Choice of End State Comfort Based on Time Spent at the Beginning State and the Precision Requirement of the End State

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CHOICE OF END STATE COMFORT BASED ON TIME SPENT AT THE BEGINNING STATE AND THE PRECISION REQUIREMENT OF THE END STATE

by

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Capstone submitted in partial fulfillment of the requirements for graduation with

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ABSTRACT

People choose actions based on many different variables. In particular, choice of posture while grasping an object typically depends upon several factors including the time spent in that posture, what postures were held prior to choosing that posture, and the precision required by the posture. The purpose of this study was to test a trade-off between choice of end-state comfort based on time spent in a posture at the beginning-state and the precision requirement of the end-state. A comfortable grasp is classified when a person has a full grasp on an object with their thumb pointing up. This posture also puts the wrist in its joint midrange which allows for more control (or precision). This means that a comfortable posture often affords the most precision in movement as well. To determine the trade-off between choice of comfort and choice of precision, we varied how long a subject had to hold the beginning state before moving an object to an end location (a hole). We made the end-state precision either small or large. When the requirement was to hold the initial grasp longer, and the end-target was large, we predicted that we would see more comfortable postures adopted at the beginning state, whereas, when the final placement was small and the initial posture was not constrained, we predicted we would see comfort adopted at the end state. A choice of comfort or precision would be demanded by the conditions with long beginning-state hold times and high precision demands. We aimed to determine which aspect of movement was of greater importance to individuals, overall comfort or precision. We found that as beginning-state grasp time increased, individuals adopted a beginning-state comfort grasp which minimized their precision at the end-state. This was true for both small targets and large targets. We also found a difference between grasp choices for large and small targets when the beginning-state grasp time was constrained under 5 seconds. Individuals maintained an end-state comfort grasp technique longer with the small target (high precision) versus the large target (low precision).
Acknowledgements

I would like to thank Dr. Breanna Studenka for all the hard work and exceptional help she gave me during this capstone experience. This project would not have been possible without her. I would also like to thank Julio Hernandez for his help in setting up the project and collecting data on our research team. I express appreciation to the Emma Eccles Jones College of Education and Human Services at Utah State University and the Department of Kinesiology and Health Science for allowing us to use their facilities and the Undergraduate Research and Creative Opportunities (URCO) grant for funding.
Introduction

There are multiple ways in which an individual can choose to grasp or move an object. Factors that influence an individual's decision include the size and shape of the object and the intention behind moving or grasping the object (Rosenbaum & Jorgensen, 1992). Precision requirements of the task (Short & Cauraugh, 1999) and the tasks that were performed before and after the grasp are to be considered as well (Studenka, Seegelke, Schütz, & Schack, 2012). For example, if a person intends to pour water into an overturned glass, the individual might grasp the glass in an uncomfortable thumb-down position foreseeing that the end position, after turning the glass, will be more comfortable and better facilitate pouring water into the glass.

Individuals generally prefer more comfortable/less awkward positions for the end of motor actions, which has been termed end-state comfort (Rosenbaum & Jorgensen, 1992). An individual or group of joints' range of motion (e.g., pronation and supination for the wrist joint) will dictate the degree of comfort of a thumb-up or thumb-down posture. Research has shown that a thumb-down position is generally perceived to be less comfortable than a thumb-up position while performing tasks that involve 90 or 180 degree rotations of objects (Rosenbaum et al., 1990; Rosenbaum et al., 2012; Coelho, Studenka, & Rosenbaum, 2014).

The choice of grasp also reflects the amount of precision needed to complete the task. Studies have found that a more precise behavior can be obtained when the posture is at a joint-angle mid-range (e.g., half way between pronation and supination for the wrist; Rosenbaum, van Heugten, & Caldwell, 1996). The “precision hypothesis” suggests that being at the midpoint of a joint’s total range of motion allows for faster adjustments to movement and better error detection and correction. Several studies have shown that, when precision demands at the end-state are reduced, the end-state comfort effect is likewise reduced (i.e., participants choose less end-state-comfort), supporting the idea that comfortable end-states represent movements at joint angle mid-ranges, which also afford the most precise movement (Rosenbaum et al., 1996; Short & Cauraugh, 1999).

