DISTRACTED VISUAL ATTENTION DURING WALKING: RESPONSE TO AN UNEXPECTED EVENT WHILE WALKING AND USING A SMARTPHONE IN YOUNG HEALTHY ADULTS

by

DEBORAH WANG

A THESIS

Presented to the Department of Human Physiology
and the Robert D. Clark Honors College
in partial fulfillment of the requirements for the degree of
Bachelor of Science

September 2015

An Abstract of the Thesis of

Deborah Wang for the degree of Bachelor of Science
in the Department of Human Physiology to be taken September 2015

Title: DISTRACTED VISUAL ATTENTION DURING WALKING: RESPONSE TO AN UNEXPECTED EVENT WHILE WALKING AND USING A SMARTPHONE IN YOUNG HEALTHY ADULTS

Approved: ______________________

Dr. Li-Shan Chou

Introduction: Smartphone usage while walking is prevalent in today's society. Previous studies have explored how texting while walking negatively impacts gait performance by decreasing the walking speed and increasing body sway (Parr et al, 2014; Plummer et al, 2014). However, little is known about how smartphone usage affects a person's ability to react to an unexpected event during gait. The purpose of this study was to investigate how visual attention divided by smartphone usage affects gait performance when reacting to an unexpected event.

Methods: Eleven healthy young adults (6 males, 5 females, age: 20.9±1.04 years) were recruited from the community. Twenty-nine reflective markers were placed on the subjects' bony landmarks in order to collect whole body motion using a 10-camera system. Subjects were instructed to walk and stop in front of a projected red line onto the walkway. The line was projected at the same location with the same timing for the expected (**EX**) condition. Subjects then completed an unexpected (**UN**) condition, during which the line was projected at different locations with different timings. Finally,

subjects completed the unexpected condition while completing a Stroop test on an iPod touch (**UN_Stroop**). Subjects were also asked to complete a Stroop test while sitting (**Sit_Stroop**). The dependent variables we examined were derived from both cognitive and gait performances. Cognitive performance was quantified by the Stroop reaction time and accuracy rate. Gait variables included toe-line distance, toe-line trial-to-trial variability, failure rate of stopping in front of the projected line, center of mass forward velocity (vCOM) and center of mass medial-lateral deviation (COM_{ml}). Paired t-tests were employed for the Stroop reaction time and accuracy rate. One-way repeated measure ANOVAs were used to detect the effect of testing conditions on the toe-line distance, toe-line trial-to-trial variability, failure rate, vCOM and COM_{ml}. A significance level for both was defined as a p-value equal to or below 0.05.

Results: *Cognitive Performance:* The Stroop test reaction time was significantly higher during the **UN_Stroop (**1.43±0.08 s**)** condition than **Sit_Stroop** (1.09±0.04 s; *p<0.0001*) but there was no statistically significant difference in the Stroop accuracy rates (*p=0.57*). *Gait Performance:* Toe-line distances were significantly lower for **UN** (8.68±1.20 cm, *p=0.001*) and **UN_Stroop** (16.32±2.69 cm, *p=0.023*) when compared to **EX** condition (18.60±2.18 cm). **UN** (7.47±1.05 cm) and **UN_Stroop** conditions (8.21±1.36 cm) demonstrated a significantly higher toe-line trial-to-trial variability (*p=0.*018) than **EX** (3.74±0.66 cm). Failure rates in making a successful stop was higher in **UN** (30.6±8.2%, *p=0.003*) and **UN_Stroop** (16.9±5.0%, *p=0.006*) than the **EX** failure rate (0%). vCOM gradually decreased from **EX** (1.32±0.07 m/s), **UN** (1.13±0.06 m/s), to **UN_Stroop** (0.98±0.05 m/s) conditions. There was a statistically

significant increase in COM medial-lateral deviation (COM_{ml}) between **EX** (0.04±0.003 m) and **UN_Stroop** (0.05±0.002 m, *p=0.00*) conditions.

Discussion: This study examined both cognitive and gait performances when subjects reacted to an unexpected event while using an iPod Touch to complete a Stroop test (**UN_Stroop**). While walking and engaging in a Stroop test, subjects completed their test approximately 320 ms longer than when they were just completing it while sitting. However, even though they took more time on their Stroop test, subjects still had a greater failure rate, toe-line trial-to-trial variability and COM_{ml}. Additionally, there was a decreased vCOM and toe-line distance compared to the **EX** condition.

Conclusion: This study's findings have suggested that concurrent walking and smartphone usage decreases ones ability to process cognitive information as well as increase walking hazard levels when they are reacting to an unexpected event. This may lead to a negative impact on pedestrian safety. However, further research needs to be conducted in order to understand the underlying mechanisms of these strategies. A future application would be to see how this task impacts the strategies utilized by the elderly population or other clinical populations such as stroke patients.

Acknowledgements

I would first like to thank Dr. Li-Shan Chou and On-Yee “Amy” Lo, for helping me to fully examine the specific topic of distracted walking and consider the various perspectives and contexts related to this subject matter. Thank you very much for providing me with the privilege to work with excellent professors and mentors who are willing to guide me through this strenuous but rewarding process. Additionally, I want to thank Professor Susanna Lim for assisting me on my defense committee. Finally, I would like to thank my parents, Young-Chung Wang and Sheng-Lin Ting, for encouraging me to excel in my educational pathway as well as their continued support and faith in me during this long journey.

Table of Contents

List of Figures

Background

Most college-aged students engage in mobile phone usage. In 2013, 91% of Americans reported owning a cell phone (Duggan, 2013) and 61% of them identified their phones as smartphones (Smith et al, 2013). Due to the convenient access to these cellular devices, many people engage in risky behaviors such as driving or walking while texting. Though the issue of texting and driving has been discussed and researched extensively over the past few years (Lopresti-Goodman, 2012), the problem of distracted walking, texting or other smartphone usage while walking, has only recently been brought up as a hazard to pedestrians in their day-to-day lives (Plummer et al, 2014).

A 2010 Pew Internet & American Life Project Poll showed that 1 in 6 surveyed adults have bumped into various obstacles such as inanimate objects or other humans while handling their devices (Smith et al, 2013). The number of injuries to pedestrians is also linked to the passage of time. The average amount of injuries tends to increase as mobile phone usage becomes more prevalent (Nasar and Troyer, 2013) so it can be assumed that the current percentage of texting and walking accidents is even higher. People who engage in such behavior generally react in a more cognitively distracted manner because their brains are occupied by more than one task. This distraction may lead to any range of accidents from a temporary incidence like tripping and falling (Parr, 2014) or permanent damage such as death (Lamberg, 2012). Not only are accidents more probable, street-crossing success rates are also decreased (Neider et al, 2010) because of the increased cognitive and motor demands from the task. Subjects not only need to use their lower extremity to propel them forward, but they also need to use their upper extremity to focus on the screen and physically handle their devices (Plummer et al, 2014). Mobile phones have also been shown to reduce awareness towards one's own surroundings (Nasar and Troyer, 2013) and ability to evaluate one's environment (Smith et al, 2013).

