Spring 6-15-2020

Kinesthetic Aftereffects and Anticipation Timing of a Weighted Bat Warm-up in Softball Players

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Exercise and Sport Science

Submitted in Partial Fulfillment of the
Requirements for the Degree of Bachelor of Science
In the HTC Honors College at
Coastal Carolina University

Summer 2020

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Abstract

It has long since been a tradition for baseball players to use weighted bats in the on-deck circle and for many sport companies to market these training aids with promises to “increase swing velocity” and “improve hand speed and strength”. Increased research in the area has indicated the potential adverse effects of weighted-bat warm up, including potential impacts on swing mechanics, bat swing velocity, and anticipation timing. Since bat swing velocity and interceptive timing are crucial elements to success in baseball and softball batting, there is a need to further investigate the effects of weighted bat warm-up. In this study, female subjects will perform several maximal effort swings with a softball bat following two different warm-up conditions. They will partake in a total of three different sessions: an initial familiarization session and two more subsequent experimental trials that will utilize the Modified Bassin anticipation timer (Lafayette Instruments) to simulate a game-like hitting scenario. Data relevant to anticipation timing, bat swing velocity, temporal error and subjective swing perception will be recorded and properly analyzed. Research examining the effects of weighted implement warm up on performance has primarily centered on the measured outcome of swing velocity. Collectively, results have demonstrated little impact of a weighted bat warm up on actual bat swing velocity. Findings from research that investigates subjective-objective mismatches of perceived versus actual bat swing velocity, however, seems to suggest that a weighted implement warm-up can influence an individual’s perceived “kinesthetic aftereffects” and subsequently affect their anticipation-timing performance.

Keywords: anticipation timing, temporal error, bat swing velocity, kinesthetic after effects

Review of Literature

Studies conducted by Soviet researchers and track and field coaches with shot put, javelin and discus throwing athletes in the late 70s and early 80s demonstrated that weighted implement training can potentially facilitate speed strength development (Konstantinov, 1979 & Kanishevsky, 1984). More specifically, they suggested that the weight of any implements used should range only between 5 and 20 percent heavier or lighter than that of the "standard" weight and should be used in a 2:1 frequency ratio of heavy or light implement weight to standard weight (Vasiliev,1983). Results from such studies encouraged similar exploration in other areas of athletic performance, such as the skill of baseball batting, including literature that examines the various kinematic aftereffects of weighted implement training and/or warm-up (Derenne & Szymanski, 2009).

Weighted implement training for baseball hitting involves swinging with either under or overweight bats relative to the "standard" weight bats (typically around 30 ounces) used during competitive games. Such training can be incorporated either in a practice or warm-up regimen to facilitate increased swing velocity, with the ultimate goal of increasing ball exit speeds and enhancing chances of success in the sport ((Derenne & Szymanski, 2009). A wide variety of these weighted devices exist, including "donut rings", "power swing fans", and "power tubes", all of which can be attached to a standard bat for increased swing resistance (Derenne & Szymanski, 2009).

Results from research on the effects of weighted implements seem to vary. For example, research by DeRenne and colleagues found that warming up with implements weighing either 12% heavier or 12% lighter than that of the "standard" weight produced the highest swing velocities, whereas implements outside of this range (lighter than 27 ounces or heavier than 34 ounces) actually decreased velocity (DeRenne, Hetzler, & Chai, 1992). Studies by Montoya and colleagues expanded on this, with their results suggesting that heavy implements have more adverse effects than lighter ones: “light” and “normal” bats (9.6 and 31.5 ounces respectively) produced significantly faster post warm-up swing velocities than did warming up with the “heavy” bats (55.2 ounces) (Montoya, Brown, Coburn, & Zinder, 2009). Further, research by Southard and Groomer (2003) suggests that using bats weighing closest to that of the “standard” game bat is optimal for increased performance, and that choosing overly heavy implements can potentially change the kinematics of an athlete’s swing pattern. Doing so was shown to increase the moment of inertia, which in turn decreases the resultant swing velocity and changes the athlete’s swing pattern (Southard & Groomer, 2003). These findings support those reported earlier by DeRenne et al (1992) that suggest choosing weighted warm-up implements within 12% heavier or lighter of “standard” game bats is optimal for game performance.

