EFFECTS OF DECEPTIVE BEHAVIOR ON BIOMECHANICAL

MEASURES OF STANDING POSTURE

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ABSTRACT

The accurate detection of deception has potential applications in many fields including credibility assessment, security screening, homeland security, and counter-terrorism. Techniques currently used for deception detection typically capitalize on deception-related physiological changes, and include polygraph testing, voice stress analysis, brain activity analysis, and thermal scanners. However, the use of these techniques in natural environments is limited as they often require intrusive sensors to be attached to the body. These limitations may be addressed with posturography, which involves studying the ground reactions associated with standing balance without the need

for intrusive sensors. Therefore, the objective of the current study was to examine deception-related effects on measures of standing posture using a mock security screening interview. We hypothesized that deceptive participants, compared to truthful would demonstrate significant differences in ground reactions during the interview.

Participants were required to pack a backpack with various items. One group of participants had items that were "prohibited", whereas the other group had equivalent, non-prohibited control items. Both groups were questioned about the contents of the backpack. The group with "prohibited" items was instructed not to reveal that they were carrying any prohibited items.

Results of the study indicated that there was a significant deception-related decrease in center of pressure movement. The deception related decrease in both center of pressure pathlength and mean velocity suggests that people "freeze" when they are being deceptive. This notion was supported by increased oscillations in the anterior-posterior direction.

APPROVAL PAGE

The faculty listed below, appointed by the Dean of the School of Computing and Engineering, have examined a thesis titled "Effects of Deceptive Behavior on Biomechanical Measures of Standing Posture" presented by Darren Stanford Mullin, candidate for the Master of Science degree, and certify that in their opinion it is worthy of acceptance.

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CHAPTER 1

INTRODUCTION

Deception is defined as a psychological process by which one person deliberately attempts to convince another to accept as being true what the liar knows to be false [1]. The accurate detection of deception has potential applications in many fields including credibility assessment, security screening, homeland security, and counter-terrorism. Techniques currently used for deception detection typically capitalize on deception-related physiological changes, and include polygraph testing, voice stress analysis, brain activity analysis, and thermal scanners [2]. However, the use of these techniques in natural environments is limited as they often require intrusive sensors to be attached to the body.

Video-based deception detection techniques provide an alternative to those relying on physiological measures. Video-based techniques for deception detection have shown that distinctive body movements can be used to differentiate between deceit and truth-telling, and that such behavioral indicators can successfully be captured and tracked automatically using computer vision techniques [3] [4] [5]. However, video-based methods can be insensitive to occluded or small movements, difficult in terms of feature

extraction and data reduction, and are prone to image processing errors in real-world scenarios.

The usage of computerized static posturography (CSP) may have the potential to augment or overcome the limitations of video-based deception detection. CSP involves analyzing the center of pressure (COP) of a person's body while standing still. The COP is defined as the point of application on the ground of the body's net resultant force vector [6]. CSP has previously been used in clinical settings to evaluate balance deficiencies caused by age-related or by disease-related factors such as peripheral neuropathy [7] [8] [9], stroke [10] [11], and Parkinson's disease [12] [13].

CSP has also been used on a limited basis for the classification of human movement patterns. Pattern recognition analyses have been applied to COP-based parameters in order to successfully discriminate between fallers and non-fallers [14], between people with good and poor postural stability [15], between non-alcoholics and alcoholics [16], and between people with and without sleep deprivation [17]. Given the previously observed deception-related effects on body kinematics, such classification techniques may have potential in the field of deception detection. However, no researchers have successfully used COP-based parameters to discriminate between truthful and deceptive persons.

As a preliminary step in achieving this goal, traditional statistical techniques were used to investigate differences in deception-related COP parameters. A study was conducted in which participants took part in a security screening interview. Participants were required to pack a backpack with various items. One group of participants packed

items that were "prohibited", whereas the other group did not. Both groups were questioned in the interview about the contents of their backpack. The group with "prohibited" items was instructed not to reveal to the interviewer that they were carrying any of these prohibited items. It was hypothesized that truthful participants, compared to deceptive participants, would exhibit varied COP patterns when responding to interview questions.

CHAPTER 2

BACKGROUND

Deception

Deception is defined as a psychological process by which one person deliberately attempts to convince another to accept as being true what the liar knows to be false [1]. Deception is typically performed for the purpose of gaining a personal benefit, or to avoid some type of a loss [1]. Deception is present in everyday social and professional life [18].

Some researchers extend the definition of deception by stating that deception must be voluntary, and must occur without forewarning [19]. By this definition, there must be no instructions given to the deceiver telling them to be deceptive or exactly when they should tell a lie. However, such instructions are a feature of most deception studies found in the literature. Researchers using the extended view of deception stated above would argue that most deception-related studies do not actually measure deception; rather they measure complex executive functions that are associated with deception.

Deception is socially rooted, and the processing of deception is modified by moral perception of a situation. These moral perceptions are typically dependent upon the deceiver's expectation of there being consequences for their actions, whether they are positive or negative [19]. Without consequences for their actions, no harm can be done

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and no gain can occur to the deceiver or the deceived. It is believed that without consequences there cannot be a valid representation of the processes involved in deceptive acts. This has also been a significant limitation of previously performed deception studies [19].

Indicators of Deception

In response to the need for accurate deception detection, researchers have long been trying to decode human behavior in order to discover deceptive cues. Knowledge of such cues allow for the development of methods to detect deception [18]. Such methods may have application in fields such as credibility assessment, security screening, homeland security, and in counter-terrorism [20].

Several studies have been conducted with the goal of identifying cues to deception. An extensive literature review was conducted in order to determine known cues to deception. A wide variety of cues were examined; however, an emphasis was placed upon examining cues that may manifest themselves as COP variations. In a study conducted by Zuckerman et al. [21], the Four-Factor theory of deception predicted that liars typically have four differing characteristics when compared to truth-tellers, including (1) increased general arousal, (2) emotions more associated with guilt, (3) more complex cognitive activity, and (4) attempts to control verbal and non-verbal behavior to avoid getting caught. All of these characteristics may be exploited in order to obtain insight into deception-related cues.

In a recent study conducted by Dilizan et al. [18], it was determined that deceptive behavior cues may be attributed either to over-control or agitation. When liars are over-

controlling they exert extra effort in an attempt to hide any deceptive behavioral cues that they might otherwise display. This may be evident in reduced movements of the hands, legs, and head. On the other hand, some liars show signs of agitation, which are triggered by nervousness and fear. This agitation is usually accompanied by speech that tends to be faster [18]. Deception is thought to be a dynamic process; liars adjust their behavior according to how much they believe they are suspected of being deceitful [18]. This makes the task of deception detection very difficult since the cues to deception are not always the same for each response, even for a particular individual. It may not always be correct to assume that either over-control or agitation is a definite sign of deceptive behavior; rather it is usually more reliable to look for deviations from a person's normal behavior. It is likely that liars will unintentionally reveal at least some behavioral cues as a result of their lie [18].

In addition to non-verbal cues, deceptive individuals also exhibit verbal behavior suggesting that they are less forthcoming than non-deceptive individuals [22]. For example, previous studies have shown reduced response lengths, less detailed responses, and less unique words when participants answer questions requiring deception [23] [24] [25] [26]. Liars also tend to be hold back in their responses [22], as evidenced by blocking access to information [27], increased response latencies, an increased rate of speaking [28], and by pressing together their lips [22].

Liars have also been found to tell less compelling versions of events than truth-tellers [22]. Liars' responses often make less sense; they are not plausible and their version of events may seem internally inconsistent [29]. Liars often appear less

engaging, shown by being less verbally expressive, using less eye contact and by the use of fewer hand movements [22]. When people are being deceptive they typically give the overall impression of being more uncertain, evidenced by several subjective and objective measures such as sounding insecure, not being very dominant, and by having difficulty when answering some questions [30]. The uncertainty can also be accompanied by the deceiver raising their chin and pushing up their lower lip [22]. When answering questions liars also have been found to use more word repetitions and phrase repetitions [30].

Liars are generally less positive and pleasant than truth-tellers [22]. Studies have shown them to be less cooperative and that they provide more negative statements and complaints [31]. Liars have also been shown to have reduced facial pleasantness [22].

Studies have shown that liars are generally tenser than truth-tellers [22]. Liars often seem nervous, and may make body movements associated with their feeling of nervousness [30]. Specifically, facial fidgeting such as playing with hair or rubbing of the face increases when people are being deceitful [30]. However, object fidgeting such as tapping a pencil or playing with something that they are holding decreases when being deceitful [32]. Liars typically exhibit more vocal tension [30], and a higher pitched voice [33]. When liars become aroused their pupils usually tend to dilate and the rate at which they blink tends to increase [22].

Several studies have demonstrated that lying results in an increased cognitive load. Cognitive processes are often overlooked in research focused on the nature of deception, and only consider behavioral cues to deception [34]. Deception is a difficult

task; the deceiver must control facial, vocal, and bodily expressions and gestures, and thus, executive processes are vital in the formulation of a convincing lie. Executive processes refer to cognitive activities such as working memory, directed attention, inhibiting inappropriate responses and activating appropriate ones. Executive processes are important in decision making, planning, problem solving and in various other complex cognitive tasks [34]. Results from several studies have shown that lying requires greater mental effort than telling the truth [34] [20] [19]. Interpersonal Deception Theory, which was proposed by Burgoon et al. [25], describes deception as a two way interactive communication. It also states that deception is a mentally taxing process, as the deceiver must construct and maintain the lie while they are monitoring their own behavior. If the deceiver experiences a cognitive overload, then they will display leakage in the form of non-verbal cues [25]. This assumption has been used to explain deception-related behavioral cues such as longer response latency, pupil dilation, speech hesitation, and fewer hand movements [21].

Studies focused on deception-related increases in cognitive load have revealed, via brain scanning techniques, that anterior cingulate and dorsolateral prefrontal cortices are particularly more active when people are lying [20] [34] [1] [19]. These areas of the brain have been identified as being responsible for performing executive processes [34], which supports the idea that deception increases the cognitive load that the deceiver must process.

Behavioral cues that are of particular interest in the current study are posturographic measures that are associated with an increased cognitive load. To the best

of our knowledge there have been no posturographic deception-related studies; however, since deception is associated with an increased cognitive load, the posturographic changes that are associated with an increased cognitive load may also be extended to deception. In a study conducted by Stins et al. [35], COP excursions were found to decrease with an increase in cognitive load. This observation can be explained by stiffening of the ankle joint via a co-contraction mechanism. The increase in stiffness may be explained by a heightened level of awareness, and reduced postural automaticity [35]. This observation has also been supported by a study conducted by Dault et al. which showed a decrease in postural sway during a working memory task [36]. In addition to the decrease in COP excursions, the mean COP frequency was found to increase. This result was found in studies conducted by Stins et al. [35], and by Dault et al. [36] which had also observed reduced COP excursions. The increased frequency may be explained by changes in ankle stiffness when a co-contraction mechanism is employed since it is a more automatic control process. This more automated control process releases cognitive resources for the primary focus of the person. It can be expected that the increased cognitive load required for lying will also result in an increased COP frequency.

This stiffening response has a close resemblance to the "freezing" behavior commonly observed in nature. Freezing is a common defensive response in animals that are threatened by predators [37]. It may be characterized by reduced body motion, and a decrease in heart rate [37]. In a study conducted by Roelofs et al., it was shown that social threats can also elicit the freezing response in humans. Participants in that study

exhibited a freezing response, as evidenced by reduced COP sway, when they were shown images depicting angry faces in comparison to responses observed for happy faces. Freezing may be described as part of an early orienting response, possibly serving to aid in the detection of information for a subsequent fight-or-flight response which involves whole-body movements [37]. Since social threats elicit a freezing response, it follows that the reduction in COP excursions due to an increased cognitive load may be the cause of this observed effect.

Current Deception Detection Techniques

Several different techniques have been utilized for detecting deception. The need for these techniques has arisen as a result of the inability of humans to detect deception. Even after receiving training, humans' accuracy at detecting deception is just better than chance [2]. People typically rely on misconceptions as to which cues are best for deception detection. Many deception detection techniques simultaneously measure several different cues, rather than just a single cue to deception [2]. Humans typically have difficulty tracking several cues, and may have difficulty tracking some of the more subtle cues which may be the best indicators of deception [2].

Polygraph

Polygraph testing is the most successful and commonly used system for deception detection [2]. Polygraph testing combines both interrogation and physiological measurements including heart rate, blood pressure, respiratory rate, and electrical conductance at the skin surface [18] [34].

Although polygraph testing is widespread, it is not a perfect system. The use of a polygraph requires it to be continuously connected to the subject's body [18]. This means that the subject must be cooperative and must be close to the device. Invasive sensors must be attached to the subject's body during testing; a blood pressure cuff is attached to the arm to determine their blood pressure and heart rate, galvanometers are attached to the finger tips to determine the skin's electrical conductance, and respiratory rate is determined by using two pneumographs which are placed at the subject's chest. The use of a polygraph requires accurate calibration of the device at the start of session so that a baseline can be established [18].

Despite the calibration step, the polygraph system may not always provide accurate readings if, for example, the subject's heart rate increases for reasons that are not related to deception [18]. Since the polygraph is an overt system people may devise techniques to trick the machine. These techniques include remaining calm, controlling the heart rate, or being excited during the calibration phase [18].

