VISUAL FEEDBACK INCREASES ACCURACY IN ACTIVE SHOULDER JOINT ANGLE REPLICATION TASK

by

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A THESIS

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Approved: ______________________________________

Dr. Andrew Karduna

Although visual feedback is typically occluded in joint position sense (JPS) research to avoid the confounding influence of an additional sense, it has not been established that vision impacts JPS accuracy. The purpose of this research was to examine the effect of added visual feedback on absolute error during a shoulder joint angle replication task. It was hypothesized that the addition of visual feedback would result in lower absolute error when compared no visual feedback. Data were collected from eighteen subjects using an Apple iPod Touch® attached to the upper arm of a seated subject. The application guided the subject to a target angle with high and low tones, the subject memorized the position, then replicated it without auditory feedback. Target angles of 50°, 70°, and 90° were used with each presented four times for four visual conditions (open vs. closed in guided replicating stages). Results revealed a main effect ($p < 0.001$) of visual condition on absolute error, with the added visual feedback reducing absolute error by 1.5°. Additionally, a main effect ($p < 0.001$) of target angle on absolute error was found with reduced error at 90°, in consistency with previous research. Based on these results, the hypothesis that added visual feedback would reduce absolute error in a shoulder joint angle replication task was supported.

Acknowledgements

I would like to express my deepest and sincerest gratitude to each of the members of my thesis committee—Dr. Andrew Karduna, David Philips, and Professor Melissa Graboyes.

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I am so grateful to Professor Melissa Graboyes for her support and for transforming the way I look at research ethics. If the brilliant faculty of the Robert D. Clark Honors College have taught me anything, it’s to never be satisfied without digging more deeply.

I would also like to thank the many individuals who volunteered their time for me as research subjects. The value of those precious, finite hours during a bustling academic term is certainly not lost on me.

Finally, I would like to thank my parents, who taught me to be curious about the world and who have always believed in me. There are no words to express how grateful I am for the endless support and opportunities they have given me.

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Introduction

Proprioception and vision both contribute towards an awareness of one's own body (Proske & Gandevia 2012; Graziano 1999), though it is a point of confusion how exactly these sensory pathways converge. The vague understanding of how sensory information is integrated and prioritized to form a functional body schema poses a challenge in designing protocols to measure proprioception in a relevant and meaningful way.

Joint position sense (JPS), the awareness of joint position, is one of the most commonly assessed modalities of proprioception. Other proprioceptive modalities include force sense (a sense of force exerted by ones' muscle) and kinesthesia (a sense of self movement). JPS is typically measured using joint angle replication protocols in which vision is conventionally restricted via a blindfold in order to reduce the influence of vision (Han et al. 2016; Goble 2010; Proske & Gandevia 2012; Ribeiro & Oliveira, 2011). Yet, visual feedback is almost always present in everyday applications, and its impact on accuracy in joint position sense protocols has not been tested. Much of the previous research exploring the relationship between vision and proprioception focuses on reaching tasks in the horizontal plane rather than on joint angle replication tasks (Sarlegna & Sainburg 2007; Robin et al. 2004; Lateiner & Sainburg 2003). Furthermore, visual feedback in these studies tends to be artificially modified or restricted to offer specific information. These studies do not reflect how vision would instinctually or voluntarily be used in a joint angle replication task.

The consensus of previous vision-proprioception research reveals a bias favoring visual information—whenever there is a discrepancy between visual and proprioceptive information (muscle tension, change in muscle length), the visual information is favored (Bagesteiro et al. 2006). Visual information about the starting position of the hand has been demonstrated to be particularly relevant to planning movement direction and distance (Lateiner & Sainburg 2003; Bagesteiro et al. 2006). However, this seems to be sensitive to the plane of the workspace—sagittal movements weigh visual information more heavily, while movements in the horizontal plane weigh proprioceptive information more heavily (Van Beers et al. 2002; Apker et al. 2011). More research certainly needs to be done to conclusively tease out which information is favored under which circumstances.

The purpose of this project is to investigate whether performing a shoulder joint repositioning task with eyes open would result in lower errors than when performed with closed eyes, as is the convention. The primary hypothesis is that the addition of visual feedback would result in lower errors when compared to a condition of no visual feedback. The secondary hypothesis is that the availability of visual feedback throughout the entire trial would result in lower errors than if it were available during only one part of the trial. Additionally, it was hypothesized that without visual feedback, errors would decrease as the target angle approaches 90°, but with visual feedback, a minimal baseline error would persist across all angles.