- **Weighted Implement Training and Swing Velocity**

Research in this area has also explored the concept of weighted implement resistance training, in which athletes partake in a preseason power training program designed specifically to enhance batting performance and increase swing velocity. DeRenne and Okasaki (1983) conducted a study in which ex-college and professional baseball players swung overweighed implements (a 34 ounce wooden bat and a power swing device) for 7 weeks and reported significant increases in swing velocity. In another study by DeRenne and colleagues (1995) for 12 weeks players swung a total of 150 swings 4 times a week: 100 swings with either an under- or over-weighted implement and 50 additional swings with their standard game bat. The participants were randomly assigned to either the batting practice, “dry swing” or control group, in which the batting practice group hit live pitched balls while alternating between over, under and standard weight bats and the "dry swing" group simply performed practice swings while alternating between weighted bats (Derenne, Buxton, Hetzler, & Ho, (1995). These authors reported significant increases of nearly 10% in bat swing velocities after the 12 week training study and suggested that these improvements were likely due to a transfer of learning effect from using "loads specific to the target activity" (i.e., baseball swinging) while also implementing enough variation in weight to induce training adaptation (Derenne et al., 1995). Sergo and Boatwright (1993) conducted a similar 6-week resistance training study in which the control group swung any bat of preference, a second group swung a 62 ounce bat and a third group alternated between the 62-ounce bat and a light bat. These authors found increases in swing velocity among all three groups, whereas DeRenne at al. (1995) did not find any improvements in their control group.

Considering these results, it is generally agreed upon that implementing a weighted-bat training protocol (240-600 swings per week for anywhere between 6-12 weeks) can result in increased bat swing velocity and should be incorporated in the pre-season (DeRenne & Szymanski, 2009). However, given the potential adverse effect of altering swing mechanics, there is still some concern from coaches and researchers alike with using overly-heavy bats in training (DeRenne et al., 1993).

- **Swing Kinematics**

More recent research seems to suggest that weighted implement warm-up directly before game performance does not actually produce any significant differences in post warm-up swing velocities or swing mechanics. A particular study examining the effects of 10 different weighted implement devices found no notable differences in average post warm-up swing velocity even though the weight of these devices ranged from 22 to 96 ounces (Szymanski, Beiser, Bassett, Till, Medlin, Beam, & DeRenne). Another study with NCAA division 1 baseball players also found that weighted implement warm up did not significantly influence any of the examined kinematic variables of interest (Williams, Wilson, Cazas-Moreno, Eason, Hoke, Allen, Wade, & Garner, 2019). An interesting study conducted by Reyes and Dolny (2009) sought to explore the effects of diverse warm up protocols by varying the sequence of "standard", "light" and "heavy" bats swung, however none of the 9 different protocols used produced any significant differences in post warm-up swing velocity.

A possible explanation for these differing research results seems to be age, as well as experience level. Studies that demonstrated no significant effects on post warm-up swing velocity or swing kinematics used collegiate, NCAA DI and DIII baseball players, whereas those that did find notable differences primarily used high school or recreational players. Given that collegiate players have designated time set aside for hitting practice, as well as structured strength and conditioning, they should possess a more highly developed swing pattern that is less susceptible to the potential kinematic aftereffects of using weighted warm-up implements than those of high-school aged, recreational players (DeRenne &Szymanski, 2009).

Results from Kim, Yand, and Hinrichs (2005) were similar in that no significant differences in post warm-up swing velocities were found; in addition, their research subjects interestingly reported feeling as if they were swinging "significantly faster" after warming up with a heavy implement. This suggests that weighted implement training can potentially influence perceived kinesthetic aftereffects, or the athlete's subjective feeling of how they are moving. According to Sage (1984), kinesthetic aftereffects are the perceived changes in either the physical characteristics of an object such as its size, shape or weight, or those changes an individual might perceive in their movement limb position or overall muscular force production.