Polygraph testing requires a trained operator, and the accuracy of the polygraph test is dependent upon their skills and abilities. The operator is also in control of the length of the interview, and the operator may sometimes need breaks or may get tired, thus affecting the accuracy of the test [18].

Limitations of the polygraph illustrate a need for a covert system that does not require the subject's cooperation. There is also a need for a system that does not require obstructive sensors to be attached to the subject. Overcoming these limitations would

allow for deception to be measured in natural environments. There is also a need for a system that is automated, thus eliminating the possibility of operator error.

<center>Voice Stress Analysis</center>

Vocal stress analysis is another currently-used deception detection technique, since vocal stress is present in most instances of deception [38]. Commercial voice analysis products have been marketed to security agencies and law enforcement for over 30 years [38]. Vocal deception detection is a covert technique; the subject can be tested without their knowledge or consent. Voice stress analyzers have many potential applications, such as detecting deception in statements made by suspects or by witnesses [38]. Voice stress analyzers typically rely on extracting various voice frequency ranges of interest, which are believed to be affected to physiological and psychological reactions of deception [39] [38]. Mathematical algorithms are used to extract these frequencies and to assign meaning to them (i.e. truthful or deceptive) [38].

Despite their potential, commercial voice analysis products that are currently available have not been widely utilized for deception detection. This is largely due to several significant limitations that have not yet been overcome. In a study that was conducted by Harnsberger et al. [38], trained operators of a layered voice stress analysis system were only able to achieve true positive rates of 42-56%, and false positive rates were as high as 40-65% [38]. These rates are at about chance levels of detection, and thus results obtained using these systems are often viewed skeptically. The National Research Council's 2003 literature review concluded that voice stress analyzers offer

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little to no scientific justification for their use over the more successful polygraph test [40].

Manufacturers of voice stress analyzers claim that their systems are able to detect a wide variety of emotional and cognitive states, such as stress due to traumatic experiences, fatigue, intoxication, degree of concentration, and sexual arousal [38]. However, high false positive rates are at odds with this claim, suggesting that current systems are not yet able to achieve these claims. Shortcomings of voice stress analyzers may in part be explained by most of the current research being performed on simulated field studies which attempt to mimic natural environments. Lab studies may not elicit the same stress levels that may be present in real-world settings [38]. The accuracy of the test is also dependent upon both the skill of the operator and the skill of the interrogator. Further research between the operator and the equipment needs to be carried out to fully understand the importance of using a well-trained operator [38]. In addition, currently used systems are not able to automatically discriminate between truthful and deceptive responses [39] [38].

Researchers have cited the need for a greater fundamental understanding of the relationship between psychological stress, deception and how speech is articulated [38]. Further research also needs to be conducted to determine the applicability of voice stress analyzers to different languages. Currently there are no voice stress analyzers that are designed for multiple languages, and their applicability to different languages is not currently known [38].

Video-Based Techniques

Recently developed video-based deception detection techniques have been used for the automatic extraction of behavioral indicators of deception. Video-based techniques typically involve collecting high quality digital video, which is processed using algorithms that perform facial and hand recognition by differentiating among colors present in the video [2]. Based upon the analysis of hand and head locations inferences have been made in previous studies about levels of involvement, dominance, tenseness, and arousal [2]. These levels are then used to assign a deceptive rating to a subject's response [2]. Other studies have furthered these techniques by also including the tracking of micro-expressions during testing [18].

Video-based methods are very complex to successfully implement. Researchers involved in video-based deception detection have admitted that there needs to be progress made in the precision of the feature extraction methods that are used [2]. Currently used methods suffer from misclassification of body parts due to occlusion and body parts leaving the frame [2]. It is usually necessary to use several high-quality digital video cameras in order to collect all of the necessary data [18]. This may be difficult to implement in natural environments. Researchers working in this field have stated that current video-based techniques to date have not yet succeeded in explaining all of the factors which are necessary to fully explain deception [2]. Additional factors that have been suggested include motivation to succeed in deception, individual characteristics, cultural factors, and the interviewing style of the individual interviewer [2]. Video-based techniques which have employed subject-specific models have achieved classification

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rates as high as 81.6%, which significantly outperformed similar non-subject specific models achieving classification rates of only 60% [18].

Brain Activity Analysis

Brain activity scanning techniques offer another option for deception detection. Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) are two scanning modalities that have been recently implemented, both of which have demonstrated reliable measurement of brain activity associated with thoughts, feelings, and behavior.

EEG measures signals known as event related potentials (ERP) [41]. ERP signals are measured by using multiple sensors attached to the scalp of the subject. ERP signals can be measured from the scalp 300-500ms after the subject has been exposed to a stimulus [41]. By using this technique researchers have been able to determine whether the subject is familiar with a particular claim. EEG deception detection tests have achieved correct rates of 75-85% [41]. EEG has the advantage of being relatively small, inexpensive, and portable when compared to other deception detection techniques [41].

EEG deception detection has shown promise as an alternative system to the more commonly used polygraph. However, there are limitations of using EEG. One of the more common techniques, called brain fingerprinting, relies on proprietary methods of analysis due to the inventor attempting to commercially develop the product [41]. This has stopped researchers from independently validating the technique [41]. A considerable amount of work must be done in order to standardize the technique before it could be ready for routine use in real-world deception detection applications.

Blood oxygenated level-dependent fMRI studies also show promise for deception detection, and a greater amount of research has been devoted to its development than to EEG based methods [42]. Brain fMRI is performed by placing the head into the bore of an MRI scanner. The scanner is built around a powerful electrical magnet, which generates two magnetic fields [42]. The main field is perpendicular to the plane of the central bore, and the weaker gradient field is at an angle to the main field [42]. The rapid switching from on to off of the gradients causes hydrogen nuclei in the body water to resonate and emit radiofrequency signals that can be reconstructed into three-dimensional images [42]. fMRI has a spatial resolution of 1-3mm, and a temporal resolution of 2-3 seconds [42]. When the local oxygen demand in the brain rises in response to an increased amount of metabolism and electrical activity, the inflow of oxygenated hemoglobin causes the fMRI signal emanating from the tissues supplied by a particular blood vessel to increase [42]. fMRI relies on cognitive subtraction, which involves calculating the difference between a target and a control stimuli; thus selection of an appropriate baseline is critical [42].

The reliability, safety, and availability of fMRI have made it an attractive system to use for the purpose of deception detection. The development of fMRI-based techniques has been fueled by the inability of currently used techniques to detect deception reliably and accurately. fMRI techniques also have the advantage of being highly repeatable due to automated data processing techniques that have been developed [42]. fMRI studies have been successful in achieving correct rates from 76-90% [42]. There is a significant existing amount of work that has been done which correlates

specific areas of brain activity with basic cognitive functions such as response inhibition, cognitive conflict, and attention. These studies provided direction for initial deception studies.

fMRI studies have identified several different areas of the human brain that are thought to be more active when people are being deceptive, including the dorsolateral prefrontal cortex and the adjacent cingulated cortex [19] [1] [42]. Results from these studies have associated the dorsolateral prefrontal cortex with executive processes that are involved in deception, regardless of whether or not there is any emotional involvement [1]. Studies have found the dorsolateral prefrontal cortex to be used for inhibition, decisions relating to social interactions involving competition, cooperation, and in reputation management [19]. The adjacent cingulate cortex is thought to be used in decision making, relating actions to consequences, problem solving, motivation, and in anticipation [19]. fMRI deception detection largely relies on detecting activity in these areas of the brain that have been found to be active when a person is lying [42] [19] [41]. However, it is important to note that just because these areas are active; it does not necessarily mean that a person is being deceptive [19]. The currently existing body of research on this topic has yet to find an area of the brain or cognitive process that is unique to deception [19].

There are several limitations that are common to both EEG and fMRI methods for deception detection. Both techniques typically are making inferences about individuals based upon group studies. Studies using other techniques, such as video-based methods have shown there to be subject-specific factors, which if included will improve

classification rates [18]. Both brain scanning techniques are limited by their applicability in natural environments. EEG testing requires several sensors to be attached to the subject's scalp, and fMRI requires the subject to place their head inside of an MRI machine. Since both are overt systems subjects must be cooperative. Countermeasures to beat the tests have not yet been studied in detail for either technique [41]. There is also an ethical concern for the possible misuse of data that is collected for purpose of "mind reading". As brain scanning techniques continue to develop, an individual's cognitive privacy may become of increasing concern [41].

Posturography

The most commonly used measure in posturography is the center of pressure (COP). The COP can be calculated based on ground reaction force and moment data that is collected by a force plate. Equation 1 and Equation 2 can be used to determine the center of pressure in both the x-direction and y-direction, which typically correspond to the medial lateral (ML) and the anterior-posterior (AP) directions respectively.

$$COPX = \frac{-(M_y + F_x az_0)}{F_z} \qquad \text{Equation 1}$$

$$COPY = \frac{(M_x - az_0)}{F_z} \qquad \text{Equation 2}$$

The value of az_0 is defined as the perpendicular distance of the force plate relative coordinate system relative to the plate's surface, and is specific to the particular force plate being used [43].

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Stabilograms, which may also be referred to as stability diagrams, are plots of the COP displacement in the ML direction against the COP displacement in the AP direction. Stabilograms provide a visual representation of the movement of the COP, and are useful for qualitative assessment of COP movement. An example of a stability diagram during quiet stance is shown below by Figure 1.
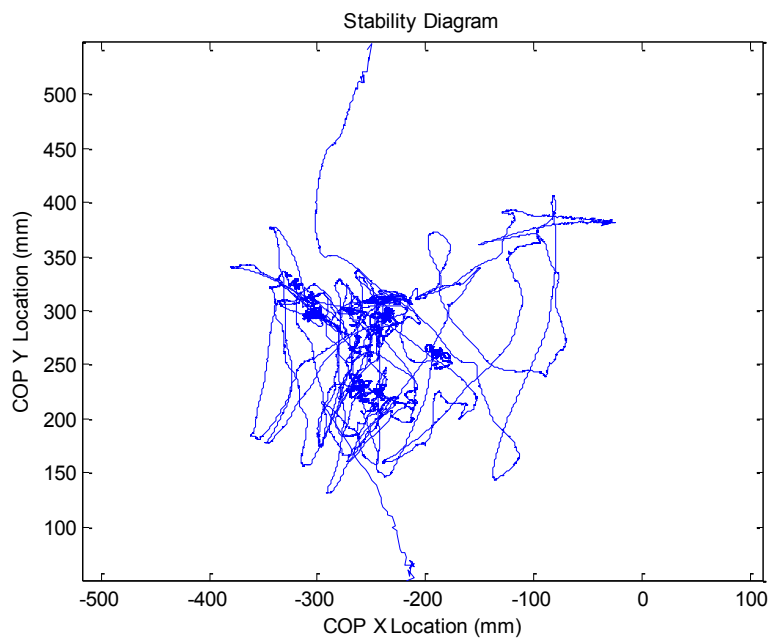

Figure 1: Typical Stability Diagram

There are several different measures that can be derived from a COP time series. The most commonly used amplitude measures are COP displacement, COP pathlength, COP sway, COP sway area, COP velocity, and the major axis length and the eccentricity of an 85% confidence ellipse fit to the (x,y) COP trajectory. It is often useful to express

these amplitude measures as resultant magnitudes and as separate ML and AP components. From each of these amplitude measures, the minimum value, maximum value, mean value, and the standard deviation are commonly extracted. COP displacement is usually defined as the distance away from the mean COP location to each point in the COP time series. The COP displacement in the ML and AP directions can be calculated by using Equation 3 and Equation 4 [44].

$$ML[n] = COPX[n] - \overline{COPX} \qquad \text{Equation 3}$$

$$AP[n] = COPY[n] - \overline{COPY} \qquad \text{Equation 4}$$

The mean COP displacement in the ML and AP directions can be calculated by using Equation 5 and Equation 6 [44]:

$$Mean\ ML\ COP\ Displacement = \frac{\sum_{i=1}^{N} ML(i)}{N} \qquad \text{Equation 5}$$

$$Mean\ AP\ COP\ Displacement = \frac{\sum_{i=1}^{N} AP(i)}{N} \qquad \text{Equation 6}$$

COP sway is defined as the net range of COP motion in the ML and AP directions. The COP sway in the ML and AP directions can be calculated by using Equation 7 and Equation 8 [44]:

$$SWAY_{ML} = COPX_{max} - COPX_{min} \qquad \text{Equation 7}$$

$$SWAY_{AP} = COPY_{max} - COPY_{min} \qquad \text{Equation 8}$$

The sway area is defined as the area enclosed by the COP path per unit time. The sway area can be calculated by using Equation 9 [44].

$$AREA - SW = \frac{1}{2T} \sum_{n=1}^{N-1} |AP[n+1]ML[n] - AP[n]ML[n+1]| \qquad \text{Equation 9}$$

In this equation T is the total time.