Little research exists about how the time spent in certain postures (and therefore the amount of time spent in either comfortable or uncomfortable states) influences an individual’s choice of posture (e.g., comfortable end-state). Only one study, to our knowledge, has directly manipulated the time in which beginning or end-states were to be held. Seegelke, Hughes, and Schack (2011) had participants hold the beginning state posture of a dowel grasp for either 0 or 9 seconds. Participants then rotated the dowel 180 degrees to the right or left and set the dowel down in a small target. No significant difference in end-state comfort between the two beginning state conditions was found, however, the task used by Seegelke, Hughes, and Schack (2011) required participants to set the object down, adding to its precision requirement, and all instructions were given on a computer screen following a “go” signal, potentially inducing additional cognitive and attentional demands.

Recent work from Dr. Studenka’s lab has shown differences in the postures chosen when the time spent in the end-state or the beginning state (or both) were constrained. Participants grasped a wooden dowel rod, moved it to the left or to the right, and set it down inside a target.
The beginning state was either unconstrained or held for 5s, and the end state was either unconstrained or held for 5s. Modersitzki & Studenka found that, when no time constraints were placed on postures, participants naturally held end-state postures longer (Modersitzki & Studenka, in review). In addition, when the initial posture was constrained (held for 5s), 9 out of 27 individuals chose beginning-state, rather than end-state comfort. This finding indicated that minimizing overall discomfort of the sequential task was important, but that another constraint (likely the precision required to set the dowel down at the end-state) also mattered.

The purpose of this study was to examine the trade-off between precision at the end-state and time spent at the beginning-state, both globally, and between individuals. In this experiment, we looked at how the time spent in the beginning-state of a sequential movement influenced the choice of posture when precision requirements at the end-state were either low (large target) or high (small target). We hypothesized that if being precise at the end-state is more important than overall comfort, individuals, on average, will choose comfortable end-states when precision is high even if the beginning-state is held for a longer time. Alternately, if individuals, on average, prefer to be in comfortable/less awkward postures for the majority of the movement, a greater ratio of beginning-state comfort should be seen as the duration of time to hold the beginning-state increases. A secondary aim of this study was to examine individual differences in planning to see if different groups exist (e.g., some people prefer comfort over precision).

Method

Participants

We recruited 48 participants through SONA systems (an undergraduate subject pool). Participants (24 female, 24 male) were between 18 and 26 years old (mean = 21.0 and standard deviation = 1.9) with no known neurologic or motor impairments. Participants signed an informed consent approved by the Utah State University Institutional Review Board and were compensated with either $10 or class credit.

Apparatus and tasks

Subjects were seated in front of a wooden table (70 cm high; see Figure 1). Directly in front of participants and to the left was a circular target (5.6 cm in diameter) indicating the start position of the wooden object. To the right of the participant was a removable panel with a hole (either 5.6 or 12.7 cm in diameter). A wooden dowel rod (half white and half black; 5 cm in diameter, 12.5 cm long) stood horizontally on the start target. The rod stood on its own. The part of the table directly in front of the participant was covered with aluminum foil and was attached via an alligator clip to an Arduino board (MakeyMakey, JoyLabz LLC, Santa Cruz, CA). Another alligator clip connected the Arduino board to a finger covering made of tinfoil that was placed on a participant’s left index finger. The wooden dowel rod was painted with black conductive paint, and then a light shade of white was painted over half of the object so that it would still conduct electricity through either end. The tin foil on the table and the participants finger as well as the conductivity of the object ensured that an electrical circuit would be connected any time the participant’s right hand touched the table or the object. A custom written program in Matlab (The MathWorks Inc., Natick, MA) recorded a timestamp (about every .0001 ms) when the circuit was connected, allowing for the collection of response time, movement time.
of the hand from the table to first touching the wooden dowel, and grasp time of the hand on the wooden dowel. This also allowed for the proper control of initial grasp time.