Background

Proprioception is a form of sensory information that informs the body’s position in space and includes many modalities including joint position sense (a sense of the angle of a joint), force sense (a sense of muscle tension or force), kinesthesia (a sense of movement), and the sense of balance (Proske & Gandevia 2012; Lateiner & Sainburg 2003; Graziano 1999). Proprioception originates in proprioceptors (a subtype of mechanoreceptors) including muscle spindles and golgi tendon organs within skeletal muscles, and is supported by information originating in skin tactile receptors, cutaneous receptors, and joint receptors (Guyton & Hall 2011). Muscle spindles, which exist in parallel with muscle fibers, sense the stretch and speed of muscle fibers while golgi tendon organs existing in series with muscle fibers sense the tension (compression) of muscle fibers (Roijezon et al. 2015).

Conscious proprioceptive sensory information travels up afferent pathways in the spinal cord through the medulla and thalamus via the dorsal column-medial lemniscal system at fast velocities of 30-110 m/sec ultimately reaching the somatosensory cortex, the primary destination for much of the body’s collected sensory information. Unconscious proprioceptive information travels through the spinal nucleus ultimately to the cerebellum via the spinocerebellar pathway (Roijezon et al. 2015). This information creates an image of the body’s position in the somatosensory cortex that contributes to efferent motor signals developed in the motor cortex (Guyton & Hall 2011).

The other major sensory information illuminating body position is visual. Visual nerve signals travel from the eyes to the optic chiasm, then in optic tracts to the dorsal lateral geniculate nucleus of the thalamus, then ultimately to be processed in the primary visual cortex (Guyton & Hall 2011). Visual information travels from the primary visual cortex to secondary visual areas via two major pathways. The faster pathway infers three-dimensional position and motion information and travels to the posterior midtemporal area and into occipitoparietal cortex. A second, slower, pathway parses together color and more precise visual details (Guyton & Hall 2011).

It is unknown how information from these pathways converge. It has been suggested that an “online” body schema informed by sensory information exists for comparison to an “offline” representation (Proske & Gandevia 2012). A study investigated the premotor cortex as a site of convergence in monkeys, showing that the neurons respond to both proprioceptive and visual cues, but suggests that convergence happens during earlier processing such as in the parietal lobe (Graziano 1999). One major proposed site of convergence is the posterior parietal cortex, which is an important brain area for the self-recognition of body and face (Proske & Gandevia 2012).

Atypical proprioception or proprioceptive sensory integration is associated with many clinical conditions, including strokes (Handley et al. 2009), concussions (Reneker & Cook 2015), progressive neurodegenerative disorders like Parkinson’s (Konczak et al. 2009), viral or diabetic neuropathies (Goble 2010), autism (Casico et al. 2012), and ADHD (Inglesias et al. 2014). Parkinson’s disease seems to be particularly associated with difficulties in proprioceptive sensory integration. Mapping proprioceptive information onto motor commands seems to be a major contributor to the motor deficits observed in patients with Parkinson’s (Konczak et al. 2009). Joint-specific proprioceptive disorder may also simply be associated with injury and overuse of joint, as in shoulder tendinopathy (Maenhout et al. 2012). That said, a review of existing literature suggests that there is evidence that proprioceptive training may meaningfully improve sensorimotor function, particularly when subjects train both with and without visual feedback, though the authors admit there is certainly a need for further research to properly assess whether training transfers beyond the trained tasks. (Aman 2015). To properly clinically assess and monitor proprioception, a standardized protocol for measuring and monitoring proprioception would be beneficial.

There is not one standardized measure of proprioception because different testing techniques measure different modalities of proprioception (such as joint position sense, force sense, kinesthesia, etc.), and the understanding of how this information is integrated remains incomplete.

A recent review highlights three types of proprioceptive tests dominating the literature (Han et al. 2016). One technique measures the threshold to detection of passive motion. In this method, a subject's limb is moved by a machine and the subject is instructed to indicate when movement is perceived. The subject reports the perceived direction of movement to reduce the unreliability of self-reporting. Passive positioning protocols are valued for reducing the influence of information generated via efference copy. The second examined technique assesses joint position reproduction/matching. This tests a subject's ability to replicate a guided joint angle. The third method of measurement tests active movement extent discrimination. This procedure first familiarizes the subject with a few numbered positions, then the subject is then passively guided into the positions at random and asked to identify them by number

(Han et al. 2016). It should be noted that the examined tests assess only the position and motion sense modalities of proprioception, and do not touch on force sense or balance.