The COP pathlength is defined as the sum of the incremental displacements between pairs of points in the COP time series. The pathlength can be calculated by using Equation 10 [44].

$$Pathlength = \sum_{n=1}^{N-1} [(AP[n+1] - AP[n])^2 + (ML[n+1] - ML[n])^2]^{1/2} \qquad \text{Equation 10}$$

COP velocity can be calculated by numerical differentiation of the COP displacement. In most cases the mean velocity is calculated by dividing the COP pathlength by the total time, T, that has elapsed in the trial as this eliminates the need to compensate for directional effects that result when the velocity is determined by numerical differentiation of the COP time series. The mean velocity can be calculated by using Equation 11 [44].

$$Mean\ Velocity = \frac{Pathlength}{T} \qquad \text{Equation 11}$$

The elliptical measures are based on an ellipse that covers 85% of the sway area. The major axis corresponds to the direction of least stability. The length of the major axis can be calculated by using Equation 12 [44].

$$a = \left[F_{0.05[2,n-2]}(s_{AP}^2 + s_{ML}^2 + D)\right]^{1/2} \qquad \text{Equation 12}$$

The length of the minor axis of the ellipse can be determined using Equation 13.

$$b = \left[F_{0.05[2,n-2]}(s_{AP}^2 + s_{ML}^2 - D)\right]^{1/2} \qquad \text{Equation 13}$$

In Equation 12 and in Equation 13, $F_{0.05[2,n-2]}$ represents the F statistic at a confidence level of 85% for a bivariate distribution with n data points, and s_{AP} and s_{ML} represent the standard deviation of the AP and ML time series respectively. The value of D can be calculated by using Equation 14 [44]:

$$D = [(s_{AP}^2 + s_{ML}^2) - 4(s_{AP}^2 s_{ML}^2 - s_{APML}^2)] \qquad \text{Equation 14}$$

In Equation 14, s_{APML} is the covariance. The eccentricity of the ellipse corresponds to the comparative directionality of the COP [45]. The eccentricity of the ellipse can be determined using Equation 15.

$$Eccentricity = \sqrt{1 - \left(\frac{b}{a}\right)^2} \qquad \text{Equation 15}$$

The major axis angle of an ellipse that covers 85% of the sway area represents the angle between the major axis of the ellipse and the positive ML axis [46]. The direction of least stability is typically in the AP direction during quiet stance, therefore this would imply an expected major axis angle of approximately 90 degrees.

Frequency-based measures are also commonly derived from COP time series, often using a Fast Fourier Transform (FFT), which enables the development of a COP power spectrum. Spectral measures such as median frequency (the frequency at which the area under the power spectrum plot is divided into equal halves) may then be extracted from the power spectrum to characterize COP oscillations [44].

Age Related Balance Deficiencies

COP measures are commonly used to asses age-related declines in balance ability. For example, Prieto et al. [44] studied age effects on several different COP based

measures for both an eyes-closed and an eyes-open condition to determine the importance of the visual system in maintaining balance. The results showed that different COP measures identified differences between the eye conditions for the young and elderly subjects, particularly the 85% confidence ellipse measures and all of the frequency-based measures. This result suggests that the role of vision in maintaining postural stability changes with age. The mean velocity in the AP direction was the only measure that was found to identify age-related differences for both the eyes-open and the eyes-closed group. The mean COP velocity was found to increase with age for the eyes-closed condition and for the elderly subjects. The study showed that elderly people who have visual impairments (approximated by the eyes-closed condition) must make significantly more postural adjustments in order to maintain balance, which is reflected by the increased COP velocity.

The age-related postural differences shown in previous studies suggest that deception-related changes in postural control may also vary among people of different ages. When designing a study to investigate the effects of deceptive behavior on measures of standing posture, it was desirable to choose participants that were close in age, as this would ensure that any age effects not related to deception were not present.

<center>Disease Related Balance Deficiencies</center>

COP measures are commonly used to assess disease-related declines in balance ability. For example, postural stability in stroke patients is another topic that has been examined in previous studies. Stroke survivors typically are left with residual sensorimotor deficits which result in a negative impact on the quality of their lives.

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Motor control deficiencies following a stroke have been found to result in force production that is slow, weak and lacking in precision, making it difficult for stroke patients to provide a rate of force development sufficiently high in magnitude to maintain postural control [47].

In a study that was conducted by Chern et al. [48], dynamic postural control during a trunk bending and reaching task was examined by comparing healthy adults and stroke patients. In this study, they calculated COP pathlength, displacement in the ML and AP directions, mean velocity (based on the pathlength), and the limb weight bearing ratio (LRWBR), which was defined as the ratio between the load applied to the affected limb to the load applied to the unaffected limb. The pathlength was found to be significantly larger among stroke patients, except for targets located on their non-paresis side. Additionally, COP displacement in the AP direction was found to be significantly larger for stroke patients than for the healthy subjects, and stabilograms were highly irregular for stroke patients when compared to the healthy subjects. The greater COP pathlength and velocity were found to characterize decreased postural adaptability. This result is similar to the result described above, in that the stroke patients must make significantly more postural adjustments to maintain balance. The reason for this increase in mean COP velocity was attributed to impaired neuromuscular activation such as insufficient activation or change in muscle activation pattern of the postural muscle in the lower limb.

Dyslexia is another condition that has been shown to affect postural control. Dyslexics commonly fail to automate postural responses due to balance perturbations.

This has been attributed to attention deficiencies in dyslexics. Attention deficiencies in dyslexics have most commonly been identified by their difficulty in reading and in performing component skills such as spelling and being able to tell left from right [49]. These attention deficiencies have been associated with motor skill impairments and a reduction in the speed of information processing.

In a study that was conducted by Patel et al. [50] postural control was compared between a dyslexic group and a group of healthy adults while standing on a firm and a soft foam surface during an eyes-open and an eyes-closed condition. In the study the torque exerted by the subject was determined by multiplying the center of pressure by the vertical reaction force that is exerted by the subject. A significant dyslexia-related effect was found for the torque variance in both the AP and ML direction on the foam surface for both the eyes-open and the eyes-closed condition. A significant interaction was found between the surface and vision, which shows the importance of the contribution of vision in postural control. Dyslexics are known to have deficiencies in auditory, cognitive, and learning capabilities. This study showed that dyslexics exhibited increased postural instability especially of a softer surface, which perturbs balance and thus increases the attention requirement to maintain postural stability. The attention deficits in dyslexics have been hypothesized by several researchers to be caused by deficiencies in the cerebellum [50].

Based upon the studies that have been examined, it was desirable to ensure that participants that were included in a deception study were all in good health. This

criterion was used in order to ensure that any observed differences in postural control would due to the deceptive behavior, rather than any underlying health condition.

Self-Induced Balance Deficiencies

Posturography has been used to detect fatigue caused by sleep deprivation. For example, in a study conducted by Ma et al. [51], effects of sleep deprivation on various COP measures were examined. This study, like many others, demonstrates the importance of vision in maintaining postural control; it was found that the standard deviation of COP displacement in the ML and AP directions were good indicators of fatigue in both eyes-open and the eyes-closed conditions. The results of this study also revealed that pathlength decreased during eyes-open and eyes-closed conditions in the sleep deprived group, which implies that the mean velocity also decreased after sleep deprivation. This result differs from those observed in other balance deficient groups such as stroke patients and the elderly, in which the mean velocity and pathlength were found to significantly increase. As a result of this study it was determined that posturography has the potential to identify mental fatigue due to sleep deprivation. The results also imply that the contributions of the somatosensory, visual, and vestibular information are altered as a result of sleep deprivation.

Postural control in alcoholic men and women has been analyzed in recent studies. Alcoholics have a characteristic amount of excessive sway during quiet stance, even after prolonged periods of sobriety. This excessive sway has been used to explain why current or recovering alcoholics have a greater fall rate than healthy sober people. In a study that was conducted by Sullivan et al. [16], postural control of recovering alcoholic men and

women was analyzed during quiet stance both with and without stabilizing conditions (touch, vision and stance type). The results of the study showed that alcoholics had significantly longer COP pathlengths and greater COP sway, especially in the AP direction for the condition which did not allow balance aids. Alcoholic men, when compared to alcoholic women, exhibited significantly greater improvement in postural stability with the balancing aids. This study highlighted differences between alcoholic men and alcoholic women, as well as the persisting liability for falling even after prolonged periods of sobriety. The results of this study are also consistent with other conditions associated with balance deficiencies such as those found in stroke patients, dyslexia patients, and in the elderly in that they all exhibited longer COP pathlengths and greater COP sway than in healthy people.

Based upon the studies that have been examined, it was desirable to ensure that participants included in the deception study were not current or recovering alcoholics. It would also be desirable to instruct participants to be well rested upon arrival for testing. These criteria would ensure that any observed differences in postural control would be due to deceptive behavior, rather than any self-induced balance deficiencies.

Improving Postural Control

There have been multiple methods proposed to improve postural stability. In a study conducted by Boudrahem et al. [52] the effects of visual feedback of the resultant COP was studied. The results of the study showed that the majority of subjects improved their postural control with the aid of visual feedback. All of the significant effects found in this study were isolated to the AP axis, which is similar to the earlier study that was

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examined involving elderly subjects that was conducted by Prieto et al. [44]. This finding was attributed to the tendency of the ankle and hip joint mechanisms responsible for postural control when the feet are spread apart, as well as visual sensory mechanisms playing a significant role in controlling posture in the AP direction.

These studies concerning improving postural control are of interest when considering the use of posturography for the purpose of deception detection as they show that conscious efforts may be successfully made to modify one's normal sway patterns. This means that given training that people may be able to alter their sway patterns in a way that will hide their lie.

Non-Traditional Posturographic Studies

A recently developed area of posturography is the classification of specific body movements based on various COP measures. In a study conducted by Saripalle et al. [45], COP measures were used to classify a number of body motions including head shaking, head nodding, shoulder shrugging with and without hand movement, touching the back of the head, touching the nose, scratching the opposite arm, outstretching of the hands, shifting weight from one foot to the other, shifting weight to the tiptoes and tapping of the foot. COP measures calculated during this experiment included displacement, pathlength, sway, velocity, and the length of the major axis and the eccentricity of a confidence ellipse, as well as the median frequency. These were found in the AP and ML directions and the mean, maximum and standard deviation were found for the applicable measures. Modern machine learning techniques were applied to conduct feature selection of classifiers for each movement. Multiple techniques were

used for classification of movements, including linear discriminant analysis, nearest neighbor classifiers, support vector machines, and neural networks. The results of the study revealed that many of the COP features were subject-specific. Following optimization, the resulting classification methods were able to achieve average correct rates up to 92% across all of the 11 movements by using various classification models. However, there was no single model or feature set that was considered to be sufficient for all of the movements. This type of study is unique in that, unlike most other posturographic studies, its aim was not to characterize postural instability. This study exhibited promise for future studies/applications in which a quick, automated classification of body movements relating to emotional state or gestural movement could be identified. It shows that COP data can be used in order to identify relatively complex movements in a reliable manner. This study has great potential to be expanded upon in other non-traditional posturographic studies such as deception detection.

Posturography for Deception Detection

Based upon the posturographic studies that have been reviewed in previous sections of this chapter, there are several COP measures that have proven to be very versatile. The two measures that seem to have the widest use are the COP pathlength and mean velocity. Other useful measures include mean displacement in the AP and ML directions, median frequency in the ML and AP directions, sway in the ML and AP directions, as well as the eccentricity, major axis length and major axis angle of an 85% confidence ellipse. These measures were all selected for the study that was conducted since they have demonstrated utility for other applications.

In the current study, posturography was used in an attempt to determine the effect of deception upon measures of standing posture. The first goal of the study was to identify COP-based measures that are useful in identifying differences between people who are being deceptive and between people who are being truthful. We hypothesized that deceptive participants, compared to truthful, would exhibit varied COP patterns. A positive result for this hypothesis would provide support for the future goal of discriminating between truthful and deceptive participants.

Based on the literature review, it was suspected that deception-related posturographic effects due to an increased cognitive load may be identified in the current study. It was hypothesized that there would be a reduced COP pathlength, mean velocity and sway for interview questions that require participants to develop a cognitively demanding response, as well as an increased median COP frequency in the AP direction.

Based on previous applications of posturography, it was also determined that participants should all be in good health, close in age, and have no vision impairments. These criteria were chosen to eliminate any underlying effects that would skew the results, ensuring that any observed differences in sway patterns could be attributed to deception effects alone.

Using posturography for the purpose of deception detection, if successful, has the potential to overcome many of the limitations of other commonly used techniques. Posturographic systems for deception detection may be used in a covert manner; they don't require the use of intrusive sensors, or participant cooperation. The cost of force plates varies considerably, but posturographic systems are relatively inexpensive

compared to techniques such as fMRI. Successful posturographic deception detection systems would have many potential applications, such as in credibility assessment, security screening, homeland security, and counter-terrorism. The aim of this study was to demonstrate the feasibility of posturographic methods, paving the way for further research on the topic and eventually even commercial development of such systems.

CHAPTER 3

METHODS

Participants

A total of sixty-eight adult participants (mean age 22 ±7.1) were recruited for the study after providing written informed consent prior to testing. Participants were randomly assigned to either an experimental group (EG) or a control group (CG). The participants consisted of volunteers from the UMKC student body, the majority of which were recruited via pools of undergraduate Psychology students. Each semester researchers in the UMKC Department of Psychology recruit students to participate in their research projects via the "Psych Pool". The "Psych Pool" is an online research participant recruitment system. Students that are interested in participating in research studies sign up via the "Psych Pool". Participants were given the option of receiving course credit for their participation (psychology students only) or a $10 incentive. Institutional Review Board (IRB) approval was obtained prior to testing.

Data collection was successful for forty-eight of the participants. The remaining trials were unsuccessful due to an unexpected computer lag, which resulted in a loss of some of the required audio data. For the unsuccessful trials the audio computer displayed an error message when the operator attempted to begin recording all of the data for the

participant. Since audio data was needed to align COP data with particular interview questions, the remaining data for the participant was not processed. All of the participants were in good health and were able to comply with the requirements of the study.