![Figure 1. Depiction of the task set up. Panel (a) represents the condition with the small target hole, and panel (b) represents the condition with the large panel hole.](image)

The task consisted of grasping the dowel, lifting it, moving it to the right, and placing it into the hole. The two holes sizes were just slightly larger than the dowel (5.6 cm in diameter) and much larger that the dowel (12.7 cm in diameter). The distance from the center of the object to the left edge of the hole was the same to control for effects of movement distance (time) influencing grasp choice. Dropping the rod into a hole eliminated any precision requirement based on setting the object down. Videos were recorded of each trial and were later used to score grasp posture choices at the beginning and end-state (thumb-up or thumb-down).

**Procedure and Design**

Eight blocks of 16 trials were performed. The time to hold the object varied (unconstrained, 1s, 3s, or 5s). Additionally, the precision of the end-target was either small or large. Sixteen trials were performed for each constraint on initial grasp time and each degree of precision. Eight of the sixteen trials required a rotation of the object during transport (white end
down to black end down or black end down to white end down). The other eight trials required only a transport of the object (e.g., white end down to white end down). This resulted in a total of 128 trials. To allow participants to take advantage of planning for the beginning and end-state, each combination of beginning state grasp time and end-state precision was blocked; participants performed all 16 trials of one block before moving on to another block. Participants were also told that all grasp times were the same for the beginning-state within the current block. The color of beginning and end state required was randomized for all blocks. The order of blocks performed was counterbalanced for the group of 48 participants.

Prior to the start of each block, the custom-written Matlab code indicated to the experimenter—who was sitting across from the participant—how long the initial posture should be held. The experimenter then informed the participant of this initial constraint. Prior to each trial, the Matlab code informed the experimenter which color should be down at the beginning and end-state grasp after which the experimenter placed the wooden dowel in the correct orientation (without using a thumb-up or thumb-down grasp) and placed a small laminated circle indicating either black or white directly to the left of the hole (indicating the color to be placed first into the hole). The experimenter then said to the participant, “whenever you’re ready”. The participant placed his/her hand on the table in a small rectangular target area within the tinfoil, which triggered the custom-written program to begin a trial. A period of 750 ms elapsed and then a tone sounded signaling that the participant should lift his/her hand from the table and grasp the rod. For the unconstrained condition, the participant lifted the object directly and placed it into the hole with the appropriate color down. In the three constrained conditions, the participant held his or her grasp on the dowel until a second, higher pitched, tone sounded, then transported the object and placed the indicated color into the hole. The participant was informed to perform the transport and object drop at a comfortable pace. Participants were monitored carefully to ensure they did not toss the dowel into the hole and that the specified end always entered the hole first. The participant was not told the specific duration of the time between tones. There is some evidence that prior grasp choices influence future ones (Herbort, Mathew, & Knude, 2016) In order to ameliorate the effect of one block on planning actions in the subsequent block break of 30 seconds was given, in which a participant got up from their seat, walked approximately two yards away and played with a Rubik’s® Cube (Rubik’s Brand Ltd, Hungary). The experiment in total took about an hour.

Following the experimental trials, participants were asked a series of questions regarding their personal perceptions of motor and cognitive abilities. Questions included: how old are you?, what is your gender?, which hand is dominant?, do you have a history of concussions and if so how many and how long ago was the last one?, do you have musical experience and if so with which instruments and for how long?, on a scale of 1-10 how would you rate your short term memory, long term memory, attention span, physical fitness, physical flexibility, and musical ability?, what was your high school GPA?, what was your SAT score?, what was your ACT score?, and what is your college GPA?
Data collection and reduction

The custom written Matlab code sampled data approximately every 10 ms anytime the electrical circuit was connected. The time stamp, beginning when the experimenter hit a space key was recorded allowing for data regarding the time spent prior to lifting the hand (response time), the time spent reaching for the object (movement time), and the time spent grasping the object (grasp time) to be collected.