Studies using these protocols vary in execution. Joint position reproduction/matching protocols vary in movement speeds, sensory feedback permitted (visual, auditory), joint examined, plane of motion, whether active vs passive motion is used, dominant versus non-dominant limb, subject population, angles tested, target presentation time, etc. These details of the protocol have been shown to influence proprioceptive accuracy and are unlikely to be standardized until the mechanisms of sensing and processing proprioceptive information are better understood. For example, it has been suggested that passive and active protocols assess proprioception arising from different receptors because feedback from muscle spindles is diminished in passive protocols because the muscles are less active, so these protocols may be weighing cutaneous receptors more heavily (Han et al. 2016).

Due to a lack of consistency in protocols and individualized equipment developed and used by laboratories, it can be challenging to review and draw conclusions from results across studies, and limited portability of equipment poses challenges in acquiring high sample numbers (Han et al. 2016). Unfortunately, the individualized nature of these protocols and equipment makes clinical use of these tests impossible. These protocols for measuring proprioception require specialized, expensive equipment that is generally confined to a laboratory.

Mobile devices are gaining legitimacy as a method of collecting and monitoring health information. For example, in late September 2016, Aetna became the first major health insurer to subsidize the cost of an Apple watch for its customers. The sensors built into smartphones allow for convenient data collection and mobile applications such as Google’s Science Journal begin to tap into this potential.

An iOS mobile application has been developed to provide a method to measure joint position sense that is cheap and portable compared to conventional methods. The validity of this application has been tested in comparison to an established protocol using Polhemus magnetic motion tracking equipment (Edwards et al. 2016). The protocol requires subjects to close their eyes throughout data collection to limit the influence of non-proprioceptive information. However, the effect of visual feedback on angle replication has not been confirmed, and this experiment aims to explore this question. If similar results are achieved when subjects execute the protocol with open eyes as with closed eyes, then the application is perhaps not testing what it is intended to.

The three commonly reported measures of joint position sense accuracy include absolute error, constant error, and variable error, with most studies reporting either absolute or constant error (Brindle et al. 2004). Constant error may mask inaccuracy if an overshot value is averaged with an undershot value. On the other hand, absolute error cannot reveal tendencies to over or undershoot a target. A tendency to overshoot proprioceptive targets and to undershoot visual targets has been observed, and understanding these tendencies may clarify the relationship between the two forms of sensory feedback (Goble et al. 2010). Variable error reveals variability in performance, but not accuracy. It is debated which measure is most relevant in a joint angle replication task because the central nervous system control mechanisms relevant to proprioception are not well understood (Brindle et al. 2004). It has been suggested that variable error may be reducible with practice, unlike constant error (Brindle et al. 2004).

The dominant side is most often selected for testing, although the effect of arm dominance on absolute error has not been determined consistently. A previous study demonstrated smaller errors in ipsilateral remembered and contralateral remembered proprioceptive target-matching tasks performed using the non-dominant elbow, and smaller errors in visual target-matching tasks performed using the dominant elbow (Goble & Brown, 2008). Based on these results, the author suggested a right hemisphere advantage for proprioceptive processing, and a left hemisphere advantage for visual processing, speculating that this is consistent with how dominant vs. non-dominant arms are used in day to day life (Goble & Brown, 2008; Goble 2010). Because the study only included right-handed subjects, it is unclear whether the proprioceptive advantage is tied to the non-dominant arm of the subject, or the left arm—and thus how the advantage would manifest in left-handed subjects. Another study demonstrated that joint position sense accuracy is similar between the elbow and shoulder joints, but failed to replicate the statistically significant difference in accuracy between dominant/non-dominant arms (King et al. 2013). Their findings are consistent with the results of another study that tested joint position sense in the wrist (Adamo & Martin 2009).

The purpose of this experiment is to investigate the effect of visual feedback on angle replication accuracy. Even so, there are several potential applications for this work. This experiment may provide insight or help lay the groundwork for future research into how to use best use visual feedback to enhance motor learning. For example, mirrors are common tools in dance studios to aid in motor learning, but much of the research on the use of mirrors in dance is vague and contradictory; further research may help clarify the role of visual feedback in dance (Batson 2009; Dearborn & Ross 2006). Mirrors and videotaping have also been shown to improve weight training technique (Sewall et al. 1988), and further research may help evaluate when and how to use these visual aids to maximize performance. Further understanding of the role of visual feedback in motor learning may have clinical applications as well—a review of existing literature suggests that there is evidence that proprioceptive training may meaningfully improve sensorimotor function, particularly when subjects train both with and without visual feedback, though the authors admit there is certainly a need for further research to properly assess how training transfers beyond the trained task (Aman 2015).