An additional $200 incentive was offered to the two participants from the EG that were the "most deceptive", as well as to the two participants from the CG that were the best at convincing the interviewer that they were being truthful. Additionally, participants from the EG were told that if they failed to be deceptive, they would be required to take part in an additional screening session after the interview. The $200 incentive and possibility of additional screening were intended to increase the motivation for participants to be deceptive in order to provide a more realistic replication of deception. Given previous work on deception and motivation [19], these consequences for successfully or unsuccessfully being deceptive was believed to result in behavior that will much more closely match deceptive behavior in natural environments than if there was no motivation.

Procedure

The participants were instructed to pack a backpack with various items. In addition to items that were identical between the CG and EG groups (socks, shoes, shirts and jeans), the CG was required to pack "control" items (cookies, sunglasses and a travel-size container of mouthwash), while the EG was required to pack "prohibited" items (pocket knife, bottle of rubbing alcohol and cigars). The EG was instructed not to reveal that they were carrying any prohibited items during the interview that followed. After

packing the backpack each participant was instructed to stand on a force plate by an embodied conversational agent (ECA), a computer-generated interviewer (Battelle, Inc., Columbus, OH, USA) using text-to-speech technology. The ECA is shown in Figure 2.

Figure 2: Embodied Conversational Agent

Once the subject was standing on the force plate, the interviewer asked a series of questions about the contents of the backpack. Figure 3 shows a participant answering interview questions during testing.

Figure 3: Participant Standing on Force Platform

The interview was divided into 49 events, which are shown in detail in the Index Key (Appendix B). For analysis purposes, the interview was separated into 11 different intervals, which corresponded to subject responses to interview questions. Three of the 11 intervals were characterized as control (C) intervals, which were answered truthfully by both CG and EG groups. The remaining 8 intervals were characterized as test (T) intervals consisting of questions that the CG should have answered truthfully and the EG should have answered deceptively. Table 1 provides a description of each interval.

Table 1: Interval Description

Interval (Type)	Question/Instruction
1 (C)	Did you pack your own luggage?
2 (T)	Are you carrying any [prohibited] items?
3 (C)	Does your bag contain any fruits or vegetables?
4 (T)	Does your bag contain any flammable liquids?
5 (T)	Does your bag contain any large containers of liquids?
6 (T)	Please describe the container of liquid that is in your bag
7 (C)	Does your bag contain any cameras or photography equipment?
8 (T)	Does your bag contain any cigars or tobacco products?
9 (T)	Does your bag contain any knives or sharp implements?
10 (T)	Just to be sure you aren't carrying prohibited items please tell me each item that is in your bag
11 (T)	Is there anything else in your bag you did not tell me about?

To ensure that the analysis would be specific to each participant, the outcome variables within each test interval were normalized to the average value of their own control responses obtained in intervals 1, 3, and 7. This resulted in unit-less outcome variables. Data collection for each subject required both an operator and a handler, whose responsibilities are described in the following paragraphs.

Handler Procedure

The handler was responsible for all interaction with the participants prior to and after testing. Before each participant arrived, the handler assigned the participant a subject ID and randomly assigned them to either the CG or EG. The paperwork that each participant was required to fill out was placed on the table along with the backpack which

corresponded to whether they were part of the EG or the CG. Table 2 shows the contents of the backpack for both the EG and CG:

Table 2: EG and CG Backpack Contents

Backpack Contents	
CG	EG
Shoes	Shoes
Socks	Socks
Shirt	Shirt
Jeans	Jeans
Cookies	Pocket Knife
Sunglasses	Rubbing Alcohol
Travel-Size Mouthwash	Cigars

The handler welcomed participants into the packing room and established whether they wanted to receive the $10 payment or course credit (applicable for Psych Pool students only). The handler then administered the informed consent to the participant (Appendix B). After each participant provided informed consent, the handler asked the participant each of the questions on the demographics survey (Appendix B). The handler checked for exclusions due to age, health, hearing, vision, illness, or being unable to stand. Participants were dismissed if they met any of the exclusion criteria. The handler then asked the participant to remove their shoes, and to put on socks (which were provided). All participants were given the same type of socks to wear.

Following consent and screening, the handler instructed each participant to pack a backpack with the items described above (Table 2), and that they would then be interviewed by a computer-generated interviewer about the contents of their backpack. The handler told the participant whether or not they were carrying any prohibited items. The handler informed EG participants that the interview would finish early if they successfully concealed the "prohibited" contents of the backpack; and that they would otherwise be required to participate in an additional hour of screening. CG participants were instructed to truthfully answer questions about the contents of their backpack. The EG participants were informed that if they were one of the two most deceptive participants that they would receive a $200 reward. Likewise, the CG participants were informed that if they were one of the two most truthful participants that they would receive a $200 reward. This part was reinforced by having them fill out a rewards form (Appendix B). The handler applied a wireless microphone to the participant's clothing, and instructed them to put on the wireless headphones, and proceed to the interview room once they had finished packing the backpack.

After the interview, the handler met participants in the post interview room to administer the post interview survey (Apendix B), which ensured that participants completed the interview in the manner that they were instructed by the handler. The handler then debriefed the participant and removed the wireless microphone. Payment was made to participants who elected to receive the $10 compensation, and participants who elected to receive course credit were informed that they their credit would be assessed in the Psych Pool within 24 hours. The handler told the participants that they

would receive a letter in the mail, which would tell them a little more about the study, and would contain the additional $200 payment if they were selected. In order to maintain the integrity of the study, participants were asked to avoid discussing any details of the study with other students until the study had been completed (July 2011).

Operator Procedure

The operator was responsible for setting up and running all of the equipment required for the collection of the COP, audio and video data. Before testing each day the operator set the origin of the force plate to the corner of the plate that the subject was instructed to stand on, and ensured that the force plates displayed a force of zero in all directions when no force was applied to it. The audio from the computer generated interviewer and from the wireless microphone were also checked to ensure that each signal could be adequately recorded.

Before the arrival of each participant, the operator set up a file for the next participant in the Nexus software, and for the audio recording. During testing, the operator was present in the interview room behind a curtain, which ensured that each participant was unaware of their presence. Figure 4 shows the interview room layout.

Figure 4: Interview Room Layout

The operator started the data collection as they heard the participant enter the room. The operator then guided the computer generated interviewer timing by pressing "Y" or "N" in response to the participant's answers to the questions that were asked of them.

For each participant, the operator noted whether the instruction to stand on the force plate was followed, and whether they put the backpack onto a table in front of them as instructed by the computer generated interviewer. At the end of the interview the operator, who was blinded as to whether the participant was part of the EG or CG, noted a rating of 1-7 as to whether they thought that the participant was being truthful or deceptive (with 1 being most deceptive and 7 being most truthful).

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Measurements

Force and moment data were continuously sampled at a rate of 1000 Hz by using a single force plate (AMTI, Watertown, MA, USA). Participant audio data was captured using a wireless microphone that was attached to the participant's clothing. The interviewer's audio data was captured from the interview PC's audio output. All audio data were captured at a rate of 8000 Hz using LABVIEW 2010 (National Instruments, Austin, TX). A sampling rate of 8000 Hz was chosen for the audio data collection in order to ensure that the audio data was of a high enough quality for later interpretation. A sampling frequency of 8000 Hz is used for telephone communications [53], and thus was determined to be sufficient for the purpose of this study. The data collection process was automated by using a single LABVIEW VI.

Data Processing

The COP time series for both the medial lateral (ML) and the anterior-posterior (AP) directions were exported using Vicon Nexus software (Vicon, Centennial, CO, USA). All data were processed using MATLAB 2009a (The Mathworks, Natick, MA, USA), with a custom written code (Appendix A). Calculation of COP-based measures was done between the offset of the interviewer's question and the offset of the participant's response, which were extracted from captured audio data using Audacity 1.3.14 (Freeware). Video and audio data were combined using audio and video using Windows Movie-maker 2.1(Microsoft, Redmond, WA) to ensure that data collection of the audio and video computers were correctly synchronized (the video computer also captured the force plate data). Due to a lag in the initialization of the audio computer for

some participants, not all trials were successfully synchronized. This issue was addressed by determining the offset between the audio and video and by adjusting the values determined in Audacity accordingly. The audio data offset was adjusted manually by ensuring that the words spoken in the audio data matched the lip movements of the participant. This ensured that the COP data that was collected was properly aligned with the interval being examined.

Equation 1-Equation 15 were used in order to determine 8 of the 11 COP-based outcome measures by using custom written MATLAB code. The remaining 3 variables, major axis angle of an ellipse that covers 85% of the sway area, AP median frequency, and ML median frequency were also calculated in MATLAB as follows. The FFT was calculated in MATLAB using an in-built command. This was then used to develop the power spectrum that was required for determination of the median frequency. The median frequency was found to be the frequency corresponding to half of the area under the power spectrum. The major axis angle of an ellipse covering 85% of the sway area was determined using a custom written code, using a principle component method as described by Duarte et al. [46]. The major axis angle was calculated in MATALAB as the angle between the positive ML axis and the major axis of the ellipse that was created. The calculation of these measures was performed within each of the indices extracted with Audacity (Freeware). The measures that were calculated are summarized by Table 3.

Table 3: COP Outcomes Measures

Outcome Measure	Description
P	Pathlength -Total distance travelled of the COP
SWAP	Sway AP - range of COP motion in the AP direction
SWML	Sway ML - range of COP motion in the ML direction
MV	Mean COP velocity
MDAP	Mean AP displacement
MDML	Mean ML displacement
E	Eccentricity
MAL	Major axis length of 85% confidence ellipse
MAA	Major axis angle of 85% confidence ellipse
MFAP	Median frequency - AP
MFML	Median frequency - ML

Statistical Analysis

The statistical analysis was performed using SPSS 18 (SPSS, Inc., Chicago, IL, USA), and by using MATLAB 2009a (The Mathworks, Natick, MA, USA). Hotelling t-squared, t-tests, and Mann Whitney non-parametric tests were all performed. The tests were performed at a confidence level of 90% ($\alpha = 0.1$).

Hotelling's t-square test was used to identify intervals in which significant overall deception-related effects were present. Hotelling's t-square test is the multidimensional extension of the t-test [54]. The test t-square statistic for comparison of two independent samples with unequal covariance matrices is given by Equation 16 [54].

$$t^2 = (\bar{X}_{EG} - \bar{X}_{CG})^T \left\{ \frac{S_{EG}}{n_{EG}} + \frac{S_{CG}}{n_{CG}} \right\}^{-1} (\bar{X}_{EG} - \bar{X}_{CG}) \qquad \text{Equation 16}$$

The individual covariance matrices S_{EG}, and S_{CG} were determined using Equation 17 and Equation 18 respectively [54].

$$S_{EG} = \frac{\sum_{i=1}^{n_{EG}} [(X_{EGi} - \bar{X}_{EG})(X_{EGi} - \bar{X}_{EG})']}{n_{EG} - 1} \qquad \text{Equation 17}$$

$$S_{CG} = \frac{\sum_{i=1}^{n_{CG}} [(X_{CGi} - \bar{X}_{CG})(X_{CGi} - \bar{X}_{CG})']}{n_{CG} - 1} \qquad \text{Equation 18}$$

The test t-square statistic for comparison of two independent samples is shown by Equation 19, assuming equal covariance matrices [54].

$$t^2 = (\bar{X}_{EG} - \bar{X}_{CG})^T \{S_p\}^{-1} (\bar{X}_{EG} - \bar{X}_{CG}) \qquad \text{Equation 19}$$

In Equation 19, $\bar{X}_{EG}$ and $\bar{X}_{CG}$ are the vectors representing the mean values of each of the COP-based measures within a given interval, S_p is the pooled covariance matrix, and n_{EG} and n_{CG} represent the sample size for the EG and CG. In Equation 19, S_p is the pooled covariance and is given by Equation 20 [54].

$$S_p = \frac{(n_{EG} - 1)S_{EG}^2 + (n_{CG} - 1)S_{CG}^2}{n_{EG} + n_{CG} - 2} \qquad \text{Equation 20}$$

The test t-square statistic for unequal variances is shown by Equation 21 [54].

$$t^2 = (\bar{X}_{EG} - \bar{X}_{CG})^T \left\{ S_p \left(\frac{1}{n_{EG}} + \frac{1}{n_{CG}} \right) \right\}^{-1} (\bar{X}_{EG} - \bar{X}_{CG}) \qquad \text{Equation 21}$$

In order to determine whether the variances were equal, Box's M test was performed for each interval. Box's M-test was performed using SPSS 18 (SPSS, Inc., Chicago, IL, USA) in order to determine whether the variances were equal. Based on the

results of Box's M-test the appropriate equation for determining the t^2 statistic was chosen.