Aftereffects such as these were observed by Otsuji et al. (2002), during which subjects described their “normal” weight bat as feeling lighter in addition to believing that they could swing it faster following a weighted implement warm-up, despite the fact that doing so actually proved detrimental to their post warm-up swing velocity and should not have elicited such perceptions.

- **Kinesthetic Aftereffects and Anticipation Timing**

The kinesthetic aftereffects described above relate to the topic of anticipation timing. In terms of baseball or softball batting, temporal anticipation, in which an individual must produce a motor response coincident with some external event, is critical to success (Marinovic, Plooy, & Tresilian, 2008, 2010). More specifically, an effective combination of receptor and effector anticipation is crucial for the interceptive action of baseball hitting: receptor anticipation involves the estimated time of arrival of the baseball itself and effector anticipation involves the estimated time needed to perform the interceptive action of physically swinging the bat (Poulton, 1950, 1957, 1965). According to research done by Tresilian (2005), successful interceptive action is largely related to being aware of one’s own movement time, combined with the experience of any subjective factors, such as swing velocity expectations or perceived bat weight. This indicates that perceived kinesthetic aftereffects similar to those documented by Kim, et. al (2005) and Otsuji et al. (2002), could alter the hitter’s interceptive strategy and potentially degrade their batting performance. This outcome of mismatched subjective feelings and actual swing outcomes is further supported by research from Scott and Gray (2010), which demonstrated larger anticipation errors accompanied by altered swing velocities following weighted bat warm-up. Research by Nakamoto, Ishii, Ikudome and Ohta (2012) did not exactly replicate this same subjective-objective mismatch, however, they did demonstrate that the effects of weighted implement warm-up do play a large role in interceptive tasks that are highly dependent on successful anticipation. More specifically, they concluded that perceptual-motor control was negatively impacted by this warm-up and did not recommend it for “actual athletic situations” (Nakamoto et al., 2012).

Research examining the effects of weighted implement warm up on performance has primarily centered on the measured outcome of swing velocity. Collectively, results have demonstrated little impact of a weighted bat warm up on actual bat swing velocity. However, more recent research has investigated the effects of a weighted bat warm up on subjective-objective mismatches of subjects’ perceived swing velocity compared to actual measured velocity. Findings suggest that a weighted implement warm-up in baseball batting can influence an individual’s perceived “kinesthetic aftereffects” and subsequently affect their anticipation-timing performance. More specifically, the bat warm-up weight might impact the individual’s effector anticipation, or their estimated movement time needed to perform the interceptive action of physically swinging the bat to time the arrival of the incoming ball.

➢ **Purpose of Study**

The limited research investigating the effect of weighted bat warmup on the outcome of anticipation-timing performance have yielded mixed results and is in need of replication and extension. It is likely that bat warm up weight might interact with other variables impacting anticipation-timing performance, such as task experience, gender, and age. While this past research used male subjects in the sport of baseball, the present study uses female softball players to examine any potential subjective-objective mismatches in this population and to measure the relationship between weighted implement warm-up and effect on anticipation-timing. The purpose of this study was to compare differences in anticipation timing and kinesthetic aftereffects observed between those who participated in a weighted bat warm up and those who did not.

Methods

The anticipated subjects for this study were 10-12 current Coastal Carolina female who were members of the club softball team. This particular demographic was targeted due to the expected experience level of each player seeing as this campus organization travels to compete in competitive tournaments and even holds tryouts and subsequent "cuts" before each season. Subjects were also required to show no indication of current or previous injury that would prevent them from participation, such as injury of the lower back, shoulder, elbow, and/ or wrist.

Each subject was asked to perform multiple maximal effort swings with a softball bat following two different warm-up conditions. They took part in a total of three different sessions. The first familiarization session consisted of paperwork and subject orientation to the experimental setup. The order of the second and third sessions was randomized and consisted of the control and experimental sessions, respectively. All sessions were performed on separate non-consecutive days. All sessions utilized the Modified Bassin anticipation timer (Lafayette Instruments), which was composed of a track containing a series of LED lights and an infrared beam located at the end of the track. The LED lights were lit in sequence giving the illusion of an oncoming object, and the speed of these approaching lights was set to near average softball pitching speeds. The goal was to swing the bat across the infrared beam at the moment the oncoming object reached the end of the track to simulate a game-like hitting scenario. Information regarding temporal errors was provided via a computer software program connected to the anticipation timer. A high-speed radar device was placed directly in front of each subject in order to determine bat speed of each swing.