Studies examining the relationship between vision and proprioception have done so to evaluate the specificity of practice hypothesis, referring to the notion that learning is specific to the type of sensory information learned during practice (Robin et al. 2004). After practicing a task with access to a specific set of sensory information, both adding or removing access to different types of sensory information would be expected to decrease accuracy (Toussaint et al. 2017). The earlier study examined the effect of adding or removing visual feedback on accuracy in replicating target reaches using a stylus on a tablet. The study found that removing visual feedback decreased accuracy early in practice but not after intensive practice, as well as that adding visual information after modest/intensive practice had no effect on accuracy (Robin et al. 2004). In contrast, in a later study using a leg positioning recall protocol, removing visual feedback after intensive practice resulted in decreased accuracy (Toussaint, et al.

2017). The authors attributed this to visual dominance, but noted it took time and practice for visual dominance to occur (Toussaint, et al. 2017).

Recognizing whether vision is more valuable during the guided versus replication step may benefit athletes aiming to learn new body positions. A better understanding of how vision affects angle reproduction accuracy may promote a better understanding of when vision is necessary for the accurate execution of certain tasks, for example in some industrial settings. Another potential use of this application is in providing a quick assessment of proprioception to easily screen for conditions such as concussions.

Methods

Subjects recruitment

Subjects were recruited from the general student population of the University of Oregon. Data were collected from eighteen subjects (13 female, 5 male), with an average age of 21±1 years. Individuals with a history of shoulder injuries, pain, or pathology were excluded, as were subjects with prior experience with the protocol. Subjects were required to have normal or corrected to normal vision. Subjects provided informed consent and the study was approved by the Internal Review Board at the University of Oregon.

Procedure

Data were collected with a mobile application developed for assessing shoulder joint position sense. The following protocol was adapted from the study validating the application (Edwards et al. 2016).

Subjects were seated in an ergonomic kneeling chair to limit cutaneous feedback, and in a black cubicle to limit visual reference points. An Apple iPod Touch® in a sport band was attached to the lateral humeral aspect of a subject’s dominant arm. Subjects were instructed to sit up tall with shoulders back and relaxed, head facing forward and to keep still throughout the protocol. The up-and-down movement of the arm in the sagittal plane was demonstrated for subjects, and they were instructed to keep their hand flat with thumb pointed up, and elbow extended, taking care to move only their shoulder (figure 1).

Figure 1: Experimental set up.

In the guided stage of a trial, the application guided the subject from a resting position to a target angle by providing auditory feedback (a high tone indicated that the subject's arm was too high, a low tone signaled that the arm was positioned too low). Upon reaching the target angle, the subject held and memorized the position for three seconds until prompted by the application to "relax" and return to the resting position. In the replication stage of the trial, the subject again began in the resting position and was prompted to "find target" and replicate the memorized angle without auditory feedback. When the subject's angular velocity dropped below 0.25 degrees per second, the device recorded the position and prompted the subject to relax, signaling the end of the trial.

Each subject participated in four blocks of twelve trials testing three target angles (50°, 70°, 90°) that were each presented four times. During one block, the subject was allowed visual feedback and was instructed to keep their eyes open throughout each trial (open-open or OO condition). During a second block, the subject was denied visual feedback and instructed to close their eyes throughout each trial (closed-closed or CC condition). During a third block, subjects were allowed visual feedback during the guided phase but not the replication phase (OC condition). During the fourth block, subjects were allowed visual feedback during the replication phase but not the guided phase (CO condition). The order of these visual condition blocks was randomized for each subject.

Data Analysis

Data was processed using a custom LabVIEW program. From the processed data, the absolute error for each trial was calculated by taking the absolute value of the difference between the presented and repositioned angle. The absolute error of the four trials collected per angle in each visual condition for each subject were averaged to obtain an average absolute error, and is calculated as:

$$MAE = \frac{\sum\left|A_p - A_r\right|}{n}$$

Here, MAE represents mean absolute error, A_p represents the presented angle, A_r represents the repositioned angle; n represents the number of trials per angle per condition per subject. In most cases, n=4, but in cases where a trial was excluded from analysis, only three trials were averaged.

Statistical Analysis

A 3x4 factorial analysis of variance (ANOVA) was conducted to assess the influence of visual condition (OO, CC, CO, and OC) and target angle (50°, 70°, and

90°) on absolute error. The α level was set at 0.05. Follow up post-hoc tests for a significant main effect were performed with a Bonferroni adjustment between the four visual conditions (OO, CC, CO, and OC) with an adjusted α level of 0.013 and between the three target angle (50°, 70°, and 90°) with an adjusted α level of 0.017.