For very large samples the t-square statistic will approximately follow a chi-square distribution. However, since relatively small samples were used for the analysis that was conducted, this approximation does not take into account the variation due to estimating the variance-covariance matrix. In order to account for this it is necessary to transform the t-square statistic into an F-statistic. The test F-statistic was determined by using Equation 22 [54].

$$F_0 = \frac{n_{EG} + n_{CG} - p - 1}{p(n_{EG} + n_{CG} - 2)} t^2 \qquad \text{Equation 22}$$

In Equation 22, p represents the number of COP based variables that were included in the analysis. The null hypothesis is rejected if the condition shown in Equation 23 is met for $\alpha = 0.1$ [54].

$$F_0 > F_{p,n_{EG}+n_{CG}-p-1} \qquad \text{Equation 23}$$

Once intervals of interest had been identified, the individual intervals were separately examined to determine the particular COP-based variables that were significant. A two sample t-test was performed by using SPSS 18 (SPSS, Inc., Chicago, IL, USA). The two-sample t-test was used to identify deception related differences between the COP-based measures that were calculated. The two sample t-test was used to test for significant differences between the EG and CG sample means. The null hypothesis is given by Equation 24 and Equation 25 [55]:

$$H_0: \mu_{EG} = \mu_{CG} \qquad \text{Equation 24}$$

$$H_1: \mu_{EG} \neq \mu_{CG} \qquad \text{Equation 25}$$

The two sample t-test is based upon the assumption that each sample taken from independent populations that are normally distributed. The hypotheses are evaluated by using a t-statistic, which is shown by Equation 26 [55].

$$t_0 = \frac{\bar{X}_{EG} - \bar{X}_{CG}}{\sqrt{\dfrac{S^2_{EG}}{n_{EG}} + \dfrac{S^2_{CG}}{n_{CG}}}} \qquad \text{Equation 26}$$

In Equation 26, $\bar{X}_{EG}$ and $\bar{X}_{CG}$ represent the mean of a given COP-based measure for the EG and CG, S^2_{EG} and S^2_{CG} represent the variance for the EG and CG, and n_{EG} and n_{CG} represent the sample size for the EG and CG. The degrees of freedom are determined by using Equation 27 [55].

$$v = \frac{\left(\dfrac{S^2_{EG}}{n_{EG}} + \dfrac{S^2_{CG}}{n_{CG}}\right)^2}{\dfrac{\left(\dfrac{S^2_{EG}}{n_{EG}}\right)^2}{n_{EG} - 1} + \dfrac{\left(\dfrac{S^2_{CG}}{n_{CG}}\right)^2}{n_{CG} - 1}} \qquad \text{Equation 27}$$

The null hypothesis, given by Equation 24 would be rejected if $t_0 > t_{0.05,v}$, where $t_{0.05,v}$ represents the value of the value of a t-distribution for v degrees of freedom and for a confidence level of 90% (a two sided test was used).

Both the Hotelling t-square test and the two-sample t-tests required that the data be normally distributed. Although the majority of the COP-based variables were found to be normally distributed over each interval, there were some intervals for which the variables were not normally distributed. Although both of these tests are fairly robust for non-normally distributed data, it was determined a non-parametric distribution free

analysis should also be performed to account for the violations of the normality assumption.

The Mann Whitney non-parametric test, also referred to as the Wilcoxon Signed Rank Test, was used to identify deception related differences between the COP-based measures that were calculated. The Mann Whitney test was selected due to the lack of normality in the data that was collected. The Mann Whitney test is appropriate for use for ordinal data that has a continuous symmetric distribution.

The Mann Whitney test is used in order to test the null hypothesis that sample means are equal. The null and alternative hypotheses are shown by Equation 28 and Equation 29 respectively.

$$H_0: \mu_{CG} = \mu_{EG} \hspace{3cm} \text{Equation 28}$$

$$H_1: \mu_{CG} \neq \mu_{EG} \hspace{3cm} \text{Equation 29}$$

The test procedure is performed by arranging all observations in ascending order of magnitude, and then by assigning ranks to them. If there is a tie (identical observations) then the mean of the ranks is assigned to each of the identical observations. Letting W_1 represent the sum of the ranks in the smaller sample, n_1, and W_2 represent the sum of the ranks in the larger sample, n_2, the following test statistic shown by Equation 30 is used.

$$W_2 = \frac{(n_1 + n_2)(n_1 + n_2 + 1)}{2} - W_1 \hspace{2cm} \text{Equation 30}$$

This test statistic is compared to critical values of W_α in order to evaluate the null hypothesis for the given sample sizes. The null hypothesis is rejected in favor of the alternative hypothesis if either W_1 or W_2 is less than W_α [55].

A significant amount of effort was put into attempting to develop a binary logistic regression model that would make use of an optimized set of COP-based measures. This model was desirable as it would have allowed for the prediction of whether a particular subject was being truthful or deceptive for a given response. However, a reliable model could not be developed due to significant co-linearity of the COP-based measures. The development of a binary logistic regression models requires that the predictor variables must be independent of one another [56].

CHAPTER 4

RESULTS

The results of the Hotelling t-squared test is shown by Table 4:

Table 4: Hotelling t-squared Results

Interval	n_{EG}	n_{CG}	t^2	F	p
2	27	21	23.7677	1.691	0.1154
4	27	21	14.536	1.0342	0.4383
5	27	21	12.7064	0.904	0.5461
6	27	21	15.4726	1.1008	0.3884
8	27	21	28.1877	2.0054	0.0574
9	27	21	14.0706	1.0011	0.4645
10	27	21	126.001	8.9645	<0.0001
11	27	21	32.8992	2.3407	0.0270

The results of both the two sample t-tests and the Mann-Whitney tests are shown by Table 5.

Table 6 shows the key, which explains significant results shown in Table 5.

Table 5: T-test and Mann Whitney Results

Interval		P	SWAP	SWML	MV	MDAP	MDML	E	MAL	MAA	MFML	MFAP
							Mean					
2	EG	0.88	0.75	0.79 MW p=0.083	0.88	0.97	1.06 MW p=0.06 T p=0.056	1.04 MW p=0.076	0.77	0.19	1.12	1.03
	CG	0.96	0.75	0.97 MW	0.96	0.91	0.69 MW T	0.98 MW	0.85	1.61	1.10	1.02
4	EG	0.98	1.25	0.85	0.98	1.12	0.97	1.04	1.15	-0.04	1.16	1.11
	CG	1.07	0.71	0.66	1.07	0.80	0.73	1.00	0.67	1.38	1.02	1.13
5	EG	0.93 MW p=0.047	0.82	0.85	0.93 MW p=0.047	0.87	0.84	1.05	0.94	-1.11	1.11	0.97
	CG	0.98 MW	0.87	0.98	0.98 MW	1.01	0.84	1.02	0.93	0.90	1.01	1.01
6	EG	2.12	3.08	1.77	2.12	1.30	1.09	1.05 T p=0.042	1.94	0.40 MW p=0.083	0.61	0.67
	CG	1.90	1.65	1.68	1.90	0.95	1.07	0.97 T	1.82	-1.91 MW	0.64	0.70
8	EG	1.08 T p=0.088	1.54	1.05	1.08 T p=0.088	1.00	0.82	1.04	1.33	0.41	1.08	0.91 MW p=0.037 T p=0.032
	CG	0.95 T	0.96	1.03	0.95 T	1.43	1.02	1.01	1.07	0.15	1.21	1.13 MW T
9	EG	1.08	0.79	0.95	1.08	0.96	0.87	1.05	0.94	-0.15	1.03	0.98
	CG	0.99	1.80	1.50	0.99	1.42	1.43	1.00	1.96	-0.04	0.98	1.08
10	EG	3.25 MW p<0.001 T p<0.001	2.22	1.93 T p=0.084	3.25 MW p<0.001 T p<0.001	1.47	1.12	1.03	1.78	-1.09	0.53	0.55 MW p=0.025
	CG	5.20 MW T	3.08	2.92 T	5.20 MW T	1.70	1.37	0.98	2.76	0.68	0.43	0.43 MW
11	EG	1.70	0.93	0.97	1.70	1.49 MW p=0.076	0.95	1.03	0.88	0.22 MW p=0.045 T p=0.021	0.64	0.73
	CG	1.77	0.98	1.37	1.77	0.97 MW	1.26	1.00	1.26	-3.20 MW T	0.75	0.84

Table 6: Results Key

	Key
T	Indicates t-test significance p < 0.1
MW	Indicates Mann-Whitney significance p < 0.1

Representative time series plots of both a CG and EG subject's COP position results are shown by Figure 5 and Figure 6 respectively.
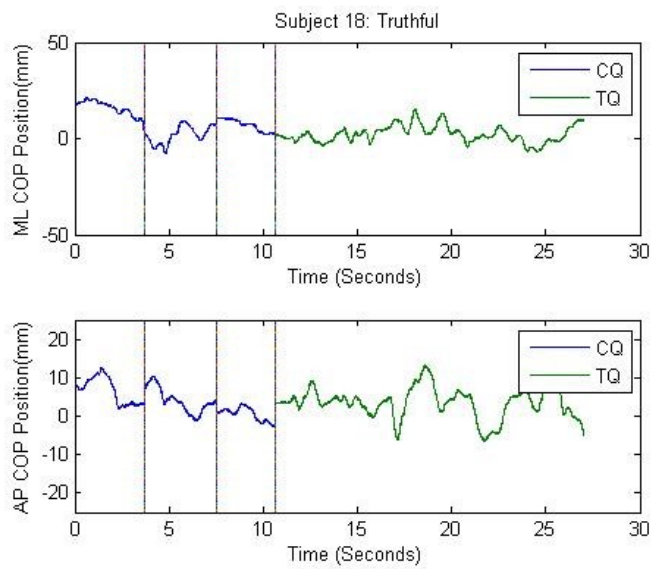
Figure 5: Representative CG Time Series Plot

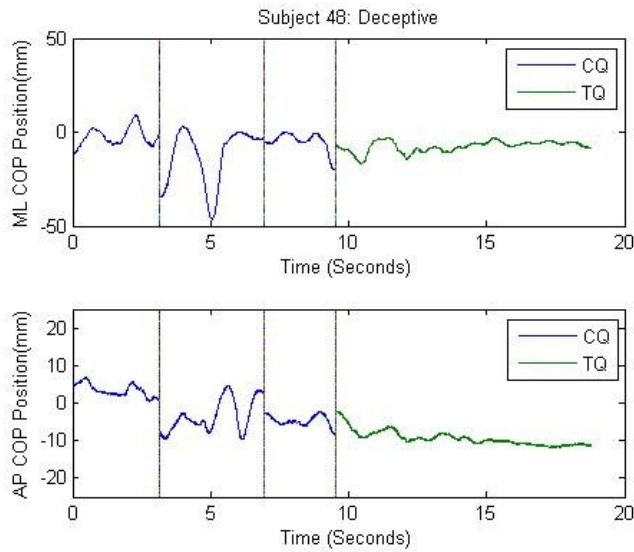Figure 6: Representative EG Time Series Plot

The vertical lines which are shown in Figure 5 and in Figure 6 separate different intervals. The first three intervals on each plot show control intervals 1, 3 and 7. The final interval that is shown is the test interval 10. Interval 10 was chosen for the test interval since it was the interval which contained the most significant differences between the CG and EG.

CHAPTER 5

DISCUSSION

The results of the Hotelling t-square test shown in Table 4 indicate that there was a significant deception-related effect in intervals 8, 10, and 11. The Hotelling t-square tests were followed up with t-tests and Mann-Whitney tests.

The results of both the Mann Whitney tests and t-tests indicate a significant deception-related decrease in pathlength and mean velocity for interval 10. Mann Whitney tests exhibited a similar deception-related decrease in pathlength and mean velocity for interval 5. This result suggests that EG participants significantly reduce the overall amount of COP excursions when they are telling a lie. The t-tests also revealed a deception-related decrease for COP sway in the ML direction in interval 10. These findings are consistent with previous studies describing deception-related decreases in body movement, an effect that is attributable to an increased cognitive load and manifests itself as stiffening of the ankle joint via a co-contraction mechanism [36] [35]. The increase in stiffness may be explained by a heightened level of awareness, and reduced postural automaticity [35].

In addition to the deception-related decrease in COP pathlength and mean velocity, Mann Whitney tests revealed a deception-related increase in median AP frequency. The increased frequency may be explained by changes in ankle stiffness

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when a co-contraction mechanism is employed since it is a more automatic control process. This more automated control process releases cognitive resources for the primary focus of the person. The combined effect of reduced COP excursions, shown by reduced COP pathlength and mean velocity, and an increased AP median frequency is consistent with previous studies citing these effects as signs of increased cognitive load [35] [36].

The observed stiffening response closely resembles the "freezing" behavior commonly observed in nature. Freezing is a common defensive response in animals that are threatened by predators [37]. It may be characterized by reduced body motion, and a decrease in heart rate [37]. Freezing may be described as part of an early orienting response, possibly serving to aid in the detection of information for a subsequent fight-or-flight response involving whole-body movements [37]. Since social threats often elicit a freezing response [37], it follows that a deception-related reduction in COP excursions due to an increased cognitive load may be the cause of this observed effect. It is also possible that participants may have felt threatened by the computer generated interviewer. Several recent studies have shown that threat-related images can result in a reduction in body sway [57] [37] [58].

An alternative explanation for reduced body movement is that participants deliberately attempted to control their behavior. For instance, deceptive participants may believe that an excessive amount of motion would give away their lie, and therefore intentionally avoid any non-essential movements. Suppressing non-essential movements that are normally made during quiet stance results in an unusual amount of rigidity [59].