The familiarization session allowed each subject to become familiar with this experimental setup and allowed for the completion of paperwork (informed consent, a health history questionnaire, and a survey of previous playing experiences). The two testing sessions employed a standardized and proper warm-up protocol prior to testing. The warm up protocol consisted of light movements/calisthenics, select stretches and several progressively increasing bat swings using either a standard weight bat or a weighted bat, per their testing condition. The subject concluded the warm up by performing five swings at maximal effort in their testing condition. During the control session, each subject employed the warm-up protocol, but used a standard weight bat for their 5 maximal swings. During the experimental session, subjects employed the warm-up protocol and performed 5 maximal swings with the weighted bat. Subjects were then allotted 20 seconds following their designated warm up and 5 maximal swings before completing 4 test trials with the anticipation timer. 30 seconds of rest were provided between each trial. In real-game scenarios, batters who employ a weighted warm-up will typically put down the weighted bat and briefly swing their "normal" game bat before stepping into the box. Subjects were given the opportunity to do the same during the allotted 20 seconds to simulate this transition from the on-deck circle to the batter's box. They completed 3 blocks of these trial swings, for a grand total of 12 recorded swings in each session. Following each session, subjects were also asked to fill out a brief, subjective survey regarding their individual perception of bat swing velocity based off their assigned warm-up or testing condition (see Appendix B)

- **Data Analysis**

Three dependent variables were employed in this study: (1) bat swing velocity (BV), (2) anticipation-timing performance, or the absolute timing error (AE), and subjective perception of bat swing velocity (SP). BV and AE were subjected to a one-way ANOVA between the two conditions, Standard (S) or Weighted (W). Appropriate post-hoc statistical tests were conducted to determine significant group differences ($p<.05$) in the BV and AE. For subjective perception of swing velocity (SP), only the means for each condition was calculated and compared. BV was calculated at just the impact point (i.e., the end of the trackway). To compare the difference in anticipation-timing performance between the control and experimental groups, we analyzed temporal errors via a computer software program that was connected to the anticipation timer. Appendix A is the data recording sheet for BV and AE. Appendix B shows the rating for SP.

Results and Discussion

Given the Covid19 pandemic situation, this section provides the projections of the possible results and related interpretation and discussion of several possible findings.

Projected Differences in Bat Swing Velocity

In the event of observed differences in bat swing velocity, this finding would align with past research that used bat swing velocity as the primary dependent measure, similar to Nakamoto et. al, (2012). This particular study observed "marginal" differences in bat swing velocity between the weighted and normal conditions in which participants who warmed up with weighted bats produced high swing velocities than those who did not. Several other research studies have replicated similar findings and it seems possible that observed faster swings following a weighted implement warm up occur as a result of changed muscle force generation (Nakamoto et. al, 2012).

Research by Kauffman & Greenisen, (1973) found that swinging a heavier bat generates greater neural activity not only in the agonist muscles recruited for the action of swinging a bat, but in the antagonist muscles as well, which would possibly explain observed decreases in bat swing velocity following a weighted warm-up.

Figure 1: Projected Differences in Bat Swing Velocity (BV)