Results

Excluded trials

Trials were excluded if the subject failed to follow the verbal instructions of the mobile application (i.e. started the trial prematurely, confused the stages of the trial, etc.), or if the software incorrectly processed the data. Trials in which more than ten seconds passed between the presented target angle and the replicated angle were also excluded. Entire subjects were excluded if more than two out of four trials at a given condition and angle were excluded. Three out of twenty-one collected subjects were excluded. Otherwise, on twenty-one occasions only three out of four trials were available and averaged. The percentage of excluded trials, excluding the three entirely excluded subjects, was 2.1%.

Results

Results revealed no interaction between visual condition and target angle ($p = 0.07$). A main effect of visual condition on absolute error ($p < 0.001$) was found. The CC condition ($M = 3.9$, $SE = 0.4$) had a greater average absolute error than the OO condition ($M = 2.4$, $SE = 0.4$) by 1.5° ($p < 0.001$). The CO condition ($M = 5.1$, $SE = 0.6$) had a greater average absolute error than the OO condition ($M = 2.4$, $SE = 0.4$) by 2.7º ($p < 0.001$). The CO condition ($M = 5.1$, $SE = 0.6$) had a greater average absolute error than the OC condition ($M = 2.8$, $SE = 0.4$ by 2.3º ($p < 0.001$). The CC condition ($M = 3.9$, $SE = 0.4$) had a greater average absolute error than the OC condition ($M = 2.8$, $SE = 0.4$) by 1.1º ($p < 0.005$). The CO condition ($M = 5.1$, $SE = 0.6$) had a greater average absolute error than the CC condition ($M = 5.1$, $SE = 0.6$) by 1.2º ($p < 0.01$). No significant difference in absolute error was found between the OO (*M* = 2.4, *SE* = 0.4) and OC conditions (*M* = 2.8, *SE* = 0.4), which had a mean difference of 0.4º (*p* = 0.756).

Moreover, a main effect (*p* < 0.001) of target angle on average absolute error was observed with a lower average absolute error at 90° (*M* = 3.1, *SE* = 0.5) than at 50° (*M* = 4.3, *SE* = 0.5) by 1.2° (*p* < 0.01). Average absolute errors were greater at 50º (*M* = 4.3, *SE* = 0.5) than at 70º (*M* = 3.3, *SE* = 0.4) with a mean difference of 1.0º (*p* < 0.01). No significant difference was found between 70° (*M* = 3.3, *SE* = 0.4) and 90º (*M* = 3.1, *SE* = 0.5), which had a mean difference of 0.2º (*p* > 0.99).

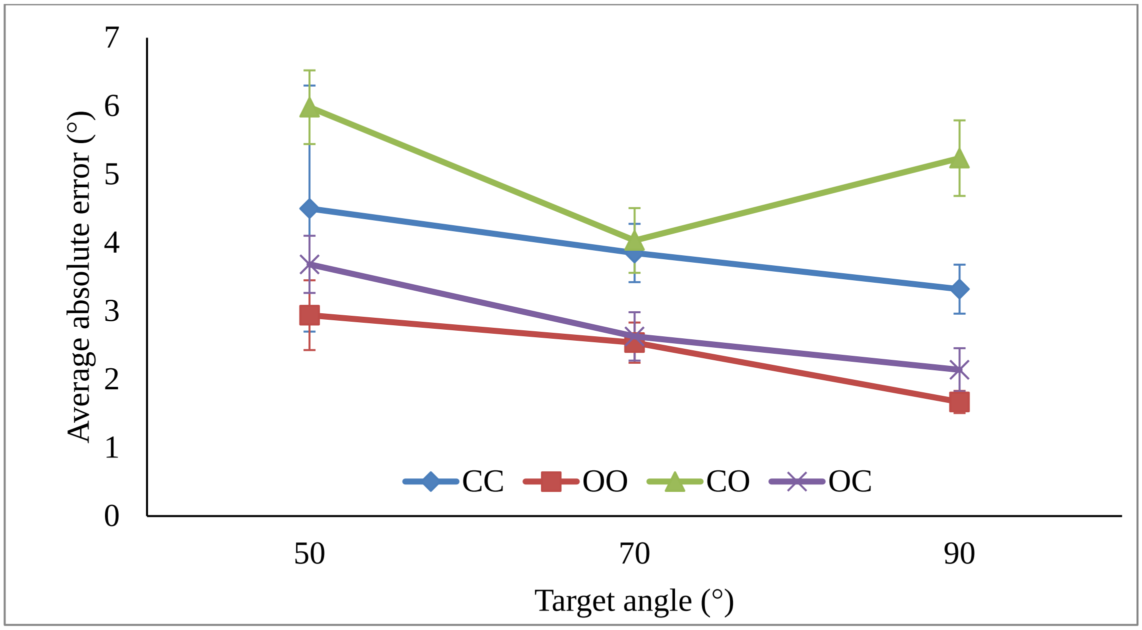


Figure 2: The effect of target angle on average absolute error within the four visual conditions (error bars show standard error of the mean).