The Mann Whitney test revealed that eccentricity was significantly greater for deceptive participants in interval 2, and the t-test showed a similar deception-related increase in eccentricity for interval 6. The eccentricity represents the ratio of the distance between foci to the major axis length of an ellipse that is fit to 85% of the stabilogram. The major axis is typically oriented in the AP direction, which implies that there is a greater amount of COP sway in the AP direction than in the ML direction. In interval 2 there was a decreased amount of deception-related sway in the ML direction, yet AP sway did not exhibit any significant deception-related changes. This implies that the minor axis (in the ML direction) will be reduced for deceptive participants, indicating a greater amount of control in the ML direction. The combined effect of reduced sway in the ML direction and unchanged AP sway implies that the increase in eccentricity was due to increased control in the ML direction. However, there was a deception-related increase in the amount of ML displacement in interval 2 which, when combined with the observed reduction in ML sway, likely indicates that participants in the EG were likely leaning to one side (to their left or right), but their range of ML motion in this position was very small. The deception-related increase in eccentricity observed in interval 6 may be explained in a similar manner; a trend of reduced ML sway was observed, although it was not found to be statistically significant.

Mann Whitney tests in interval 6 revealed a deception-related increase in major axis angle. A similar deception-related increase in major axis angle was also revealed via t-tests in interval 11. The increased major axis angle shows there to be a change in the direction of least stability in these intervals for deceptive participants, which could be

explained by a simple change such as slight trunk rotation, or by a mechanism such as leaning to one side (placing more weight on one foot). In interval 11 there was also observed to be a deception-related increase in mean AP displacement, which shows a tendency for EG participants to either lean further forward or backward.

Interval 8 exhibited results that were at odds with the notion of a deception-related decrease of COP movement. The mean velocity and pathlength were both found to increase for deceptive participants, which suggests there to be a greater amount of COP movement. Another result in interval 8 that differed from the trend in interval 10 is that there was a lower median frequency in the AP direction which suggests that there are slower oscillations in the AP direction for deceptive participants. The differing results that are shown in interval 8 may be explained by participants being aroused in a manner that causes them to be agitated, rather than over-controlling as was likely the case in interval 10. For liars, agitation is triggered by nervousness and fear. Liars who are agitated make body movements associated with their feeling of nervousness [30]. Specifically, facial fidgeting such as playing with hair or rubbing of the face increases when people are being deceitful [30]. Results of this study show that postural shifts increase when participants become agitated, evidenced by increased COP excursions and by decreased COP median AP frequency. Unlike interval 10, the response to the question in interval 8 is not very cognitively demanding (only requiring a "yes" or "no") response. This interval involves asking participants about possession of tobacco products. It is unclear why this question elicited agitation, but it may just be due to EG participants

being more uncomfortable about possession of the cigars than any of the other items that were in the backpack that they packed.

There was no COP-based measure that reliably exhibited deception effects for every interval. This variability supports the notion that deception is a dynamic process in which people adjust their actions according to their perceived level of social threat. The majority of the deception-related effects were observed in interval 10. This interval, along with interval 6, represents the questions that required participants to develop a more elaborate response in order to avoid revealing any of the prohibited items in their backpack. This suggests that open-ended questions may be more sensitive to deceptive behavior than those requiring a simple response (such as just "yes" or "no"). It makes sense that those very short responses would produce little discrimination between those being truthful and deceptive participants. In response to these questions the truthful participants had no reason to be particularly aroused and they therefore stood fairly still, and deceptive participants who were also constraining their movements were also standing very still.

Overall, the results of this study indicate that posturography has potential utility for the purpose of deception detection. If the idea that more cognitively demanding, open-ended questions elicit a greater response from deceptive people is correct, then this could lead to recommendations to include more open-ended questions in security screening applications. This study has demonstrated COP measures that may be used in order to discriminate between truthful and deceptive participants for specific questions.

These measures include pathlength, mean velocity, AP mean displacement, AP median frequency, ML sway, eccentricity, and the major axis angle.

While this study has successfully identified differences between truthful and deceptive participants, a predictive model has not yet been developed. The use of more traditional techniques such as binary logistic regression and linear discriminant analysis could not be implemented due to significant violations of the necessary assumptions. A significant amount of effort was put into developing a model using binary logistic regression; however, since the COP-based measures were so highly correlated with one another the independence of predictor variables assumption was not satisfied. This resulted in a highly unstable model which produced unreliable results. It may be possible to implement a model using binary logistic regression, but it would have to be used with a combination of other non-COP based measures that are not as highly correlated. Future work is currently being planned to utilize more advanced machine learning and pattern recognition techniques in order to predict whether a response is from a truthful or deceptive participant based on the data that has been collected in this study.

The use of posturography for deception detection does have some limitations. It requires the person being tested to stand still in one place. Unexpected movements during testing could produce unreliable results if, for example, the person happened to sneeze during their response. The data also had to be manually processed, which was a very time consuming task. Future systems with the capability of classifying a response as either truthful or deceptive will need to be automated if posturographic methods are to be used in real-time environments.

This study also revealed that there is no one COP-based measure that can reliably differentiate between truth tellers and liars. Future work should be done to address this problem, with a particular focus upon which types of questions elicit a particular type of response. Based upon the results of this study, future studies could be developed which purposefully include cognitively demanding questions, which should elicit the previously observed deception-related decrease in COP excursions coupled with an increased AP median frequency.

A further weakness of the study is that testing was performed in a laboratory setting, thus participants were told to lie. Many researchers would argue that deception must be voluntary; therefore laboratory studies aren't necessarily measuring deception. In order to overcome this limitation it will be necessary to begin testing in natural environments in a covert manner. This type of testing could demonstrate the effectiveness of posturography for deception detection in a security screening environment. For example, a future automated posturographic system could alert security agents as to people who should be selected for further screening or searches.

CHAPTER 6

CONCLUSIONS

We successfully demonstrated deception-related effects on measures of static posture. Deception-related COP measures were successfully identified. Results of the study showed that there was a significant deception-related decrease in overall COP excursions, combined with an increase in AP median frequency. The combined effect of reduced COP excursions, as evidenced by reduced COP pathlength and mean velocity, and an increased AP median frequency is consistent with previous studies citing these effects as signs of increased cognitive load. Increased cognitive loads manifest themselves as stiffening of the ankle joint via a co-contraction mechanism, and may be explained by a heightened level of awareness, and reduced postural automaticity.

Not all question types exhibited responses indicative of an increased cognitive load. Some questions showed there to be increased eccentricity, caused by a reduction in ML sway, an indication of an over-controlling response. In one question the opposite effect to those characterizing an increased cognitive load was observed; increased COP excursions accompanied by a decreased AP median frequency. This response may be attributable to participants becoming agitated for this particular question. Further research should be performed to determine which question types elicit a particular type of response from participants.

There were, however some limitations to the study. First, there were no COP measures that reliably exhibited differences between liars and truth-tellers for all question types. Open-ended questions that required liars to develop a more complex response caused liars to exhibit more of the aforementioned indicators of deception than questions requiring a simple response. This effect may be attributed to increased cognitive load or a deliberate attempt by liars to control their behavior. The results of this study could be used to provide suggestions to include more open-ended questions in security screening scenarios.

Due to the limitations of the study, and to the inability to develop a predictive model using a traditional approach it will be necessary to conduct future studies to further explore this area of research. Future studies using the same data will make use of machine learning techniques to predict whether a response is truthful or whether it is a lie. If successful, this will provide a very powerful method for detecting deception. Unlike most techniques used for deception detection, it could be used covertly without the person's knowledge or cooperation. This may lead to many potential applications such as airport screenings, counter-terrorism, and credibility assessment.