Videos were also collected (30 fps) for each trial. These videos were examined by two independent researchers. For each trial the beginning and end-state was given a score of either thumb-up or thumb-down. A custom-written Matlab code read in the separate scores and compared them. In the case of a discrepancy between individual scorers, a third experimenter examined the video file and corrected the value. In all cases it was easy to identify whether the grasp was thumb-up or thumb-down. A total of 5 discrepancies were found and corrected.

Results

End-state comfort

To test for differences in end-state comfort grasp based on time and size, we ran a generalized linear mixed model with logit link using SAS proc GLIMMIX. The GLIMMIX procedure modeled the probability of the end-state being thumb-up. The main effects of size and time were significant, $F(1, 3017) = 7.90, p = .005$, $F(3, 3017) = 19.72, p < .0001$. In addition, the interaction between time and size was significant, $F(3, 3017) = 3.13, p = .0248$ (see Figure 2). The least squares mean for each size and time combination is presented in Table 1. For the small and large target where beginning state was unconstrained, the average probability of ending with a thumb-up posture was relatively high (.82, .80). For the hold 5s condition, the average probability of ending with a thumb-up posture was much lower (.12, .13). When the beginning-state was to be held 1s or 3s, the small target had higher probability of ending with a thumb up (.53, .44) than the large target (.28, .12) indicating an interaction between time to hold beginning state and size of the end-target.
Figure 2. Plot of the estimated probability of ending with a thumb-up posture for all combinations of target size and beginning state time-to-hold.

Table 1. Table of Least Squares Means for all combinations of size and time

<table>
<thead>
<tr>
<th>Size of target</th>
<th>Time to hold beginning state</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Unconstrained</td>
<td>0.82</td>
</tr>
<tr>
<td>Small</td>
<td>1 second</td>
<td>0.53</td>
</tr>
<tr>
<td>Small</td>
<td>3 seconds</td>
<td>0.44</td>
</tr>
<tr>
<td>Small</td>
<td>5 seconds</td>
<td>0.12</td>
</tr>
<tr>
<td>Large</td>
<td>Unconstrained</td>
<td>0.80</td>
</tr>
<tr>
<td>Large</td>
<td>1 second</td>
<td>0.28</td>
</tr>
<tr>
<td>Large</td>
<td>3 seconds</td>
<td>0.12</td>
</tr>
<tr>
<td>Large</td>
<td>5 seconds</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Tukey-Kramer post-hoc comparisons were performed to assess differences between time by size least squared means. Within the small target trials, several levels of time significantly differed. The unconstrained condition was more likely to result in end-state comfort than the 3 seconds, or 5 seconds conditions \((p = .03, \text{ odds ratio } = 5.6; p < .0001, \text{ odds ratio } = 33.26)\). The l
second condition was more likely to result in end-state comfort than the 5 seconds condition, \( p = .002, \text{ odds ratio} = 8.48 \). The 3 seconds condition was more likely to result in end-state comfort than the 5 seconds condition, \( p = .02, \text{ odds ratio} = 5.95 \). Within the large target trials, the unconstrained condition was more likely to result in end-state comfort than the 1 second \( p = .0006, \text{ odds ratio} = 10.43 \), the 3 seconds \( p < .0001, \text{ odds ratio} = 30.83 \), or the 5 seconds \( p < .0001, \text{ odds ratio} = 25.82 \) conditions. There were no differences between the 1 second, 3 seconds, or 5 seconds conditions. Lastly, for the 3 seconds condition, there was a significant difference in the likelihood to exhibit end-state comfort between the small and large targets, \( p = .02, \text{ odds ratio} = 6.16 \). There were no differences between small and large targets for the unconstrained, the 1 seconds, and the 5 seconds conditions. These findings support the interaction between time to hold the beginning state and the size of the end-state target.