Discussion

The purpose of this research was to investigate how the availability of vision impacts accuracy (as measured by absolute error) during an active ipsilateral shoulder joint repositioning task. It was hypothesized that the OO condition would result in lower absolute error than all other conditions (CC, CO, and OC), and that as the target angle approaches 90°, errors would decrease in the CC condition but not the OO condition.

The OO condition indeed resulted in lower absolute errors than the CC condition, with a rather slight reduction in error of 1.5° ($p < 0.001$). Previous research has suggested that vision is especially instrumental in defining the starting position of the hand and planning movement direction in a reaching task (Lateiner & Sainburg 2003; Bagesteiro et al. 2006). The current study assigned a consistent starting position and movement direction throughout, which perhaps limited the advantage provided by the availability of vision. Future research may further investigate the role of starting position in joint repositioning tasks, as starting position is invariably kept constant in JPS protocols.

The hypothesis that the OO condition would result in greater accuracy than the CO condition was also supported ($p < 0.001$). Further research is necessary to explore why. One explanation may be that the introduction of vision into the replication stage of the CO trial introduces doubt over the body schema created during the guided stage. The subject may find that their estimated visualization of the position they proprioceptively felt does not match the position they see when they later open their eyes, and this visual information is prioritized over proprioceptive feedback.

Visual feedback has been shown to be prioritized over proprioceptive information (Bagesteiro et al. 2006, Touzalin-Chretien 2010), particularly in the sagittal plane (Van Beers et al. 2002; Apker et al. 2011). Specificity of practice studies have suggested that this prioritization may lead to proprioceptive information being neglected or ignored in the presence of vision (Proteau & Isabelle 2002; Toussaint et al. 2017; Bernier et al. 2005). If proprioceptive information is neglected during the guided stage, and if learning is indeed specific to the sensory modality used during practice—as is suggested by the specificity of practice hypothesis (Robin et al. 2004)—it follows that the visual memory developed during the guided stage would be unhelpful during the replication stage. In contrast, the CC condition was found to be less accurate than the OC condition ($p < 0.005$), which suggests that the availability of vision during the guided stage at the very least does not impair learning the position. Furthermore, no significant difference in absolute error was found between the OO condition and the OC condition ($p > 0.5$), which fails to support the hypothesis that the OO condition would perform with greater accuracy than all other conditions. Combined, these results suggest that visual information gained during the guided stage of the trial helps form a detailed body schema that is useful in the replication stage regardless of whether visual information is again available.

One recurring phenomenon in several studies assessing joint position sense via angle replication is that of the “angle effect”. It has been found that accuracy in angle reproduction increases as the target angle increases to 90° from 30° (King et al. 2013; King & Karduna 2013; Suprak et al. 2006; Chapman et al. 2009). Angles greater than 90° are associated with increased error (Suprak et al. 2006). This phenomenon exists in both the shoulder and elbow joints and does not manifest in variable errors (King et al. 2013). Proprioception at midrange angles in the horizontal plane demonstrates increased accuracy as well (King & Karduna 2013). Although several explanations for the angle effect have been proposed (increase in golgi tendon organ feedback, α-γ coactivation, cutaneous feedback, increased sense of effort/efference copy, gravity, different cortical representation of position, etc.), a lack of clarity on central sensory integration hampers meaningful conclusions (King et al. 2013). It was hypothesized that this angle effect would not be sustained under the influence of visual feedback, and that the OO condition would maintain a low, baseline error level consistent with the minimal error present at 90° in the CC condition. This hypothesis was not supported by the results, and the angle effect was observed in both the CC and OO conditions ($p < 0.001$). Perhaps this suggests that vision does not contribute enough to accuracy to reduce error to a baseline at all angles, and suggests that vision does not dominate over proprioceptive information to the extent anticipated. Alternatively, it is possible that the arm is more visible at 90°, so vision may play a disproportionate role at this angle and selectively reduce error.

Conclusion

The results support the hypothesis that the addition of visual feedback throughout a shoulder joint repositioning task results in lower absolute error when compared to the same task without visual feedback. The reduction in error with added visual feedback is 1.5° ($p < 0.001$). The greatest absolute error was found in the CO condition, followed by the CC condition, and finally between the OC and OO conditions (between which no significant difference was found). The results are consistent with previous research in demonstrating trend of decreasing absolute error as the angle approaches 90°, and the effect is preserved in the OO condition ($p < 0.001$).