APPENDIX A

The MATLAB code that was used for the data processing is shown below.

```matlab
%Process.m


clear
clc
close all

%Declare Constants
init_var; %This version uses the 13 intervals used for the initial
analysis
%init_var_48intervals    %This version uses 48 intervals
%subs=[21];% 23 28 31 32];
subs = [7 10 11 12 13 17 18 19 21 23 28 31 32 35 37 38 39 42 43 45 46
47 48 49 50 53 54 57 59 60 61 62 63 64 65 66 67 68 8 15 16 20 24 25 26
27 33 9];
counter=1; %subject # index
for sub = subs; %start of subject loop

    fprintf('Processing subject #%i...',sub)

    %Load COP and audio data

    [COPX, COPY, audio, labels,
sstr,subject_condition]=data_load(sub,counter);

    fprintf('data loaded...')

    %Define time vectors

    t_cop = [1/f_force:1/f_force:length(COPX)/f_force];
    t_audio = [1/f_audio:1/f_audio:length(audio)/f_audio];

    %Convert audio indices from seconds to samples

    for lab = labs
        index_aud(lab,:) = labels(lab,1)*f_audio; %load indices;
convert from seconds to samples
    end

    index_cop = round(index_aud.*(f_force/f_audio));

    fprintf('extracting outcome variables...')
```

```
    for index1 = indices  %Start of interval loop

        if subject_condition == 1
        sub_condition = truth(index1);
        elseif subject_condition == 0
            sub_condition=deceptive(index1);
        end
        %Define start and end indices for current time interval; use to
partition
        %COP data

        index2=index1+1;

        %start and end indices for analyzing intervals between pairs of
        %events

        %istart = index_cop(index1);
        %iend = index_cop(index2);

        %start and end indices for analyzing intervals identified for
        %analysis during meeting on 12/20/10

        istart = index_cop(startandend(index1,1));
        iend = index_cop(startandend(index1,2));

        COPX_interval=COPX(istart:iend,:);
        COPY_interval=COPY(istart:iend,:);

        %Plot COP and audio data

        plotting

        %Calculate maximum, mean and standard deviation displacement in
    the AP
        %and ML directions. The COP sway in the AP and ML directions is
also
        %calculated

        [max_displacement_x, max_displacement_y,
max_displacement,COP_sway_x,COP_sway_y,mean_displacement_x,mean_displac
ement_y,x_squared, y_squared
]=calc_displacement(COPX_interval,COPY_interval);

        %Calculate Pathlength

        [pathlength]=calc_pathlength(COPX_interval,COPY_interval);

        %Calculate the mean velocity in the AP and ML directions,
```

```matlab
        [vmax,vmean,vmax_x,
vmax_y,vmean_x,vmean_y,velocity_x,velocity_y]=calc_velocity(x_squared,
y_squared,COPX_interval,COPY_interval,pathlength,t_cop);

        %Calculate the standard deviation of COP,AP displacement, ML
        %displacement, AP velocity and of the ML velocity


[sdev_COPX,sdev_COPY,sdev_velocity_y,sdev_velocity_x]=calc_sdev(COPX_in
terval,COPY_interval,velocity_y,velocity_x);

        %Calculate zero crossing rate

        [zero_crossing_x ,
zero_crossing_y]=calc_zero_crossing(COPX_interval,COPY_interval);

        %Caluculate eccentricity, length of major ellipse axis and
angle of
        %major axis

        [major_axis_angle eccentricity
major_axis_length]=calc_ellipse(COPX_interval,COPY_interval);

        %%Calculate maximum frequency in AP and ML directions

        [maxfrequency_x,maxfrequency_y,p2,p3,freq] =
calc_power_spectrum(COPX_interval,COPY_interval,f_force);

        %%Calculate the median frequency in the AP and ML directions

            %Darren's code:

%[median_frequency_x,median_frequency_y]=calc_median_frequency(COPX_int
erval,COPY_interval,f_force)

            %Greg's code (trying a different method):
            [median_frequency_x,median_frequency_y,f,P] =
med_freq_GWK_temp(COPX_interval,COPY_interval,f_force);
            pt=transpose(P);
          figure (2)
          plot(f,pt)
          xlabel('Frequency (Hz)')
          xlim([0 50])
          ylabel('Power')
          title('Power Spectrum')
        %%Save all output measures to a single variable

        variables(index1,:,sub) = [pathlength COP_sway_y COP_sway_x
vmean vmax max_displacement_y max_displacement_x sdev_COPY sdev_COPX
vmax_y vmax_x sdev_velocity_y sdev_velocity_x vmean_y vmean_x
mean_displacement_y mean_displacement_x eccentricity major_axis_length
```

```matlab
major_axis_angle zero_crossing_x zero_crossing_y maxfrequency_x
maxfrequency_y median_frequency_x median_frequency_y,sub_condition];

    end %end of interval loop

counter=counter+1;
end%end of subject loop

fprintf('writing output file...')

stat_format

fprintf('trial done.\n')




%init_var.m
%Define Constants

f_force=1000;     % Force Plate Sampling Frequency

f_audio = 8000; %Audio Sampling frequency


%Subject vector

%subs=[21 23 28 31 32]
%subs=[21:21];
labs = [1:49];
%indices = [1:48];
indices = [1:13];    %represents 13 different intervals identified for
analysis during meeting on 12/20/10

startandend = [3 48;
               4 6;
               8 10;
               14 16;
               18 20;
               22 24;
               26 28;
               30 32;
               34 36;
               38 40;
               42 44;
               45 47;
               47 48];


%truth = [1 3 1 3 1 1 1 3 1 1 1 1 3];  %1=truthful 3=control
%deceptive = [0 3 0 3 0 0 0 3 0 0 0 0 3];    %0=decptive  3=control
```

```matlab
truth = [1 1 1 1 1 1 1 1 1 1 1 1 1];
deceptive = [0 0 0 0 0 0 0 0 0 0 0 0 0];

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

function [COPX, COPY, audio, labels,
sstr,subject_condition]=data_load(sub,counter)
sstr=int2str(sub);    %Convert subject number to a string


%Load COP Data



data=csvread(['s',sstr,'.csv'],5,0);    %Load CSV file

column = [0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 0 0 0 0 0 0 0 0 1 1 1 0
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 1];

condition = [1 0 1 1 0 0 1 0 0 1 0 0 1 0 0 1 1 0 0 1 0 0 0 1 1 0 0 1 0 0 1 0
0 1 0 1 0 1 1 0 0 1 1 0 1 0 1 0 1 0 0];    %1=truthful  0=deceptive

subject_condition = condition(counter);
if column(counter) == 1

data= data(:,12:13);                      %Assign variable data to 12th
and 13th column

elseif column(counter) == 0

    data= data(:,3:4);                    %Assign variable data to 3rd
and 4th column
end
%Subtract mean off of COP data

COPX=data(:,1)-mean(data(:,1));
COPY=data(:,2)-mean(data(:,2)) ;

%%Load audio data

    eval(['load S',sstr,'.txt;']);
    eval(['audio = S',sstr,';']);

%% Load labels
     eval(['load S',sstr,'_labels.txt;']);
    eval(['labels = S',sstr,'_labels;']);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```matlab
function [max_displacement_x, max_displacement_y,
max_displacement,COP_sway_x,COP_sway_y,mean_displacement_x,mean_displac
ement_y,x_squared, y_squared
]=calc_displacement(COPX_interval,COPY_interval)
%%add indices stuff to input/change/remove sub
%%%NEED TO MAKE SPECIFIC FOR INTERVAL


%COP displacement
max_displacement_x=max(abs(COPX_interval));
max_displacement_y=max(abs(COPY_interval));
x_squared = (COPX_interval.^2);
y_squared = (COPY_interval.^2);
max_displacement = (max(x_squared + y_squared).^(0.5));

%COP Mean Displacement
mean_displacement_x=mean(abs(COPX_interval));  %ML direction
mean_displacement_y=mean(abs(COPY_interval));  %AP direction

%COP Sway
COP_sway_x = max(COPX_interval) - min(COPX_interval);
COP_sway_y = max(COPY_interval) - min(COPY_interval);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


function [pathlength]=calc_pathlength(COPX_interval,COPY_interval)

%Calculate total path length:
            pathlength=0;%set counter

           for count=1:(length(COPX_interval)-1)

             Temp_length = (((COPX_interval((count+1))-
COPX_interval(count))^2 + (COPY_interval((count+1))-
COPY_interval(count))^2))^0.5;
              pathlength = pathlength+Temp_length;

           end
         pathlength;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


function[vmax,vmean,vmax_x,
vmax_y,vmean_x,vmean_y,velocity_x,velocity_y]=calc_velocity(x_squared,
y_squared,COPX_interval,COPY_interval,pathlength,t_cop)

%COP velocity (magnitude)
```

```matlab
pos =(x_squared + y_squared).^(0.5);
velocity = diff(pos)*1000;
vmax = (max(abs(velocity)));
vmean = (pathlength/max(t_cop));    %length/sec

%Mean and Max COP velocity in the ML direction
velocity_x=diff(COPX_interval)*1000;
vmax_x = (max(abs(velocity_x)));
vmean_x = (mean(abs(velocity_x)));    %figure out whether this should
be mean(abs(velocity))

%Mean and Max COP velocity in the AP direction
velocity_y=diff(COPY_interval)*1000;
vmax_y = (max(abs(velocity_y)));
vmean_y = (mean(abs(velocity_y)));    %figure out whether this should
be mean(abs(velocity))

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


function [major_axis_angle eccentricity
major_axis_length]=calc_ellipse(COPX_interval,COPY_interval) % ellipse
is an optional argument you can just run Vo  = ellipsef(V) for the
stats



%modified from Marcos Duarte · Vladimir M. Zatsiorsky
%"Effects of body lean and visual information on the equilibrium
maintenance
%during stance", Experimental Brain Research 2002
%ml=V(:,1);
%ap=V(:,2);
V=cov(COPX_interval,COPY_interval); % covariance matrix between the a-p
and m-l COP data
[vec,val]=eig(V); % eigenvectors and eigenvalues of the covariance
matrix
axes=1.96*sqrt(svd(val)); % axes lengths (major axis first)
angles=atan2(vec(2,:),vec(1,:)); % respective angles
%area=pi*prod(axes); % area of the ellipse
% ellipse data:
t=linspace(0,2*pi,200);
%ellipse=vec*1.96*sqrt(val)*[cos(t);
sin(t)]+repmat([mean(COPX_interval); mean(COPY_interval)],1,200); %for
plotting an ellipse
eccentricity=sqrt(1-(axes(2)/axes(1))^2);
%plot(ellipse(1,:),ellipse(2,:),'c')
%Vo=[e;angles(2);2*axes(1)];%eccentricity , angle of major axes with
respect to x axis, full length of ellipse
major_axis_length=axes(1);
major_axis_angle=angles(2);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


function [median_frequency_x,median_frequency_y,f,P] =
med_freq_GWK_temp(COPX_interval,COPY_interval,f_force)

L = length(COPX_interval);
win = 2^nextpow2(L);
f = f_force*(0:(win/2))/win;

%Calculate median frequency - X
COPX_interval_mean=COPX_interval-mean(COPX_interval);
y = fft(COPX_interval_mean,win);
P = y.*conj(y)/win;
P = P(1:(win/2)+1);

intP = trapz(P);
half_intP = intP/2;
i_median_temp = find(cumtrapz(P)>=half_intP);
i_median = i_median_temp(1);
median_frequency_x = f(i_median);


%Calculate median frequency - Y

COPY_interval_mean=COPY_interval-mean(COPY_interval);
y = fft(COPY_interval_mean,win);
P = y.*conj(y)/win;
P = P(1:(win/2)+1);
intP = trapz(P);
half_intP = intP/2;
i_median_temp = find(cumtrapz(P)>=half_intP);
i_median = i_median_temp(1);
median_frequency_y = f(i_median);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%stat_format.m

%Rewrite output variables into row format (s)

i = 0;
for sub = subs
    for index = indices
        i = i + 1;
        s(i,:) = [sub index variables(index,:,sub)];
    end
end
```

```matlab
%Define header and formatting

header = ['SUB INTERVAL '...
         'PATHLENGTH '...
         'SWAY_Y SWAY_X '...
         'MEAN_VEL MAX_VEL '...
         'MAX_DISP_Y MAX_DISP_X '...
         'SDEV_COPY SDEV_COPX '...
         'VMAX_Y VMAX_X '...
         'SDEV_VELY SDEV_VELX '...
         'MEAN_VEL_Y MEAN_VEL_X '...
         'MEAN_DISP_Y MEAN_DISP_X '...
         'ECCENTRICITY '...
         'MAJOR_AXIS_LENGTH '...
         'MAJOR_AXIS_ANGLE '...
         'ZERO_CROSSING_X ZERO_CROSSING_Y '...
         'MAX_FREQ_X MAX_FREQ_Y '...
         'MEDIAN_FREQ_X MEDIAN_FREQ_Y'...
         'SUB_CONDITION\n'];


statformat = ['%3.0f %8.0f '...
              '%5.4f '...
              '%5.4f %5.4f '...
              '%5.4f %5.4f '...
              '%5.4f %5.4f '...
              '%5.4f %5.4f '...
              '%5.4f %5.4f '...
              '%5.4f %5.4f '...
              '%5.4f %5.4f '...
              '%5.4f %5.4f '...
              '%5.4f '...
              '%5.4f '...
              '%5.4f '...
              '%5.4f %5.4f '...
              '%5.4f %5.4f '...
              '%5.4f %5.4f'...
              '%3.0f\n'];

%Initialize stats output file, write header

fid = fopen('Statistics.dat','w');
fprintf(fid,header);

%Loop to write elements of s to output file

for j = 1:length(s)
    fprintf(fid,statformat,s(j,:));
end

fclose(fid);
```

The Index Key for the security screening interview is shown by Figure A- 1:

Index Key		
index no	source	event
1	subject	onset of "yes" response to avatar question "are you standing with both feet on the grey square?"
2	subject	offset of "okay" response to avatar instruction "...say ok to continue"
3	avatar	onset of question "did you pack your own luggage?"
4	avatar	offset of question "did you pack your own luggage?"
5	subject	offset of answer to question "did you pack your own luggage?"
6	avatar	onset of explanation "regulations prohibit going past this checkpoint..."
7	avatar	onset of question "are you carrying any of these items?"
8	avatar	offset of question "are you carrying any of these items?"
9	subject	offset of answer to question "are you carrying any of these items?"
10	avatar	onset of explanation "I can scan your bag with the optical cameras..."
11	avatar	onset of explanation "I am now going to ask you about some specific items..."
12	avatar	onset of explanation "You are not allowed to take any fruits or vegetables..."
13	avatar	onset of question "does your bag contain any fruits or vegetables?"
14	avatar	offset of question "does your bag contain any fruits or vegetables?"
15	subject	offset of answer to "does your bag contain any fruits or vegetables?"
16	avatar	onset of explanation "You are not allowed to take any flammable liquids..."
17	avatar	onset of question "Does your bag contain any flammable liquids?"
18	avatar	offset of question "Does your bag contain any flammable liquids?"
19	subject	offset of answer to "Does your bag contain any flammable liquids?"
20	avatar	onset of explanation "You are not allowed to take more than a small, travel-sized bottle..."
21	avatar	onset of question "Does your bag contain any large containers of liquids?"
22	avatar	offset of question "Does your bag contain any large containers of liquids?"
23	subject	offset of answer to "Does your bag contain any large containers of liquids?"
24	avatar	onset of explanation "My sensors indicate that your bag may contain liquids..."
25	avatar	onset of instruction "Please describe the container of liquid that is in your bag"
26	avatar	offset of instruction "Please describe the container of liquid that is in your bag"
27	subject	offset of answer to "Please describe the container of liquid that is in your bag"
28	avatar	onset of explanation "You are not allowed to take any cameras..."
29	avatar	onset of "Does your bag contain any cameras..."
30	avatar	offset of "Does your bag contain any cameras..."
31	subject	offset of answer to "Does your bag contain any cameras..."
32	avatar	onset of explanation "You are not allowed to take any type of cigars..."
33	avatar	onset of question "Does your bag contain any cigars..."
34	avatar	offset of question "Does your bag contain any cigars..."
35	subject	offset of answer to "Does your bag contain any cigars..."
36	avatar	onset of explanation "You are not allowed to take any knives..."
37	avatar	onset of question "Does your bag contain any knives..."
38	avatar	offset of question "Does your bag contain any knives..."
39	subject	offset of answer to "Does your bag contain any knives..."
40	avatar	onset of explanation "We have covered some items that you are not allowed..."
41	avatar	onset of instruction "Just to be sure...please tell me each item that is in your bag"
42	avatar	offset of instruction "Just to be sure...please tell me each item that is in your bag"
43	subject	offset of answer to "Just to be sure...please tell me each item that is in your bag"
44	avatar	onset of question "Is there anything else in your bag..."
45	avatar	offset of question "Is there anything else in your bag..."
46	subject	offset of answer to "Is there anything else in your bag..."
47	avatar	onset of explanation "Thank you. I have determined..."
48	avatar	onset of instruction "Please take your bag..."
49	avatar	offset of instruction "Please take your bag..."

Legend:
- Subject response
- Avatar question or instructions
- Avatar explanation

Figure A- 1: Index Key

The demographics survey that was administered is shown by Figure A- 2

Figure A- 2: Demographics Survey

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The consent form for extra credit is shown below by Figure A- 3.

Consent for Participation in a Research Study
Security screening study

Christopher Lovelace, Ph.D., Principal Investigator
Reza Derakhshani, Ph.D., Co-PI
Gregory King, Ph.D., Co-PI

Invitation to Participate

You are invited to participate in a research study examining how people behave at security screening checkpoints. The information given below will enable you to decide whether you would like to participate in this study. You may ask questions of the study researcher at any time. If you decide to participate, you will receive a copy of this form to take with you.

Who will Participate

Participation is open to anyone between the ages of 18 and 60 yrs with no known neurological illness, normal or corrected-to-normal vision and hearing, no problems walking or standing for about 15 minutes at a time, and good English comprehension. About 60 people will participate in this study.

Purpose

The purpose of this study is to investigate how people behave when answering questions at a security checkpoint, such as at an airport customs desk, and to determine whether this behavior can be used to detect whether they are being truthful. If we can develop measures that allow a screener to more quickly and effectively determine who is or is not being truthful, then security checkpoints could be made faster and more effective.

Description of Procedures

If you decide to participate, you will first be fitted with a number of unobtrusive reflective markers. You will then pack a bag with a number of ordinary items and then proceed to another room where you will go through a simulated security checkpoint. A computerized "interviewer" will ask you a number of questions, including some about the contents of your bag. You will be told about some items that are not allowed past the checkpoint. If you have packed any of these prohibited items, then you should conceal the fact that you are carrying these items.

Following the interview, if the interviewer does not suspect that you are carrying any prohibited items, you will proceed to the post-interview room where you will be allowed to complete the study early after filling out a few questionnaires. If, on the other hand, it is suspected that you may be carrying prohibited items, you will be asked to proceed to the secondary screening room for more thorough questioning prior to filling out the post-interview questionnaires. So, to avoid the secondary screening, you should appear as credible as possible to the interviewer.

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We will use audio, video, and other measures to record your responses and general behavior during the interview. The study will take place in Flarsheim Hall in the laboratory of Dr. Greg King. Participation will take between one-half hour and one hour (depending on whether you are selected for secondary screening).

Voluntary Participation

Participation in this study is voluntary at all times. You may choose to not participate or to withdraw your participation at any time. Deciding not to participate or choosing to leave the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to leave the study the information you have already provided will be disposed of and not used for this study.

Fees and Expenses

Aside from your time, there will be no cost to you for participating in this study.

