuals react differently than non-athletic individuals in terms of how the CNS prepares them for the uncertainty involved in this task.

This research showed that uncertainty about a ball weight does affect APAs in catching in the five muscles examined. The body does not seem to prepare any differently until the load is dropped. Thus a significant effect is not seen until the Drop Period. The knowledge condition alone does not produce as significant effect, but when paired with varying ball weights an interaction effect does exist. Future research should look at a wider range of ball weights as well as adjusting other impact parameters, such as drop height. Future research should also include examining the APAs when the period before ball drop is not varied and the ball drop time is consistent. It is possible that acquiring a base integral from a maximal voluntary contraction could also assist in finding significant. This would be helpful due to the variability in the EMG data when using surface electrodes. It may also be useful to examine the onset of the muscles and look at APAs based on onset.
References