Limitations

Memory

The test was intended to evaluate proprioceptive accuracy, but the inherent reliance on memory involved in the test may result in unintended error. Inconsistencies in the time between target presentation and replication may be a source of error. Previous kinesthetic memory research has demonstrated no loss of kinesthetic target information after 10s (Chapman et al. 2009), but visually based target location memories much more rapidly after only 500ms (Westwood et al. 2001; Elliot & Calvert 1990)—based on this research it has been suggested that subjects may rely on proprioceptive information more than visual (Robin et al. 2004). Trials longer than 10s were excluded, but the rapid deterioration of visual memory may have affected results. The use of a young subject population may have limited the influence of memory deficits, but clinical application of this test will certainly need to account for this. The use of a contralateral joint position sense test—involving matching the joint angle of one limb with another, eliminating the need for memory—has been suggested, but would introduce other concerns (Goble 2010). Concerns include a lack of clarity over which arm (if not both) to fault for error, the potential interference of corpus callosum injury, and muscular asymmetries in the arms (Goble 2010).

Velocity, acceleration

Subjects were instructed to move at a pace comfortable to them, with the expectation that they would intuitively adopt the velocity and acceleration with which they are most accurate, and would be relatively consistent in speed. However, these variables were not measured or accounted for, and it is possible that they impacted accuracy. Perhaps subjects moving faster are prone to overshooting targets. Subjects moving more slowly may be getting a slightly longer exposure time to the target, which has been shown to reduce constant error (Goble et al. 2010).

Muscle fatigue

Muscle fatigue has a demonstrated negative effect on joint position sense accuracy (Ribeiro and Oliveira, 2011; Myers et al. 1999). The optimal number of trials in a JPS protocol to ensure consistent results but minimize fatigue is debated (Dover & Powers 2003). Data collection for all conditions was kept under one hour, with a three-minute timed break between each condition to limit the influence of fatigue. The relatively young and healthy subject populations may further mitigate the influence of fatigue. That said, a few subjects noted that their arm felt tired by the end of the session.

Sleepiness, attentional drift

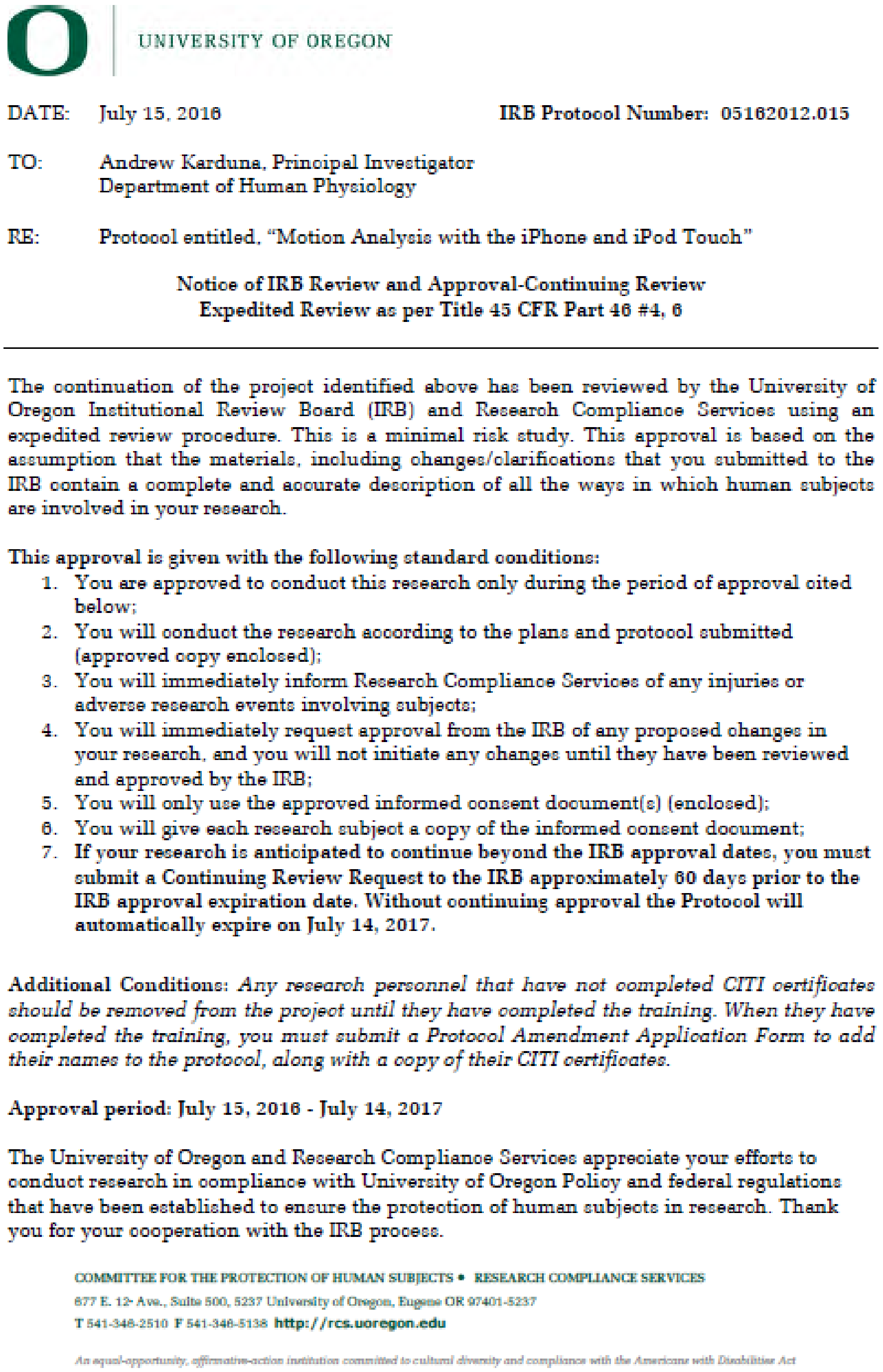
Despite keeping the data collection session short and punctuated with breaks, there is a possibility of attentional drift and sleepiness throughout data collection related to the dark nature of the cubicle in which data was collected. This is particularly true when compounded with the traditionally sleep-deprived nature of college students and the possible influence of time of day. When asked, subjects reported that they remained focused and engaged throughout the data collection session. Nevertheless, occasional incidence of errors in following protocol—such as absent-mindedly moving prior to instruction by the app, or mixing up the stage of the trial—may indicate otherwise. Subjects generally reported finding the protocol “relaxing”.