Compensation

In return for your participation, you will receive one Psych Pool credit, which may be counted toward course credit, at the discretion of your instructor. In addition, the two study participants who are judged to be the most credible during the interview will each receive an extra $200. (You will be asked to provide information so that we can mail a check to you, should you be selected.) Should you choose to exit the study early, you will receive Psych Pool credits (prorated such that 1/2 hour of participation will receive 1/2 credit), but will not be eligible for the additional payment.

Risks and Inconveniences

There are no known risks from participating in this study.

Benefits

You will not benefit directly from participating in this study, however the knowledge gained has the potential to help make security screenings faster and more efficient.

Confidentiality

The researchers will keep secret all research-related records and information from this study. You will be assigned a study ID number that will be used instead of your name to identify the information you provide. Data will be kept secure in our laboratory, accessible only to laboratory personnel. Audio and video recordings will be shared with researchers at the University of Arizona who are also involved in this project, but without any names or other identifying information. The researchers will not reveal your identity if they publish the results of this study. After the reward checks have been sent, everyone's contact information sheets will be destroyed.

In addition, you have the option of whether or not the audio and videotape records may be used in professional presentations by the investigators (without including any identifying information). Please check the appropriate box below:

☐ I agree to participate in the study, but **do not** wish to have my audio or video recordings used for presentations by the investigators.

☐ I agree to participate in this study and **do agree** to allow the researchers to use my audio and video recordings in professional presentations.

While every effort will be made to keep confidential all of the information you complete and share, it cannot be absolutely guaranteed. Individuals from the University of Missouri-Kansas City Institutional Review Board (a committee that reviews and approves research studies), Research Protections Program, and Federal regulatory agencies may look at records related to this study for quality improvement and regulatory functions.

In Case of Injury
The University of Missouri-Kansas City appreciates the participation of people who help it carry out its function of developing knowledge through research. If you have any questions about the study that you are participating in you are encouraged to call Dr. Christopher Lovelace, the investigator, at (816) 235-1067.
Although it is not the University's policy to compensate or provide medical treatment for persons who participate in studies, if you think you have been injured as a result of participating in this study, please call the IRB Administrator of UMKC's Social Sciences Institutional Review Board at 816-235-1764.

Questions
If you have any more questions about the study after signing this form, you may contact Dr. Christopher Lovelace who can be reached by telephone at (816) 235-1067, by e-mail at lovelacec@umkc.edu, or by mail at the UMKC Department of Psychology, 4825 Troost Ave., Room 124, Kansas City, MO 64110-2499.

Authorization

_____	_____	_____
Participant's name (printed)	Participant's signature	Date
_____	_____	_____
Investigator's name (printed)	Investigator's signature	Date

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Figure A- 3: Extra Credit Consent Form

The consent form for monetary compensation is shown by Figure A- 4.

Consent for Participation in a Research Study
Security screening study

Christopher Lovelace, Ph.D., Principal Investigator
Reza Derakhshani, Ph.D., Co-PI
Gregory King, Ph.D., Co-PI

Invitation to Participate

    You are invited to participate in a research study examining how people behave at security screening checkpoints. The information given below will enable you to decide whether you would like to participate in this study. You may ask questions of the study researcher at any time. If you decide to participate, you will receive a copy of this form to take with you.

Who will Participate

    Participation is open to anyone between the ages of 18 and 60 yrs with no known neurological illness, normal or corrected-to-normal vision and hearing, no problems walking or standing for about 15 minutes at a time, and good English comprehension. About 60 people will participate in this study.

Purpose

    The purpose of this study is to investigate how people behave when answering questions at a security checkpoint, such as at an airport customs desk, and to determine whether this behavior can be used to detect whether they are being truthful. If we can develop measures that allow a screener to more quickly and effectively determine who is or is not being truthful, then security checkpoints could be made faster and more effective.

Description of Procedures

    If you decide to participate, you will first be fitted with a number of unobtrusive reflective markers. You will then pack a bag with a number of ordinary items and then proceed to another room where you will go through a simulated security checkpoint. A computerized "interviewer" will ask you a number of questions, including some about the contents of your bag. You will be told about some items that are not allowed past the checkpoint. If you have packed any of these prohibited items, then you should conceal the fact that you are carrying these items.

    Following the interview, if the interviewer does not suspect that you are carrying any prohibited items, you will proceed to the post-interview room where you will be allowed to complete the study early after filling out a few questionnaires. If, on the other hand, it is suspected that you may be carrying prohibited items, you will be asked to proceed to the secondary screening room for more thorough questioning prior to filling out the post-interview questionnaires. So, to avoid the secondary screening, you should appear as credible as possible to the interviewer.

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We will use audio, video, and other measures to record your responses and general behavior during the interview. The study will take place in Flarsheim Hall in the laboratory of Dr. Greg King. Participation will take between one-half hour and one hour (depending on whether you are selected for secondary screening).

Voluntary Participation

Participation in this study is voluntary at all times. You may choose to not participate or to withdraw your participation at any time. Deciding not to participate or choosing to leave the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to leave the study the information you have already provided will be disposed of and not used for this study.

Fees and Expenses

Aside from your time, there will be no cost to you for participating in this study.

Compensation

In return for your participation, you will receive $10. In addition, the two study participants who are judged to be the most credible during the interview will each receive an extra $200. (You will be asked to provide information so that we can mail a check to you, should you be selected.) Should you choose to exit the study early, you will receive $5 for each half-hour you participated, but will not be eligible for the additional payment.

Risks and Inconveniences

There are no known risks from participating in this study.

Benefits

You will not benefit directly from participating in this study, however the knowledge gained has the potential to help make security screenings faster and more efficient.

Confidentiality

The researchers will keep secret all research-related records and information from this study. You will be assigned a study ID number that will be used instead of your name to identify the information you provide. Data will be kept secure in our laboratory, accessible only to laboratory personnel. Audio and video recordings will be shared with researchers at the University of Arizona who are also involved in this project, but without any names or other identifying information. The researchers will not reveal your identity if they publish the results of this study. After the reward checks have been sent, everyone's contact information sheets will be destroyed.

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Form Revision Date: 9/1/04

In addition, you have the option of whether or not the audio and videotape records may be used in professional presentations by the investigators (without including any identifying information). Please check the appropriate box below:

☐   I agree to participate in the study, but **do not** wish to have my audio or video recordings used for presentations by the investigators.

☐   I agree to participate in this study and **do agree** to allow the researchers to use my audio and video recordings in professional presentations.

While every effort will be made to keep confidential all of the information you complete and share, it cannot be absolutely guaranteed. Individuals from the University of Missouri-Kansas City Institutional Review Board (a committee that reviews and approves research studies), Research Protections Program, and Federal regulatory agencies may look at records related to this study for quality improvement and regulatory functions.

In Case of Injury
The University of Missouri-Kansas City appreciates the participation of people who help it carry out its function of developing knowledge through research. If you have any questions about the study that you are participating in you are encouraged to call Dr. Christopher Lovelace, the investigator, at (816) 235-1067.

Although it is not the University's policy to compensate or provide medical treatment for persons who participate in studies, if you think you have been injured as a result of participating in this study, please call the IRB Administrator of UMKC's Social Sciences Institutional Review Board at 816-235-1764.

Questions
If you have any more questions about the study after signing this form, you may contact Dr. Christopher Lovelace who can be reached by telephone at (816) 235-1067, by e-mail at lovelacec@umkc.edu, or by mail at the UMKC Department of Psychology, 4825 Troost Ave., Room 124, Kansas City, MO 64110-2499.

Authorization

_____   _____   _____
Participant's name (printed)   Participant's signature   Date

_____   _____   _____
Investigator's name (printed)   Investigator's signature   Date

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Form Revision Date: 9/1/04

Figure A- 4: Consent Form for Monetary Compensation

The post interview survey is shown by Figure A- 5.

Security screening confidence study
Post-interview Survey   rev. 6/17/10

Thank you for participating in this study. Please answer the following questions as truthfully as possible.

Truthfulness of your answers during the interview (1 – 10 rating scale)

1. How truthful were you when answering Question 1? [*Are you carrying any luggage?*]
   1 2 3 4 5 6 7 8 9 10
   Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

2. How truthful were you when answering Question 2? [*Did you pack your own luggage?*]
   1 2 3 4 5 6 7 8 9 10
   Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

3. How truthful were you when answering Question 3? [*Are you carrying weapons, explosive materials, flammable items, or dangerous chemicals?*]
   1 2 3 4 5 6 7 8 9 10
   Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

4. How truthful were you when answering Question 4? [*Does your bag contain any fruits or vegetables?*]
   1 2 3 4 5 6 7 8 9 10
   Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

5. How truthful were you when answering Question 5? [*Does your bag contain any flammable liquids?*]
   1 2 3 4 5 6 7 8 9 10
   Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

6. How truthful were you when answering Question 6? [*Does your bag contain any large containers of liquids?*]
   1 2 3 4 5 6 7 8 9 10
   Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

7. How truthful were you when answering Question 7? [*Does your bag contain any cameras or other photography equipment?*]
   1 2 3 4 5 6 7 8 9 10
   Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

8. How truthful were you when answering Question 8? [*Does your bag contain any cigars, cigarettes, or other tobacco products of any type?*]
   1 2 3 4 5 6 7 8 9 10
   Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

9. How truthful were you when answering Question 9? [*Does your bag contain any knives or sharp implements?*]
   1 2 3 4 5 6 7 8 9 10
   Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

10. How truthful were you when answering Question 10? [*Please tell me each item that is in your bag.*]
    1 2 3 4 5 6 7 8 9 10
    Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

11. How truthful were you when answering Question 11? [*Is there anything else in your bag that you did not tell me about?*]
    1 2 3 4 5 6 7 8 9 10
    Completely UNTRUTHFUL □ □ □ □ □ □ □ □ □ □ completely TRUTHFUL

Participant number _____   Page 1 of 3

The interview as a whole (1 – 7 rating scale)

12. During the interview, how important was it for you to succeed in making the interviewer believe you?

	1	2	3	4	5	6	7	
Not at all important to me	☐	☐	☐	☐	☐	☐	☐	Very important to me

13. During the interview, how important was it for you to project a truthful demeanor?

	1	2	3	4	5	6	7	
Not at all important to me	☐	☐	☐	☐	☐	☐	☐	Very important to me

14. During the interview, how did you feel?

	1	2	3	4	5	6	7	
Not nervous at all	☐	☐	☐	☐	☐	☐	☐	Very nervous
Not at all flustered	☐	☐	☐	☐	☐	☐	☐	Very flustered
Not at all tense	☐	☐	☐	☐	☐	☐	☐	Very tense
Not at all relaxed	☐	☐	☐	☐	☐	☐	☐	Very relaxed
Not at all uneasy	☐	☐	☐	☐	☐	☐	☐	Very uneasy
Not at all stressed	☐	☐	☐	☐	☐	☐	☐	Very stressed

15. During the interview, how excited were you about the challenge of trying to appear truthful?

	1	2	3	4	5	6	7	
Not excited at all	☐	☐	☐	☐	☐	☐	☐	Very excited

16. During the interview, how hard was it mentally to answer the questions?

	1	2	3	4	5	6	7	
Not at all difficult	☐	☐	☐	☐	☐	☐	☐	Very difficult
Not at all challenging	☐	☐	☐	☐	☐	☐	☐	Very challenging
Not at all easy	☐	☐	☐	☐	☐	☐	☐	Very easy
Not at all simple	☐	☐	☐	☐	☐	☐	☐	Very simple

17. During the interview, how much did you try to control your nonverbal behavior?

	1	2	3	4	5	6	7	
Didn't try at all	☐	☐	☐	☐	☐	☐	☐	Tried very hard

18. During the interview, how effective were you in controlling your nonverbal behavior?

	1	2	3	4	5	6	7	
Not at all effective	☐	☐	☐	☐	☐	☐	☐	Very effective

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19. On a scale of 1 to 5, how realistic did the scenario seem to you?

           1 2 3 4 5

    Not at all realistic ☐ ☐ ☐ ☐ ☐ Very realistic

20. On a scale of 1 to 5, how exciting was the role you played during the scenario?

           1 2 3 4 5

    Not at all exciting ☐ ☐ ☐ ☐ ☐ Very exciting

21. On a scale of 1 to 5, how effective was the possibility of receiving $200 in motivating you to appear truthful during the study?

           1 2 3 4 5

    Not at all effective ☐ ☐ ☐ ☐ ☐ Very effective

Just a few last questions about yourself. Remember, all of your answers will be confidential.

22. On a scale of 1 to 5, how good do you think you are at making others believe you when you're not being truthful?

           1 2 3 4 5

    Not good at all ☐ ☐ ☐ ☐ ☐ Very good

23. On a scale of 1 to 5, how good do you think you are at making others believe you are happy or sad when you really aren't?

           1 2 3 4 5

    Not good at all ☐ ☐ ☐ ☐ ☐ Very good

24. On a scale of 1 to 5, how comfortable are you with using computers, video games, cell phones, and other types of technology?

           1 2 3 4 5

    Not good at all ☐ ☐ ☐ ☐ ☐ Very good

25. How often do you travel by airplane?

    ☐ Never

    ☐ 1-2 times a year

    ☐ 3-4 times a year

    ☐ 5 or more times a year

26. If you travel by airplane, about how often do you travel outside the United States?

    ☐ Never

    ☐ Less than half of the time

    ☐ More than half of the time

    ☐ Most of the time

    ☐ Always

Figure A- 5: Post Interview Survey

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