**Individual differences**

Literature supports that not all subjects adopt the same strategy during motor planning (Hughes et al., 2012; Rosenbaum et al., 1996; Seegelke, Hughes, Knoblauch, & Schack, 2015; Seegelke, Hughes, Schütz, & Schack, 2012). We therefore examined individual differences in planning among the 48 subjects. Participants could have adopted end-state comfort on any number of the 8 trials within each condition that required a rotation of the object (e.g., white to black or black to white). Figure 3 shows the number of participants (out of 48) who exhibited end-state comfort on no trials (white) up to all trials (black). Most individuals adopted the same strategy throughout all trials. Sixteen subjects chose end-state comfort on all trials that required a rotation. Eighteen subjects chose to adopt a thumb down posture on all trials that required a rotation. The remaining fourteen participants changed their end-state posture choice on at least one trial in one condition.

![Figure 3](image_url)

**To test for differences in end-state comfort grasp based on time and size for participants who exhibited end-state grasp flexibility (at least one change from thumb-up to thumb-down or**
vice versa), we ran the same generalized linear mixed model with logit link using SAS proc GLIMMIX, now with only 14 participants. The GLIMMIX procedure modeled the probability of the end-state being thumb-up. The only significant effect was the main effect of time, \( F(3, 1771) = 4.95, p = .002 \) (see Figure 4). The least squares mean for the unconstrained, 1 second, 3 seconds, and 5 seconds conditions were .88, .84, .81, and .80 respectively. Tukey-Kramer post-hoc comparisons revealed that the only time conditions that were significantly different were the unconstrained and the 3 seconds condition, \( (p = .02, \text{ odds ratio } = 1.64) \), and the unconstrained and the 5 seconds condition, \( (p = .002, \text{ odds ratio } = 1.84) \). For individuals who did not choose a consistent end-state posture, there was an influence of the time to hold the beginning-state leading to slightly lower probability of adopting end-state comfort as time-to-hold increased.

![Figure 4. Plot of the estimated probability of ending with a thumb-up posture for all combinations of target size and beginning state time-to-hold for participants without a consistent end-state posture choice.](image)

It is unusual that so many subjects chose to adopt beginning vs. end-state comfort, particularly when moving to the right. In other studies, the unconstrained task has been performed first as planning may be influenced by the demand of holding the beginning-state even before a participant has had experience with grasping the object. Within our study, we had 12 participants who performed an unconstrained task first. Of these 12, 7 chose to adopt a thumb-up end-state for all trials, 1 chose to adopt a thumb-up end-state posture for all but one trial, 2 chose to adopt a thumb-down end-state for all trials, one chose to adopt a thumb-down end state for all by one trial, and 1 had some flexibility in which end-state posture he/she chose.
Interestingly, this subject chose mostly a thumb-down end-state for all conditions except the unconstrained small target (75% thumb-up end-state). A t-test revealed no significant difference in the averages (over all conditions) of end-state comfort choice between the 12 subjects who performed unconstrained prior to the other conditions and the other 36 subjects who performed a hold-beginning task first, $t(46) = 1.76, p = .09$.

**Predictions**

We were also interested in whether we could predict who might choose end-state comfort over beginning-state comfort based on several collected measures including gender, years of musical experience, personal perception of short-term memory, long term memory, attentional capacity, physical fitness, physical flexibility, and music ability, recalled high school GPA, ACT score, and college GPA. There was no correlation (Spearman’s Rho) between average choice of end-state comfort and any of the collected variables. Interestingly, ratings of musical ability and reported number of years of musical experience correlated ($r(48) = .68, p = .000$). In addition, personal ratings of short-term memory correlated with personal ratings of attention ($r(48) = .43, p = .003$), personal ratings of fitness ($r(48) = .39, p = .006$), and reported ACT score ($r(44) = .35, p = .02$). Personal ratings of attentional capacity correlated with personal ratings of physical fitness ($r(48) = .35, p = .01$). Personal ratings of physical fitness correlated with personal ratings of physical flexibility ($r(48) = .30, p = .04$). Personal ratings of physical flexibility correlated with recalled high school GPA ($r(48) = -.31, p = .03$). Reported high school GPA significantly correlated with reported ACT score ($r(44) = .42, p = .005$) and with reported current college GPA ($r(42) = .44, p = .004$).