A dual-task paradigm, comprised of one cognitive and one motor task, has been utilized to examine the interference between cognitive and motor domains. A cognitive task involves a series of mental processing such as problem solving or decision-making. A motor task, on the other hand, involves physical movement such as walking or jogging. This experiment combined the cognitive task of smartphone usage with the motor task of walking.

In this study, the subjects completed a Stroop test instead of composing and responding to texts. The implementation and cognitive domains of texting are difficult to quantify because it combines a plethora of behaviors and is hard to normalize across subjects. On the other hand, a Stroop test is an established psychological test with high reliability and validity (Strauss et al, 2005). This activity can compare to several smartphone tasks such as playing a mobile game, which heavily relies on working memory and executive control (Schabrun et al, 2014) to resolve conflicting information. A Stroop task provides a quantitative measurement to examine visual attention and its processing speed within and across subjects between static (i.e. quiet siting) and dynamic (i.e. responding an unexpected event) conditions.

To perform a Stroop test, an individual is given a color word (blue, green, red, etc) that is written in an ink color (blue, green, red, etc.). The individual has to respond with the ink color they see. The written word could be the same or different to the ink color used to write it (Macleod, 1991). For example, if the word says “green” but is written in blue ink, the individual will have to choose “blue” as his or her answer. Typically, individuals take longer time to process the ink color when the word and the ink color are incongruent or different because the subject not only has to excite a pathway to choose the right ink color they also have to suppress another pathway to inhibit stimulus of the written word’s definition. There is a greater amount of interfering effects between the two set of information (Strauss et al, 2005).

Previous research on walking phone usage is limited (Parr et al, 2014). Especially, how a subject reacts to an unexpected condition while using a smartphone remains unknown. The tasks of previous research have focused on texting and walking but not on smartphone usage. General smartphone usage can be considered more cognitively distracting than texting because many smartphone users are completing other smartphone activities such as browsing Internet sites or playing games. These activities might require more cognitive demands than texting because with texting you just need to process, compose and send a text. However, with Internet browsing you need to process relevant information and compose responses and ignore irrelevant information. As for games, you need to immerse yourself into that environment and ignore unnecessary details. I believe the reasons why smartphone usage is more demanding is not only because you have to generate the associated content, but you also have to block unnecessary information. Additionally, many accidents usually occur in an unexpected event. Therefore, studying smartphone usage in an unexpected event provides a realistic portrait of daily smartphone interactions. When a person is crossing the street, they may face an unexpected obstacle, such as a car, bike or fellow pedestrian, competing with them for the road. When such an unexpected obstacle occurs, they need to conduct a sudden gait termination in order to make sure that they do not walk into danger. Gait termination is when a person halts their steps and stops. It requires both a deceleration of forward velocity and a stable double limb support (Hase and Stein, 1998) in which both feet are on the ground at the same time. This project's unexpected event mimicked the previous situation and helped our study better understand people's natural reactions in a controlled setting.

Therefore, the purpose of this study was to investigate how visual attention divided by smartphone usage affects gait performance when reacting to an unexpected event. In particular, the experiment examined the gait and cognitive strategies subjects used to remain balanced. It was hypothesized that both cognitive and gait performance would be affected.

Methodology

Subjects

Eleven healthy, able-bodied college subjects (6 males and 5 females, age: 20.9±1.04 years) were recruited among the University of Oregon campus via flyers and word of mouth. Subjects were screened to be regular smartphone users and free from any injury that could lead to gait impairment. The study lasted around one hour for each subject and each person was compensated with ten dollars for their time.

After the subjects acknowledged the background of the study and agreed to participate, they were asked to sign a consent form (Appendix A) and fill out a health questionnaire (Appendix B). However, they were not told the dependent variables or the hypothesized results. We also let our subjects know our plans of mimicking a real world situation so they could hopefully act in as natural of a manner as possible.

Motion Analysis System and Force Plates

A 10-camera motion analysis system (Motion Analysis Corp. Santa Rosa, CA) was used to collect the whole body motion during each condition. The system captured the 3-dimensional (3D) trajectories of reflective markers at a sampling rate of 60 Hz (Cortex, nd). One Hz is a unit signifying one sample per second.

As shown in Figure 1, twenty-nine reflective markers were placed on the subject's bony landmarks including the top, front and back of the head, left and right ears, between the 2nd and 3rd dorsal metatarsal (toe markers), posterior calcaneus (heel markers), lateral malleolus (ankle markers), lateral femoral epicondyle of the knee (knee markers), middle of the tibia (shank markers), lateral thighs (thigh markers), anterior superior iliac spine (ASIS) (pelvic markers), top of the hand and wrist, lateral epicondyle of the humerus (elbow markers), left and right acromioclavicular joints (shoulder markers) and the sacrum (lower back marker). A right scapula (upper back) marker was also used for reference.

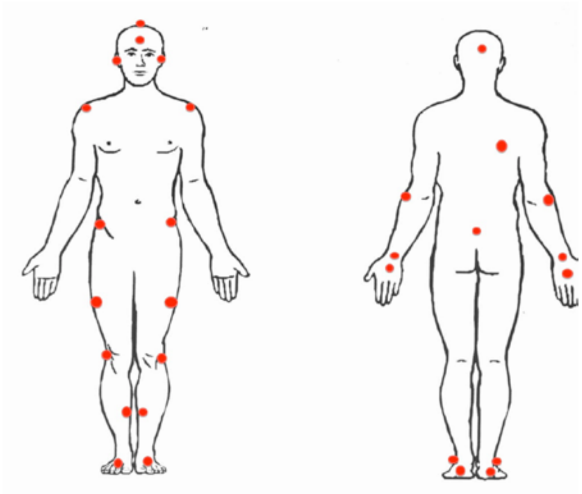

Figure 1: Marker Placement Diagram.

A diagram illustrating how markers were placed on subjects' body. The anatomical image was modified from: https://www.studyblue.com/notes/note/n/anatomical-directionsalignment-variations/deck/5159924

An additional two markers were placed on the ground where the line was projected at prior to data collection, in order to acquire information about the position of the projected lines (line markers) without letting subjects know the exact places they would have to stop.

The toe markers were used in conjunction with the line markers to identify the distance between the closest toe and projected line (Figure 2), the variability of the trial-to-trial distances and failure rate of stopping. A subject was considered to have failed the trial if they stepped on or over the projected line.