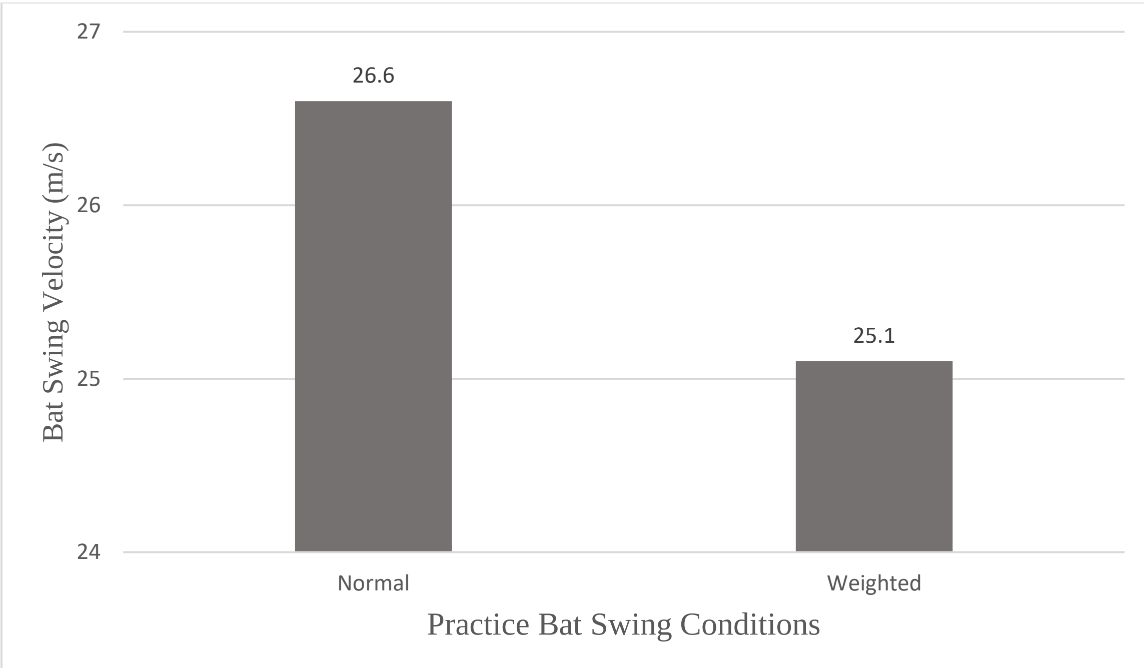

Figure 1 illustrates the projected differences in bat swing velocity (BV) between the control and experimental groups. Average bat swing velocity in the weighted warm up group was observed to be slightly slower than that found in the control group.

Projected Differences in Anticipation-Timing

The uniqueness of this study was the measurement of warm-up condition on anticipation-timing performance. Based on recent research, we expected to find some differences in anticipation-timing, independent of bat swing velocity differences. Absolute values in temporal error (ATE) would be larger in the weighted warm-up condition than in the standard warm up condition.

Nakamoto et. al, (2012) reported that kinesthetic aftereffects induced from a weighted implement warm up frequently resulted in either early or late response errors. According to the authors, the early response tendency that was observed supports the theory that weighted warm up conditions can elicit central system interferences that can impact effector anticipation, interceptive timing, and perceptual motor-control used for dynamic anticipation situations Nakamoto et. al, (2012).

Participants from the Nakamoto et. al, (2012) study felt as if their "standard" bat was lighter and that they could swing it faster after engaging in a weighted warm-up, and these perceptions aligned with recorded bat swing velocities: heavy warm-up conditions produced faster bat swing velocities. As mentioned previously, however, this study also reported larger ATE values in the weighted group compared to the control, which suggests that kinesthetic aftereffects have a "selective effect" on movement timing correction. Literature suggests that once a final motor pattern is generated for fast interceptive actions (like baseball/softball hitting), movement is more difficult to correct (Nakamoto et. al, 2012). Nakamoto et al, (2012) highlighted this and intentionally varied their stimulus speeds in order to allow batters enough time to correct their movement and examine its effect on anticipation error. When presented with the "decreasing target" stimuli (i.e, slower stimulus speed), those in the control group displayed slower swing velocities in adjustment, whereas those in the weighted warm-up group did not. In other words, these batters were not able to slow down their swings enough in order to adequately adjust their movement duration. This seems to suggest that acute kinesthetic aftereffects induced from a weighted warm-up affects motor programming and influences the batter's movement timing correction process (Nakamoto, et, al, 2012).