We further examined whether any of the collected measures were associated with a preference for choosing end-state over beginning-state comfort. We divided our participants into two groups, those who chose end-state comfort nearly 100% of the time and those who chose beginning-state comfort nearly 100% of the time. Three subjects did not seem to have a strong preference, and we left out of the following analysis. A Chi-squared analysis revealed no association between end-state posture preference and gender, $X^2 (1, N = 45) = .57, p = .45$. Mann-Whitney U comparison revealed no association with end-state comfort preference and reported years of musical experience, $U = 189, p = .15$, personal rating of short term memory, $U = 227, p = .55$, personal rating of long term memory, $U = 229, p = .57$, personal rating of attention, $U = 243, p = .82$, personal rating of fitness, $U = 179, p = .08$, personal rating of flexibility, $U = 189, p = .15$, personal rating of musical ability, $U = 176, p = .08$, reported high school GPA, $U = 243, p = .84$, reported ACT score, $U = 177, p = .39$, or reported current college GPA, $U = 188, p = .76$.

**Discussion**

The purpose of this study was to examine the trade-off between time-spent in the beginning state of a movement and the precision demands of the end-state of that same movement. We predicted that both time and precision would play a role in which postures were chosen. We further expected to find individual differences in posture choices that might be explained by participant’s reports of their own cognitive and motor capabilities. Our results provide support for both sets of expectations, but no evidence suggesting a link between perceptions of cognitive or motor characteristics and planning.
Our first prediction, that end-state comfort would decrease as the time to hold the beginning state increased was supported. We show a clear difference between the unconstrained beginning state task and the 5s beginning state task. This relationship was moderated by the precision requirement, particularly for the time requirements between the unconstrained and the 5s hold condition. The influence of time constraints on the choice of end-state comfort are equivocal in the literature. Seegelke, Hughes, and Schack (2011) showed no effect of requiring participants to hold a cylindrical rod for 9s prior to moving it to another location. Their study had a few differences from ours including that a 9s countdown, information about which direction to move, whether or not to rotate the object, and the need to hold the initial posture were all displayed on the computer screen following the “go” signal. This may have taxed a subject’s attention in a way that led them to plan differently. In our study, we gave participants all pertinent information directly prior to the go signal. The object in Seegelke, Hughes, and Schack (2011) was also taller and likely less stable adding the precision requirement of setting it down. It was, most likely the case that, in our experiment, precision demands were high enough to demand end-state comfort despite the large time constraint on the beginning state. We show similarly, that increased precision demands led to lower probability of choosing end-state comfort for intermediate beginning state durations. In the current study, there was no effect of precision when beginning states were held for 5s. The discrepancy between 9s in the Hughes et al. study, and 5s in our study is likely due to the increased precision demands of the Hughes study, although this cannot be directly compared. Future research should examine a wider range of precision demands.

Lastly, we provide additional support to the notion that greater precision requirements at the end state of movement lead to a greater probability of adopting end-state comfort. By eliminating the demands of placing an object down, we examined here, only the precision of the placement of the object, not its steadying. This links with the findings of Hughes, Seegelke, and Schack (2012). Hughes, Seegelke, and Schack (2012) tested the “precision hypothesis” by constraining the precision both at the beginning-state and the end-state. Half of their participants maintained end-state comfort even with varying precision while the other half varied their grasp choices to be more precise when required. They found that participants vary their grasp choice based on precision requirements at the beginning and end-state. Their participants adopted a comfortable end-state grasp when the precision was high at the end state, but a comfortable beginning state grasp when the precision was high at the beginning state. They also documented individual differences in how precision affected grasping. Half of the participants always ended in end-state comfort which may have been a result of the extra precision requirement of steadying the object on the table. Our study did not include that additional factor of steadying precision. Several other studies by Rosenbaum et al., (1996) and Short & Cauraugh (1999) have shown that end-state comfort is preferred when precision is high. They showed this by decreasing the precision demands of the end-state and found that the end-state comfort effect also decreased.