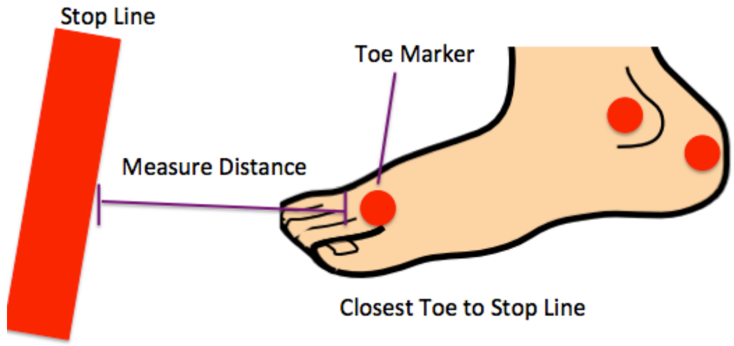

Figure 2: Diagram of Toe and Line Markers.

This diagram shows how toe-line distance is measured. It is measured from the x-axis center of the stop line to the toe marker. The foot clip art was found on: http://www.clipartbest.com/cliparts/LcK/og5/LcKog5kca.png

Bony landmark markers were used to calculate a whole body center of mass (COM) position. The COM position was then used to measure COM forward velocity (vCOM) as well as COM medial-lateral deviation (COM_{ml}).

During each condition, there were two AMTI force plates (Advanced Mechanical Technology, Inc., MA) in our walkway that subjects had to walk upon. These force plates were synchronized with the 3D motion data to collect the ground reaction forces. We used these ground reaction forces to detect when the subject first contacted the floor during their gait cycle. A gait cycle begins with one foot's heel strike and ends when the same foot strikes the ground with its heel again.

Protocol

The Motion Analysis System was calibrated and ready to collect data before the subjects arrived for the day. After filling out a consent form and health questionnaire, the subjects' heights and weights were measured in centimeters and kilograms respectively. Additionally, their foot length and width, knee width, ankle width and distance between the left and right ASIS were measured in centimeters and recorded on a data collection sheet (Appendix C).

Next, the subjects were instructed to change into shorts and a t-shirt, which were rolled up so that reflective markers could be placed directly on their skin. This way, the movement of these markers would correspond with the movement of the body and not the clothing. After all the markers were placed and the motion capture system was ready, the participants were instructed to stand behind a piece of tape and walk through the walkway at a self-selected speed (**Walk** condition). The **Walk** condition was repeated five times. The researcher identified one gait cycle and recorded stride time with an online split lap timer (http://www.online-stopwatch.com/split-timer/) for each trial. The averaged stride time of the gait trials was later used to customize the timing of the projected stop lines for each subject.

Researchers then had the subject start from the middle of the walkway, where an EXPECTED line was later projected, and walk back to the piece of tape. The researcher had to make sure to note where one gait cycle away from the subject's starting point was in order to place a photocell there. The reason for this procedure was to make sure the line could be projected at least two steps beforehand. Two steps are equal to one gait cycle. Studies have shown that people fixate two steps forward while walking in case they need to adapt their gait to any changes in their environment (Patla and Vickers, 2003).

The subject was then asked to sit down and practice a Stroop test through the EncephalApp –Stroop Test APP (http://www.encephalapp.com/) on a provided iPod Touch (**Practice_Stroop** condition). A screenshot of the test is found in Figure 3. The EncephalApp had a total of 10 trials with 10 components each. The data from the test was sent to the researcher's email after each condition for later ease of processing.

Figure 3: Screenshot of EncephalApp-Stroop Test.

EncephalApp-Stroop Screenshot. Since the word "green" is written in blue ink the correct answer that subjects should press is "blue."

For the Stroop test, subjects were told to sit down and complete each trial of the Stroop test. A successful trial meant that all of the ten components were answered correctly. If a component was answered incorrectly then the subject would have to redo that entire trial and complete ten components correctly before they could move on to the next trial.

For the EXPECTED condition (**EX**), the subject was taken back to the testing area and asked to stand behind the piece of tape then walk and stop in front of a projected red line. The line was projected in the same location with the same time delay. The subject completed three practice runs before the data was recorded to make sure they 1) knew where the line was and 2) begin to establish a consistent stop pattern. After the practice rounds, the subject was asked to stop in front of the EXPECTED line consecutively for five trials.

Afterwards, for the next ten trials, the subject was told to stop in front of an UNEXPECTED red line (**UN** condition). This meant that the line may or may not appear and if it did appear, the location and timing of the line may also change. There were ten different stop trials involving three different locations of the lines: line 1 was 600 mm from the calibrated origin of the room; line 2 was 300 mm from the calibrated origin and line 3 was 11 mm behind the calibrated origin of the room. There were two trials that used line 1, two trials that used line 2, two trials that used line 3 and four trials that did not show a line. Each line condition had a 25% increased time delay from the last line condition. The time delay meant that we would show the projected line after a certain percentage of the subject's gait cycle. For example, if the subject had a gait cycle of 1 second and there was a 25% time delay that meant the line was shown 0.25 seconds after the subject has passed the photocell. This was done for projected stimuli that were farther away from the expected line in hopes of creating a similar time delay between when the subject saw the line and had to stop in front of the line. Therefore, the ten different trials that were used are as follows:

1. Line 1 with no time delay from one stride time
2. Line 1 with a 25% time delay of one stride time
3. Line 2 with a 50% time delay of one stride time
4. Line 2 with a 75% time delay of one stride time
5. Line 3 with a 100% time delay of one stride time

6. Line 3 with a 125% time delay of one stride time

7-10. No Line shown

The sequence of the trials was randomly projected during each condition.

Afterwards, the participant was asked to perform the same UNEXPECTED conditions while concurrently completing a Stroop test (**UN_Stroop** condition) for ten trials. If the individual finished the trial before he or she got back to his or her start position, the subject just continued walking back without any distractions. If the participant got back to his or her start position without completing the Stroop test, the subject needed to finish that block before the new trial was begun.

Finally, the subject's markers were removed and they were allowed a short break before sitting down and completing a final Stroop test (**Sit_Stroop** condition).

Dependent Variables

Two groups of dependent variables were measured: cognitive and gait performance. The cognitive performance contained reaction time and accuracy rate of the Stroop test. The gait performance was determined by toe-line (marker) distance and toe-line trial-to-trial variability. Additionally, failure rate in stopping in front of the line, center of mass (COM) forward velocity (vCOM) and COM medial-lateral deviation (COM_{ml}) was calculated. COM indicates an imaginary point where the weighted relative position of the distributed mass sums to zero and is typically located near the five vertebrae of the lumbar spine in human. The movement of the COM helps generalize the movement of the body as a whole.