In comparison to Nakamoto et. al (2012), the methods of this study differed in that this study did not vary the speed of the oncoming stimulus. The only variable manipulated in this study was the weight of the warm-up implement, whereas Nakamoto et. al (2012) was slightly more involved and incorporated a "33% chance of velocity decrement or a spatial shift". It could be possible that this study would not produce the same kind of early or late response errors that were observed in Nakamoto et. al (2010), due to the fact that the stimulus speed would have remained constant and might have proven easier for the batters to accurately "intercept" the stimulus following their designated warm-up protocol.

Figure 2: Projected differences in anticipation-timing performance (absolute timing error, AE)

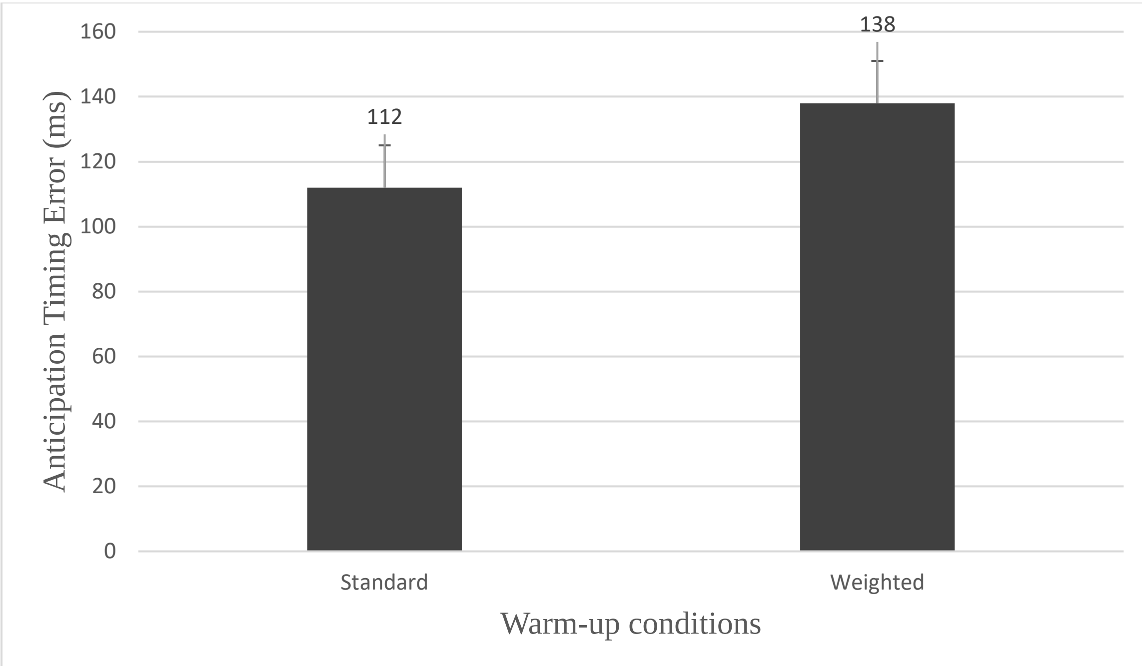

Figure 2 illustrates the projected differences in anticipation timing performance between weighted bat and standard weight bat warm up. Statistically significant differences were found ($p<.05$) among the groups; weighted bat warmup produced more anticipation timing error compared to standard bat warm up.

Projected Differences in Perception of Bat Swing Velocity

In regards to expected individual swing perceptions and based on previous research, it would be likely that this study would find that the experimental group who completed their warm-up with a weighted implement would report more changes in altered swing perception (See Appendix B) than the control group who warmed up with a standard weighted bat. Mentioned earlier, results from Kim, Yand, and Hinrichs (2005) demonstrated kinesthetic aftereffects of a weighted bat warm-up; their subjects' reported feeling as if they were swinging "significantly faster" after warming up with a heavy implement, and this study would likely yield similar results.

According to the computational theory, which suggests that the mind operates similar to a computer, sensory awareness increases when predictions, or efference copies, do not match what actually happens (afferent information) (Nakamoto et. al, 2012). Considering that weighted implement warm-up tends to elicit the perception of increased bat swing velocity after switching to a "standard" bat and implementing concepts from this theory, having the prediction of a faster swing would actually produce a slower one.