More participants adopted beginning-state comfort than we hypothesized. We hypothesized that the end-state comfort ratio would be near 100%, particularly during the unconstrained trials, but found that it was closer to 80%. This is counter to other research on dowel rod rotations of 180 degrees when moving to the right, which show a percentage closer to 100% (Coelho, Studenka, & Rosenbaum, 2014; Rosenbaum, van Heugten, & Caldwell, 1996; Modersitzki & Studenka, in review). In these other studies, the time to hold the beginning state
was either unconstrained, or the unconstrained task was performed prior to any experience holding the beginning-state. One reason participants may have chosen beginning-state comfort on unconstrained trials was that these trials, for 75% of participants, were performed following constrained trials. Three quarters of participants started with conditions that offered a beginning time constraint. These participants appeared to be more likely to maintain their beginning-state comfort grasp even when the time constraint of the beginning-state decreased. The persistence of previous grasps on future ones has been well documented (Herbert, Mathew, and Kunde, 2017).

One, more exploratory aspect of our experiment was the collection of personal information related to physical and mental capacities. We predicted that individual differences might be explained by a participant’s rating of his or her physical or cognitive abilities. Indeed, conscientiousness and agreeableness were associated with differences in planning (Rosenbaum et al., 2019). Stockel, Wunsch, and Hughes (2017) also found a relationship between anticipatory motor planning and processing speed, response planning, and cognitive flexibility. We asked a variety of questions about personal perception of short-term memory, long-term memory, attentional capacity, physical fitness, physical flexibility, and music ability, recalled high school GPA, ACT score, and college GPA. We did not find any association with these variables and choice of end-state comfort. This does not rule out the link between cognitive and motor abilities and choice of planning strategy. Future work should aim for direct measurement of these attributes, rather than self-report. The variables that look promising were reported years of musical experience, personal rating of fitness, personal rating of flexibility, and personal rating of musical ability. People who are more physically fit may have the muscular strength to endure strenuous postures for longer than others. Furthermore, people who are more physically flexible may be able to stretch to uncomfortable postures easier than others and thus not consider them uncomfortable. It could also be the case that people with musical ability have more experience being in uncomfortable postures, depending on what instrument they play, and may have grown accustomed to theses postures.

In conclusion, we showed that the time spent in the beginning-state and the precision required at the end-state of a movement play a role in the postures chosen for that movement. Some people prefer to sacrifice end-state comfort if the beginning-state is to be held for a long duration of time, particularly when the precision required at the end-state is low. Individual differences in grasp posture choices are still not well understood.
Reflective Writing

Starting this capstone was the most stressful part of my undergraduate career. I originally had a capstone project set up with a different professor, but they had to cancel last minute for personal reasons. This left me with a feeling that I would never graduate with honors, which is something I personally valued more than getting my bachelor’s degree. Luckily enough, I was set up to teach an Honors Connections with Breanna Studenka and formed a relationship with her before this all happened. Upon telling her of my struggle, she gracefully brought me on to do a capstone project with her.

My relationship has grown to a point with Dr. Studenka that I would consider her a friend for life. Her kindness and professionalism have made it easy to accomplish a capstone experience. Anybody who has done research knows that it is very stressful and there is not much to lighten that load. Having built such a meaningful relationship has allowed us to talk about things outside of research and laugh even during the research. She has become a role model of how I want to interact with my professors, fellow graduate students, and coworkers in the future.

One of the best parts about working with Dr. Studenka was that her research was within my major but different enough from my normal classes to broaden my experiences. The majority of what I learned in my undergraduate classes had to do with gross motor movements and how the human body moves. The research project with Dr. Studenka had to do more with fine motor movements and why we tend to move how we do. Thus, I was able to learn more about human movement that I would not have known otherwise.