Data Analysis

Stroop performance (reaction time and accuracy rate) as well as the toe-line distance and trial-to-trial variability data were analyzed through Microsoft Excel. For the Stroop performance between **UN_Stroop** and **Sit_Stroop** conditions, we examined the time the subjects took to complete each trial (reaction time) as well as their accuracy rate. Accuracy rate was calculated by taking the amount of correct trials divided by the total trials. For the toe-line distance, the toe and line markers data were first identified in the Motion Analysis Software, Cortex (Figure 5), and the position information was exported to Excel to calculate the distance between the closest toe marker and the projected line in each trial in centimeters. The toe-line trial-to-trial variability was calculated based on the standard deviation of the toe-line distances.

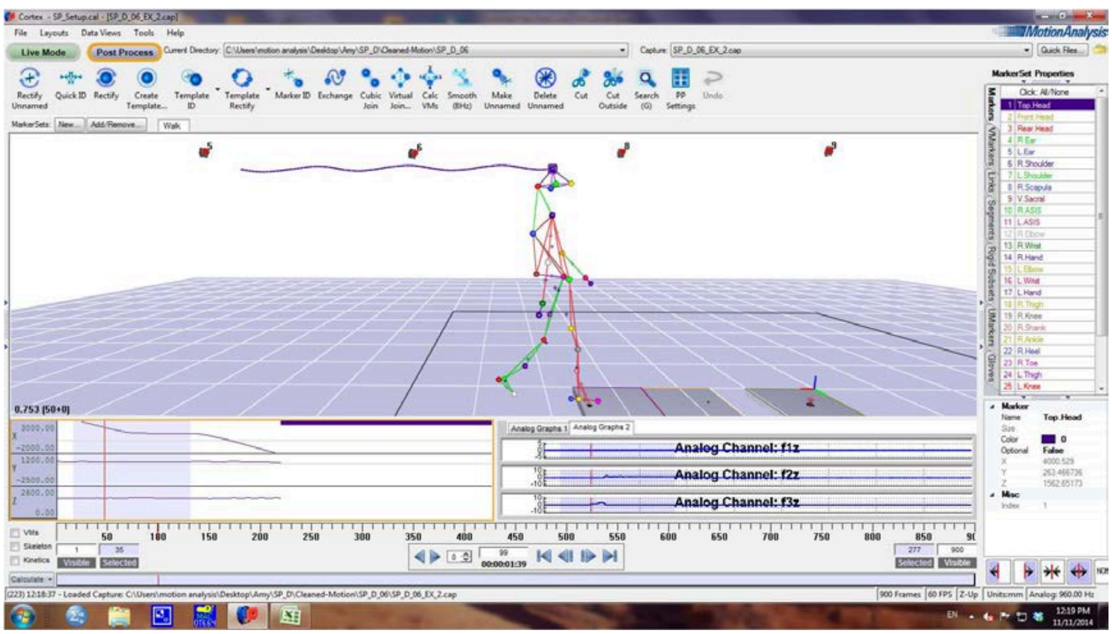

Figure 5: Screenshot of Cortex software

A screenshot of working with cortex to identify all 29 reflective markers on one subject

We also used Cortex software to identify all of the markers of the bony landmark reflective markers and used a customized Matlab program written by Amy Lo, to determine vCOM and COM_{ml} for one full gait cycle prior to gait termination. In order to avoid the interference from the failed trials, only successful trials where subjects made a complete stop before the line were analyzed for these gait parameters.

Statistical Analysis

The reaction time and accuracy rate of the Stroop test were analyzed with a paired t-test to detect a statistical significance between the **UN_Stroop** and **sit_Stroop** conditions. The components were determined to be statistically significant if they possessed a p-value below 0.05.

For the toe-line distance, toe-line trial-to-trial variability, stop failure rate, vCOM and $COM_{ml,}$ a one-way analysis of variance (ANOVA) was utilized to detect the main effect among three walking conditions (**EX**, **UN**, **UN_Stroop**). Bonferroni adjusted pairwise comparisons were used to compare the significant differences between conditions once the main effect was detected for each variable. The significance level was set as 0.05. We also controlled vCOM as a covariate for analyzing toe-line distance, variability, failure rate and COM_{ml}.

Results

Cognitive Performance

Reaction Time: Stroop reaction time was significantly longer for the **UN_Stroop** (1.43±0.08 s) than the **Sit_Stroop** (1.09±0.04 s) conditions (*p<0.0001*, Figure 6).

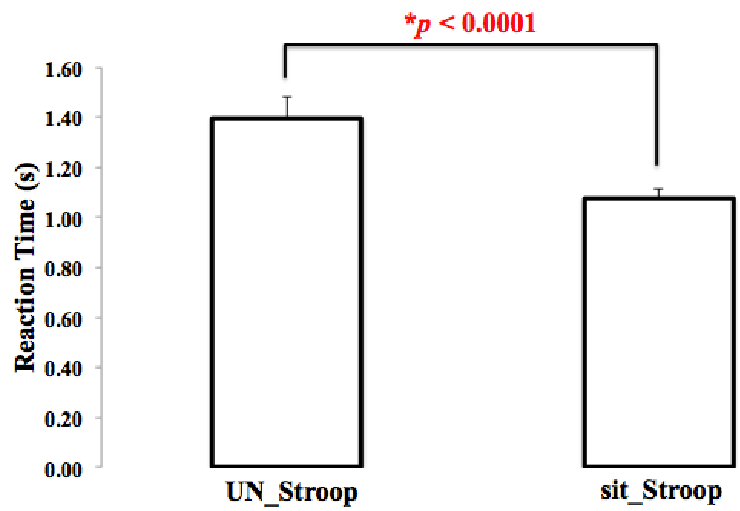

Figure 6: Stroop Reaction Time Graph

This graph shows how reaction time while completing a Stroop test was affected by the **UN_Stroop** and **Sit_Stroop** conditions.

Accuracy Rate: There was no statistically significant difference between **UN_Stroop** (88.00±3.00%) and **Sit_Stroop** condition (86.00±3.00%) *(p=0.57)* in accuracy rate.

Gait Performance

Toe-Line Distance: Toe-line distances were significantly shorter in the **UN** condition (8.68±1.20 cm) than the **EX** condition (18.6±2.18 cm) (*p=0.004*) and **UN_Stroop** condition (16.32±2.69 cm) (*p=0.031*, Figure 7).

Toe-Line Trial-to-Trial Variability: The **UN_Stroop** condition (8.21±1.36 cm) and **UN** condition (7.47±1.05 cm) had a significantly higher toe-line trial-to-trial variability than the **EX** condition (3.74±0.66 cm) both with *p values* of *0.018*.