Research on movement correction in "fast ball sports" says that athletes develop predictive mechanisms of their movement by using these efference copies in a continuous central feedback loop as a way to accurately estimate what their movement will actually be (Nakamoto et. al, 2012). Movement adjustment is then made with the help of "comparators", whose role is to improve anticipation and planning by comparing predicted feedback with actual feedback. Thus, batters who engage in weighted warm up, who in theory, have distorted their efference copies and subsequent error detection and movement prediction capabilities, will not be as effective at correcting their swings (Nakamoto et. al, 2012).

Due to the use of less complex methods of this study, we would expect to find small differences (though not statistically significant) in subjective perception of bat swing velocity.

Summary, Conclusions, and Future Directions

Swing velocity and effective timing are key elements to success in the interceptive action of baseball and softball batting. Warm-up swings with a weighted bat before switching to a standard bat in the subsequent competitive situation have previously been believed to increase swing velocity and hitting success. While the body literature that examines the effect of weighted implement warm-up is expanding, the majority of research employs male baseball players rather than female softball players. It remains important to conduct and replicate studies like this for the sport of softball.

The anticipated findings of this study likely demonstrated slower bat swing velocities following a weighted bat warm-up, similar to those found by Otsuji & Kinoshita, (2002). Similar to bat swing velocity, this study also demonstrated observed noticeable differences in individual perception of bat swing velocity: individuals felt as if they swung faster and that bat was lighter after a weighted bat warm up, as is the case in the majority of other research studies. It was also expected that statistically significant differences would be found in anticipation timing error after engaging in a weighted warm up compared to a standard warm up. These findings are similar to those demonstrated by Nakamoto et. al, (2012), in which significant differences were found in both subjective bat swing velocity and weight between the weighted group and the standard group, as well as differences in interceptive timing performance and absolute timing error.

Improvement was needed in subject number. This study was projected to employ 10-12 club-level college softball players; recruiting more subjects would have generated more data and better interpretations of the findings. It also stands to reason that the experimental conditions requested of the subjects was markedly different than conditions actually experienced during real, competitive play; hitting a live-pitched softball is much different than swinging to try and meet an oncoming stimulus displayed by a Modified Bassin anticipation timer. The temporary and unfamiliar parameters of the experiment could have impacted anticipation timing and subsequent interceptive performance.

In terms of practical application, it seems that the adverse effects of weighted bat warmups counterbalance any of the possible benefits and shouldn't necessarily be recommended. While the subjective perception of feeling like the swing is faster is understandably attractive to many players and might seem beneficial for game performance, alterations in movement programming/correction and error detection will likely have a negative effect on success in baseball/softball batting. Although extended research is still needed, it appears as though performers would do best to warm up with their "standard" game bat and that warming up in the on-deck circle with an overly heavy bat or using weighted devices such as "donuts" should not be recommended. Perhaps athletes could instead engage in specific off-season strength training programs that incorporates swinging with heavier bats rather than only using them in an on-deck circle just minutes before entering game play.

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Appendix A

Subject Name: ____

Date: ____

Experimental or control condition: ____________________________

Maximum bat swing velocity: ________________________________

Session 1 Date: ___________________

Block 1	Bat Swing Velocity	Timing Error
Trial 1		
Trial 2		
Trial 3		
Trial 4		
Average		

Block 2	Bat Swing Velocity	Timing Error
Trial 1		
Trial 2		
Trial 3		
Trial 4		
Average		

Block 3	Bat Swing Velocity	Timing Error
Trial 1		
Trial 2		
Trial 3		
Trial 4		
Average		

Appendix B

Subject Name: ____

Date: ____

Experimental or control condition: ______________________________

Maximum Bat Swing Velocity: __________________________________

Session 1 Date: _____________________

Please describe your perception of your bat swing velocity following today's warm-up. For example, after switching to the "game bat" after your 5 max effort swings, did you feel as if you swung faster, slower, or did you feel no noticeable change at all? Please circle ONE of the following:

7 Significantly faster

6 Somewhat faster

5 Only slightly faster

4 No change

3 Significantly slower

2 Somewhat slower

1 Only slightly slower