The start of my capstone project wasn’t the worst part. We found a research question that we wanted to expand on from one of Dr. Studenka’s previous research projects and we found another undergraduate that wanted to help. The hardest part was finding a way to accomplish what we wanted. This is where the most critical thinking came in. We had to find a way to manipulate precision without adding any unmeasurable precision aspects. Most of our ideas ended up being rejected because of the precision aspects of steadying an object on a flat surface. This was not acceptable because it was one of the problems that we had found we previous research articles. We eventually found the perfect solution of using a hole that barely fit out wooden dowel and a hole that would be hard to miss with a wooden dowel.

After this, I was thrown into a world of research that I had never experienced. I had to broaden what I knew about different fields to help make the research project function. The most important part was learning how to work in software called Matlab (The MathWorks Inc., Natick, MA). This software is used a lot by undergraduates in the engineering and computer science field, but it is never mentioned in my field of study. I did not learn how to write any software, but I did learn how to run through programs in the software. This was essential because it was used to give prompts to our research participants and at the same time record data through an engineering device called an Arduino board (MakeyMakey, JoyLabz LLC, Santa Cruz, CA). It was also useful to learn a few tricks about woodwork. We had Dr. Studenka’s husband help us create a table that the participants could drop a dowel in and have the dowel return to the tester. This, to me, was an enjoyable side benefit of problem solving that I would like to learn more about in the future.

When we finally had everything ready, we entered what I thought was the most tedious part of my capstone project: data collection and analysis. One of the only enjoyable experiences
with this section was associating with the research participants. This was the only time that I was able to engage in my local community, but I enjoyed meeting people. It was fun to explain to each of the participants what their role in our research was and how they were helping us to make a difference in a more global community through our findings. I honestly think that I would have ended up quitting on my capstone if I had not enjoyed associating with the participants so much. Even though I thought about quitting a few times, I was glad that I pushed through to the end. If I had to give any advice to future honors students about this portion of research, it would be to find some small joy to make it worthwhile. To me, it was meeting new people and talking with them, but it could be anything. It is just important to know that the finished project is one hundred percent worth the hard work.

The last part of the project was perhaps the most humbling: writing a manuscript. During this process it is important to take any feedback that you receive and apply it to the best of your ability. This is one of the reasons why it is so important to find a mentor that is willing to teach you everything they know. Each time that I turned in a rough draft, Dr. Studenka would return it to me and almost everything would be marked in red. She would always leave comments though about how I could improve what was written, and I always tried to apply them. It was difficult not to internalize those corrections and feel bad about my work. I had to remind myself that we were striving for a publishable manuscript and that nobody can achieve that by themselves. In the end, we finished a written capstone that I never would have thought possible.

My original purpose for joining honors and doing research was to distinguish me from other applicants for graduate school. Most applicants that are trying to get a Doctor of Physical Therapy do not do research because it is not required. I have to say though that this capstone project did more than just distinguish my application, it has made my education worthwhile. My undergraduate coursework was too easy, and I would not have been pushed hard enough if it weren’t for honors. My capstone drove me to try new things and expand my education past what a normal bachelor’s degree achieves. It has helped me learn how to get the most out of an education, which I am excited to apply to my doctorate degree. I learned that I cannot be satisfied with what is being taught, and that I must go and learn what I can by myself through whatever means necessary. This will also be important in my future goal of becoming a physical therapist and owning my own practice. I will know how to not just reach the mediocre but to constantly learn and strive to be the best that I can be.


Modersitzki, R. & Studenka, B. E. (working draft). The influence of time constraints on posture choices during an end-state comfort task.


Author Biography

Tucker Gamble majored in Human Movement science with an emphasis in Pre-Physical Therapy. He was actively engaged in the Honors Program, Pre-Physical Therapy Club, and the Undergraduate Research Fellows at Utah State University. Alongside his extracurricular activities, he maintained a 3.97 GPA and worked as a Physical Therapy Aide. His future plans include attending a Doctor of Physical Therapy graduate program and eventually starting his own physical therapy practice.