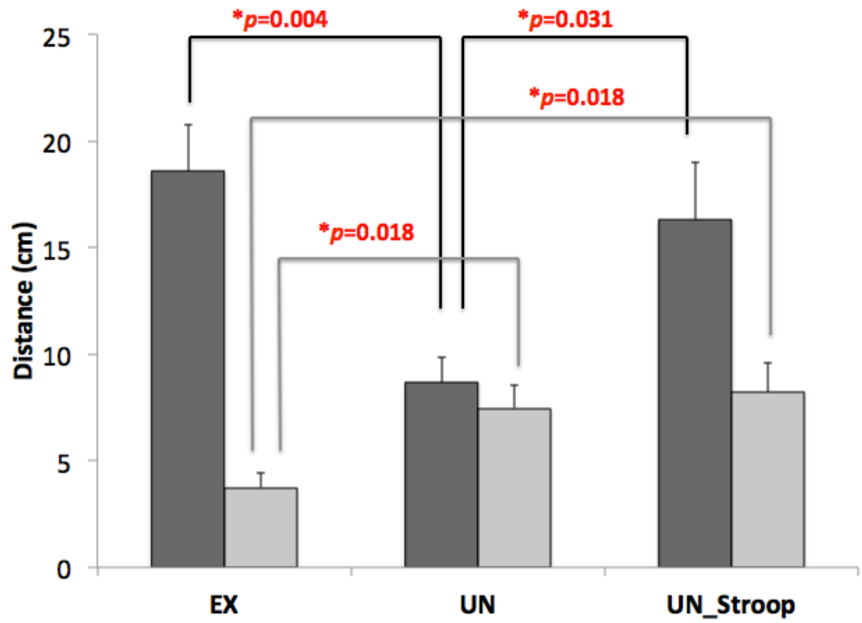

Figure 7: Toe-Line Distance and Trial-to-Trial Variability Graph

This graph shows how the **EX**, **UN** and **UN_Stroop** conditions affected both Toe-Line Distances (cm, left dark bar) and the Trial-to-Trial variability (cm, right light bar)

Stop Failure Rate: Subjects had no failure trial of stepping either on or over the projected line during the **EX** condition (0%). Therefore, the failure rate of **UN** and **UN_Stroop** conditions were significantly higher than the **EX** condition with means and standard deviations of 30.6±8.2% and 16.9±5.0% and p-values of *0.006* and *0.003* respectively. Ten out of eleven (90.9%) subjects failed at least one trial for the **UN** condition whereas only six out of eleven (54.5%) subjects failed at least one trial for the **UN_Stroop** condition.

vCOM: vCOM decreased significantly as the task became more challenging. This trend was evident between the **EX** (1.32±0.07 m/s) and **UN** (1.13±0.06 m/s) conditions (*p=0.004*, Figure 8), **UN** and **UN_Stroop** (0.98±0.05 m/s) conditions (*p=0.03*, Figure 8) and **EX** and **UN_Stroop** conditions (*p=0.002*, Figure 8).

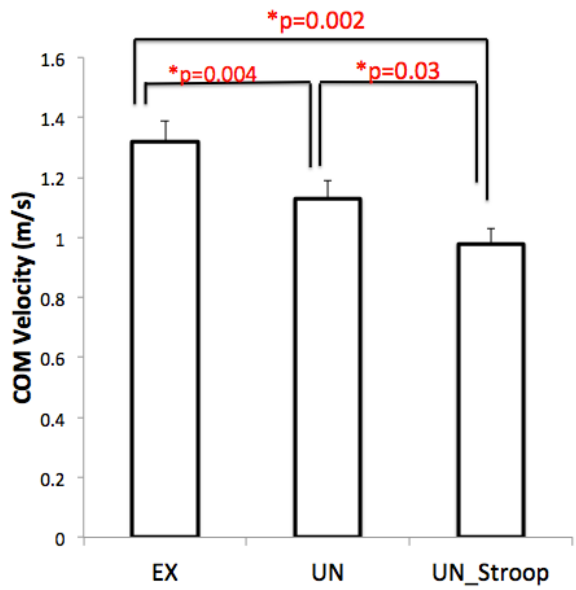

Figure 8: COM Forward Velocity Graph

This graph displays how the COM forward velocity (m/s) was affected by the **EX**, **UN** and **UN_Stroop** condition.

COM_{ml}: There is a statistically significant increase in COM_{ml} or side-to-side sway between **UN_Stroop** (0.05±0.002 m) and **EX** (0.04±0.003 m) conditions (p=0.00, Figure 9) only.

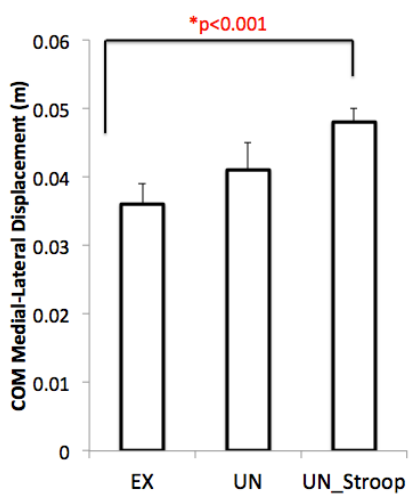

Figure 9: COM Medial-Lateral Displacement Graph

This graph shows how the **EX**, **UN** and **UN_Stroop** condition affected the COM medial-lateral displacement

Discussion

The purpose of this thesis was to explore how visual attention captured by smartphone usage contributes to a subject's cognitive response and gait termination strategies towards an unexpected event.

In terms of the cognitive performance, the subjects took approximately 320 ms longer in their reaction time for the **UN_Stroop** condition compared to the **Sit_Stroop** condition (Figure 6). There was no significant difference in accuracy rate between the **UN_Stroop** and **Sit_Stroop** conditions, indicating only the amount of time used to complete the tasks was affected and the speed-accuracy trade off can be excluded. Longer reaction time in the **UN_Stroop** also indicated the cognitive demands increased while interacting with an unexpected event. Not only did the cognitive performance of our task change between the **Sit_Stroop** and **UN_Stroop** conditions, gait performance did as well.

For our **UN** condition, we expected to see declined changes (compared to EX condition) in all dependent variables including a smaller toe-line distance, greater toe-line trial-to-trial variability, greater stop failure rate, slower vCOM and increased COM_{ml}, because the subjects could not expect the projected line and were still in the process of developing an appropriate stopping strategy. We did notice the significant changes in toe-line distance, toe-line trial-to-trial variability (Figure 7), stop failure rate, and gait velocity (vCOM, Figure 8) compared to **EX** condition. However, there was a trend but no significant difference for COM_{ml} (Figure 9) between **EX** and **UN** conditions. The fact that 91% of the subjects failed in the **UN** condition confirmed that the unexpected scenario we wanted to provide was achieved. Most of the gait parameters changed from the **EX** condition suggested that young healthy adults adapted their gait by decreasing walking speed and increasing variability to respond an unexpected event.

A Stroop test causes constraints to both the visual processing and decision-making (Doi et al, 2011) and we hypothesized the subjects would be further cognitively distracted and did not have enough visual attention to plan their stops (compared to **UN** condition). Therefore, we originally expected that the subjects would produce an even smaller toe-line distance, higher toe-line trial-to-trial variability, greater stop failure rate, slower gait velocity and more medial-lateral sway, compared to the **UN** condition. However, the results suggested that toe-line trial-to-trial variability (Figure 7), stop failure rate, vCOM (Figure 8) and COM_{ml} (Figure 9) in the **UN_Stroop** were significantly different from the **EX** condition but only toe-line trial-to trial variability and vCOM was significantly different from the **UN** condition whereas others (i.e. stop failure rate and COM_{ml}) were not. In addition, toe-line distances in the **UN_Stroop** condition were significantly different from the **UN** but not **EX** condition, indicating the toe-line distances were actually getting closer to the baseline which is defined by the **EX** condition.

The gradually declined gait velocity indicated that the subjects continuously slowed down to interact a further challenging condition while adapting their gait with a similar strategy as the **UN** condition (i.e. increasing variability and COM_{ml}).

We proposed two hypotheses to interpret the results regarding improved toe-line distance and stop failure rate found in the **UN_Stroop** compared to **UN** condition. First was that the subjects were able to better adjust their gaits at a slower walking speed.

Since our lab was a safe environment, the subjects had no time or space constraint to accomplish the task. The subjects could slow down and take their time to detect a projected line and performed an appropriate stop in addition to complete the Stroop test. By decreasing walking speed, the subjects could detect the projected line easily and stop in front of the line appropriately.

Our result agrees with other studies (Schabrun et al, 2014; Lopresti-Goodman et al, 2012) that texting and walking decreases subjects' vCOM. Since subjects need to divide their visual attention between the walkway and their phone (Schabraun, 2014), subjects may adopt a cautious gait, which translates to the slower speed (Marone et al, 2014). However, this declined velocity could potentially bring pedestrians into accidental harms in a real world situation. Other studies have connected the decreased speed to a slower street-crossing gait and a decreased ability to perform safe crossing behaviors such as looking both ways before crossing (Thompson et al, 2013). This could then lead to an increased probability of pedestrian injuries (Schwebel et al, 2012) such as being hit by a vehicle. In brief, decreased gait speed while engaging a smartphone could potentially be used to adjust for an appropriate gait adaptation in a safe lab environment; but this decreased speed may lead to a hazardous accident in daily activity.

The other proposed interpretation for improved failure rate and toe-line distance would be a potential learning effect in this study. We did not randomize the sequence between the **UN** and **UN_Stroop** conditions because we wanted the subjects to be familiar with the **UN** condition prior to adding an extra task. The fact that individuals experienced **UN** condition first may allow the subjects to be more prepared during the

UN_Stroop condition. They may have already developed a procedural memory for the walkway so they did not have to focus as much on the path and were able to orient more attentional resource towards detecting the projected lines and planning a stop. The subjects might have implicitly learned the timing and location of each projected line condition and developed a relatively anticipated strategy for gait termination. However, since the trials were randomly projected and the catch trials were involved, we believe we still created an unexpected environment.

The results we saw in terms of toe-line distance and failure rate tie in with a study conducted by Lopresti-Goodman et al (2012). Their study showed that subjects whom texted and walked through an adjustable doorway were more likely to rotate their trunks to walk through the door even though they could have easily passed through it without any changes compared to subjects that were walking undistracted. The researchers attributed it to the fact that subjects chose to increase their safety margin in order to avoid potential threat even though they were capable to achieve the task under these precautions. Our subjects therefore, could have stopped further from the line in order to increase their safety margin and make sure that they could avoid stepping on the line during the task.

The significantly increased COM_{ml} appeared in the **UN_Stroop** but not **UN** compared to the **EX** condition suggesting that COM_{ml} could be a sensitive measurement to differentiate **UN_Stroop** from **UN** condition. Previous studies have shown that the visual system plays an important part in regulating the body for gait termination (Marone et al, 2014; Perry et al, 2001; Schabrun et al, 2014). Visual inputs help to create the perception of self-motion. This information can help to initiate gait termination by working on the COM. Visual input information can help to slow down the COM progression as well as sway in order to and guide the feet and other body parts into their correct placement during double support in order to form a complete stop (Perrry et al, 2001). Therefore, because of the divided visual attention between the screen and walkway, the subject might not be able to properly coordinate their stops leading to the increased COM_{ml} as they have to make more adjustments during their gait termination.

Our result in increasing frontal plane dynamic instability (via increased COM_{ml}) when walking and engaging a Stroop test is aligned with a previous study (Marone et cl., 2014). Marone et al. found a significant increase in the frontal plane minimum margin of stability while walking and texting. This change in minimum margin of stability could cause the COM_{ml} to have changed in the way we had observed because it is more difficult to reach that margin of stability and so more sway needs to be produced in order to do so. Previous studies also found that walking and texting could cause a greater deviation from a straight-line path (Schabrun et al, 2014; Plummer et al, 2014). The findings that increased medial-lateral body sway and increased deviation from a straight-line path caused by walking and texting in the real-world could lead to pedestrian injuries because they are more likely to run into or trip over objects on the street.

As stated before, the main limitation to this project is that we did not randomize the **UN** and **UN_Stroop** conditions. A follow-up study by randomizing these two conditions is needed to rip apart two proposed hypotheses. A follow-up study would also help increase our sample size. We only collected data from eleven subjects.

Although we were able to detect significance in most of the gait variables, we would like to see if the COM_{ml} would become significant in the **UN** study compared to the **EX** condition if the sample size was to be increased.

In conclusion, strategies that subjects perform when they are engaging in smartphone usage while walking such as increased side-to-side sway or decreased speed could lead to a negative impact on pedestrian safety. Therefore, it is important to educate the public on the risks of smartphone use while walking so hopefully the instances of accidents can be decreased to create a safer environment for all who are sharing the streets.

Appendix A

ID: ____________________ Date: ____________________

UNIVERSITY OF OREGON
CONSENT TO TAKE PART IN A RESEARCH STUDY

TITLE: Smartphone Use while Walking

INTRODUCTION

You are invited to participate in a research study conducted by On-Yee Lo (Advisor: Prof. Li-Shan Chou) of the University of Oregon, Department of Human Physiology. We hope to gain a better understanding of the underlying mechanisms of smartphone use while walking upon gait behavior during over-ground walking, obstacle-crossing and in adaption to an unexpected stimulus, which would help to develop a quantified understanding of the underlying mechanisms of distracted locomotion. You are selected as a possible participant because you are a healthy individual aged 18-40 years. However, if you do not pass the screening test, you will be excluded from participation in this study.

If you decide to participate, you will be asked to engage in the following screening and testing sessions that span two days. The total data collection will take approximately 2 hours. All of the data collected is coded and therefore we maintain all personal confidentiality.

SCREENING SESSION

At the beginning, you will be asked to complete this consent form and the "Smartphone Usage and Healthy History Questionnaire". If you answer yes in any of the questions under Health History Questionnaire, you will be excluded from participation in this study. If you pass the screening test, you will continue to the testing sessions. The screening session will take approximately 10 minutes.

TESTING SESSIONS

Visit One:

Preparation session

You will first be directed to change into shorts and a tank top. Your age, height, and weight will then be measured. Further, the length and width of your feet, the medio-lateral dimensions of your ankle joints, knee joints and your pelvic width will also be measured. The entire preparation session will take approximately 10 minutes.

Reflective marker placement

A set of 29 reflective markers will be placed on bony landmarks of your body. It will take 5 minutes.

Practice the Stroop Test

You will practice the Stroop Test in an iPod Touch. In this Stroop Test, you will state the color of colored words instead of the name of the word that is presented. For example, when you see "Green", you will respond by saying "Black," instead of "Green."

Walking while Texting and Stroop Test

You will be asked to walk at your self-selected speed without any concurrent task for 5 trials. Then you will be asked to walk the same course when responding to a text message. You will be asked to respond to each question with a simple one-word answer. You will complete this walking and texting for 5 trials. You will then be asked to walk the course while working on a Stroop test on the iPod Touch. You will complete this walking and responding to the Stroop test for 5 trials. These three conditions will be in random order. All of the walking trials will take a total of 10 minutes.

Obstacle-Crossing Walking Task

You will be asked to walk and cross over an obstacle at your self-selected speed without any concurrent task for 5 trials. The obstacle will be presented as a PVC pipe bar. Then you will walk and cross over an obstacle while texting or responding to the Stroop test. You will perform 5 trials for walking and texting and another 5 trials for walking and responding to the Stroop test. These conditions will be in random order. All of the obstacle crossing trials will take a total of 10 minutes.

Sitting While Texting and Sitting While Responding to the Stroop Test

You will be asked to sit and to answer simple questions through text and to complete 5 trials of the Stroop test. This will take a total of 5 minutes.

Marker Removal

Markers will be removed from subjects after completing the aforementioned tasks.

Visit Two:

Preparation session

At the beginning, you will be asked to change into shorts and a tank top.

Reflective marker placement

A set of 29 reflective markers will be placed on bony landmarks of your body. It will take 5 minutes.

Sitting While Texting and Sitting While Responding to the Stroop Test

You will be asked to sit and to answer simple questions through text and to complete 5 trials of the Stroop test. This will take a total of 5 minutes.

Walking

You will be asked to walk across the floor for 5 trials without any obstacles. This will take approximately 5 minutes.

Distracted Walking Stimulus Adaption

A line will be projected onto the ground. You will have to walk and then stop right in front of the projected line for 5 trials. Afterwards, you will walk for 10 trials without any distractions. The line will be randomly projected onto the ground and every time it shows up, you will have to stop in front of it; if it does not show up, you can just walk to the other side of the room. After that, you will be given an iPod Touch and will have to preform the Stroop Task while walking. The line will randomly be projected onto the ground and you will also have to stop in front of the projected line whenever you see it. This will occur for another 10 trials. This part will take a total of approximately 30 minutes.

Marker Removal

Markers will be removed from subjects after completing the aforementioned tasks

The total time for this experiment is roughly 2 hours. We expect 1 hour per visit.

RISKS AND DISCOMFORTS

We expect that there will be no more risk for you during these tests than there normally is for you when walking around outside of the laboratory. However, you may feel fatigue during or after the testing. A staff member will check in with you frequently and provide any required assistance. You will be given frequent breaks as requested. There is also the possibility of discomfort involving the removal of adhesive tape (used for the motion markers) from the skin at the end of the experiment. Although you will not receive any personal benefits from this research, the full results can help to create a better understanding of distracted walking, especially texting while walking, which can create better educational programs for college-age students.

All information will be kept confidential. Computer data files, laboratory notes and videotapes will be archived in a locked filing cabinet. All records will be stored with a code number, not your name, and will be kept by the principal investigators in the locked and security-regulated Motion Analysis Laboratory.

COMPENSATION

You will receive $10 per hour for your participation in this study. This is to help defray the costs incurred for participation such as parking and transportation as well as your time. If you do not complete a full session (2 visits, 2 hours) of testing, the amount will be pro-rated. Your participation is voluntary. Your decision of whether or not to participate will not affect your relationship with the University of Oregon Department of Human Physiology or the general university campus. You do not waive any liability rights for personal injury by signing this form. In spite of all precautions, you might develop medical complications from participating in this study. If such complications arise, the researchers will assist you in obtaining appropriate medical treatment. In addition, if you are physically injured because of the project, you and your insurance company will have to pay your medical bills. If you are a University of Oregon student or employee and are covered by a University of Oregon medical plan, that plan might have terms that apply to your injury. If you have any questions about your rights as a research subject, you can contact the Office for Protection of Human Subjects, 5219 University of Oregon, Eugene, OR 97403, (541) 346-2510. This office oversees the review of the research to protect your rights and is not involved with this study. If you decide to participate, you are free to withdraw your consent and discontinue participation at any time. If you have any questions, please feel free to contact On-Yee Lo or Dr. Li-Shan Chou, (541) 346-3391, Department of Human Physiology, 112 Esslinger Hall, University of Oregon, Eugene OR, 97403-1240. You will be given a copy of this form to keep.

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, that you may withdraw your consent at any time and discontinue participation without penalty, that you have received a copy of this form, and that you are not waiving any legal claims, rights or remedies.

Print Name ____
Signature ______________________________________ Date ______________________

Appendix B

ID: ____________________ Date:________________

Smartphone Usage and Health History Questionnaire

This questionnaire is used to verify information discussed in the phone interview as well as assess your smartphone usage.

Print Name: _______________________________________ Age: _____

Smartphone Usage:

1. How often do you text each day? (How many messages do you text a day?) ________________________

2. Do you walk while texting?
ALWAYS OCCASIONALLY NEVER

3. Have you ever crossed the street while texting? YES NO N/A

4. If yes, did you feel safe while crossing the road? YES NO N/A

Health:

Have you been under recent medical care for any of the following conditions?

1. Neurological disorder? Yes No
If yes, is your daily function moderately or significantly impaired?
____

2. A significant head injury? Yes No
If yes, is your daily function moderately or significantly impaired?
____

3. Vision impairment that is uncorrected by glasses? Yes No
If yes, is your daily function moderately or significantly impaired?
____

5. Muscle, joint, or other orthopedic disorder? Yes No
If yes, is your daily function moderately or significantly impaired?
____

6. Persistent vertigo, lightheadedness, unsteadiness, or falling? Yes No
If yes, is your daily function moderately or significantly impaired?
____

7. Any other medical conditions that may affect you to walk over ground or cross an obstacle?
Yes No
If yes, please describe ____

Signature: ________________________________Date:________________

Appendix C

Subject ID: SP_D____ **Data Collection Date:** __ / ____ / _____
Subject Name: ____________ **Date of Birth:** ___ / _____ / _____ **School Years:** ___________
Ht (cm): _______ Wt (kg): _____

	R (cm)	L (cm)	JC	JC
Foot Length			R (mm)	R(mm)
Foot Width				
Knee Width				
Ankle Width				
ASIS Width				

Condition	No	Response and Notes	THS	LTO	LHS	TTO	THS	LTO	.trb	.anc	.trc	Matlab	Note
ID_Walk	1	NA											
ID_Walk	2	NA											
ID_Walk	3	NA											
ID_Walk	4	NA											
ID_Walk	5	NA											
ID_EX	1	P F											
ID_Ex	2	P F											
ID_EX	3	P F											
ID_EX	4	P F											
ID_Ex	5	P F											
ID_UN	1	P F											
ID_UN	2	P F											
ID_UN	3	P F											
ID_UN	4	P F											
ID_UN	5	P F											
ID_UN	6	P F											
ID_UN	7	P F											
ID_UN	8	P F											
ID_UN	9	P F											
ID_UN	10	P F											
ID_UN_STROOP	1	P F											
ID_UN_STROOP	2	P F											
ID_UN_STROOP	3	P F											
ID_UN_STROOP	4	P F											
ID_UN_STROOP	5	P F											
ID_UN_STROOP	6	P F											
ID_UN_STROOP	7	P F											
ID_UN_STROOP	8	P F											
ID_UN_STROOP	9	P F											
ID_UN_STROOP	10	P F											

Reference

Byington, K. W., & Schwebel, D. C. (2013). Effects of mobile Internet use on college student pedestrian injury risk. Accident Analysis & Prevention, 51, 78–83.

Cortex. (n.d.). Retrieved October 04, 2014, from http://www.motionanalysis.com/html/industrial/cortex.html

Danion, F., Varraine, E., Bonnard, M., & Pailhous, J. (2003). Stride variability in human gait: the effect of stride frequency and stride length. Gait & Posture, 18(1), 69–77.

Doi, T., Asai, T., Hirata, S., & Ando, H. (2011). Dual-task costs for whole trunk movement during gait. Gait & Posture, 33(4), 712–4.

Duggan, M. (2013, September 19). Cell Phone Activities 2013. Pew Research Centers Internet American Life Project RSS. Retrieved October 2, 2014, from http://www.pewinternet.org/2013/09/19/cell-phone-activities-2013/

Hase, K., & Stein, R. B. (1998). Analysis of rapid stopping during human walking. Journal of Neurophysiology, 80(1), 255–61. Retrieved from http://jn.physiology.org/content/80/1/255.abstract

L, C. (n.d.). Kinesiology 372 Luttrell Flashcards Anatomical Directions/Alignment Variations | StudyBlue. Retrieved November 2, 2014.

Lamberg, E. M., & Muratori, L. M. (2012). Cell phones change the way we walk. Gait & Posture, 35(4), 688-690.

Lopresti-Goodman, S. M., Rivera, A., & Dressel, C. (2012). Practicing Safe Text: the Impact of Texting on Walking Behavior. Applied Cognitive Psychology, 26(4), 644–648.

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: an integrative review. Psychological Bulletin, 109(2), 163–203. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2034749

Marketing Charts. (2013, June 18). MarketingCharts. College Students Own an Average of 7 Tech Devices. Retrieved October 4, 2014, from http://www.marketingcharts.com/online/college-students-own-an-average-of-7-tech-devices-30430/

Marone, J. R., Patel, P. B., Hurt, C. P., & Grabiner, M. D. (2014). Frontal plane margin of stability is increased during texting while walking. Gait & Posture, 40(1), 243–6.

Nasar, J. L., & Troyer, D. (2013). Pedestrian injuries due to mobile phone use in public places. Accident Analysis & Prevention, 57, 91–5.

Neider, M. B., McCarley, J. S., Crowell, J. A., Kaczmarski, H., & Kramer, A. F. (2010). Pedestrians, vehicles, and cell phones. Accident Analysis & Prevention, 42(2), 589–94.

O'Leary, D. S., Andreasen, N. C., Hurtig, R. R., Torres, I. J., Flashman, L. A., Kesler, M. L., … Hichwa, R. D. (1997). Auditory and visual attention assessed with PET. Human Brain Mapping, 5(6), 422–36.

Parr, N. D., Hass, C. J., & Tillman, M. D. (2014). Cellular Phone Texting Impairs Gait in Able-Bodied Young Adults. Journal of Applied Biomechanics, 30(6), 685-688.

Patla, A. E., & Vickers, J. N. (2003). How far ahead do we look when required to step on specific locations in the travel path during locomotion? Experimental brain research, 148(1), 133-138.

Perry, S. D., Santos, L. C., & Patla, A. E. (2001). Contribution of vision and cutaneous sensation to the control of centre of mass (COM) during gait termination. Brain Research, 913(1), 27–34.

Plummer, P., Apple, S., Dowd, C., & Keith, E. (2014). Texting and walking: Effect of environmental setting and task prioritization on dual-task interference in healthy young adults. Gait & Posture. 41(1), 46-51.

Rhea, C. K., & Rietdyk, S. (2011). Influence of an unexpected perturbation on adaptive gait behavior. Gait & Posture, 34(3), 439–41.

Schwebel, D. C., Stavrinos, D., Byington, K. W., Davis, T., O'Neal, E. E., & de Jong, D. (2012). Distraction and pedestrian safety: how talking on the phone, texting, and listening to music impact crossing the street. Accident Analysis & Prevention, 45, 266–71.

Smith, D. C., Schreiber, K. M., Saltos, A., Lichenstein, S. B., & Lichenstein, R. (2013). Ambulatory cell phone injuries in the United States: an emerging national concern. Journal of Safety Research, 47, 19–23.

Srygley, J. M., Mirelman, A., Herman, T., Giladi, N., & Hausdorff, J. M. (2009). When does walking alter thinking? Age and task associated findings. Brain Research, 1253, 92–9.

Stavrinos, D., Byington, K. W., & Schwebel, D. C. (2011). Distracted walking: cell phones increase injury risk for college pedestrians. Journal of Safety Research, 42(2), 101–7.

Strauss, G. P., Allen, D. N., Jorgensen, M. L., & Cramer, S. L. (2005). Test-retest reliability of standard and emotional stroop tasks: an investigation of color-word and picture-word versions. Assessment, 12(3), 330–7.

Thompson, L. L., Rivara, F. P., Ayyagari, R. C., & Ebel, B. E. (2013). Impact of social and technological distraction on pedestrian crossing behaviour: an observational study. Injury Prevention : Journal of the International Society for Child and Adolescent Injury Prevention, 19(4), 232–7.