Eye movement

Subjects were not given instructions on how to use vision/where to look, and differences in how subjects moved their eyes may have given some subjects additional proprioceptive information from the eyes that aided them in reducing error.

IRB Documentation

Approval



UNIVERSITY OF OREGON

DATE: July 15, 2016 **IRB Protocol Number: 05162012.015**

TO: Andrew Karduna, Principal Investigator
Department of Human Physiology

RE: Protocol entitled, "Motion Analysis with the iPhone and iPod Touch"

Notice of IRB Review and Approval-Continuing Review
Expedited Review as per Title 45 CFR Part 46 #4, 6

The continuation of the project identified above has been reviewed by the University of Oregon Institutional Review Board (IRB) and Research Compliance Services using an expedited review procedure. This is a minimal risk study. This approval is based on the assumption that the materials, including changes/clarifications that you submitted to the IRB contain a complete and accurate description of all the ways in which human subjects are involved in your research.

This approval is given with the following standard conditions:

1. You are approved to conduct this research only during the period of approval cited below;
2. You will conduct the research according to the plans and protocol submitted (approved copy enclosed);
3. You will immediately inform Research Compliance Services of any injuries or adverse research events involving subjects;
4. You will immediately request approval from the IRB of any proposed changes in your research, and you will not initiate any changes until they have been reviewed and approved by the IRB;
5. You will only use the approved informed consent document(s) (enclosed);
6. You will give each research subject a copy of the informed consent document;
7. **If your research is anticipated to continue beyond the IRB approval dates, you must submit a Continuing Review Request to the IRB approximately 60 days prior to the IRB approval expiration date. Without continuing approval the Protocol will automatically expire on July 14, 2017.**

Additional Conditions: *Any research personnel that have not completed CITI certificates should be removed from the project until they have completed the training. When they have completed the training, you must submit a Protocol Amendment Application Form to add their names to the protocol, along with a copy of their CITI certificates.*

Approval period: July 15, 2016 - July 14, 2017

The University of Oregon and Research Compliance Services appreciate your efforts to conduct research in compliance with University of Oregon Policy and federal regulations that have been established to ensure the protection of human subjects in research. Thank you for your cooperation with the IRB process.

COMMITTEE FOR THE PROTECTION OF HUMAN SUBJECTS • RESEARCH COMPLIANCE SERVICES
677 E. 12th Ave., Suite 500, 5237 University of Oregon, Eugene OR 97401-5237
T 541-346-2510 F 541-346-5138 http://rcs.uoregon.edu

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UNIVERSITY OF OREGON

Sincerely,

Daniel Berman
Research Compliance Administrator

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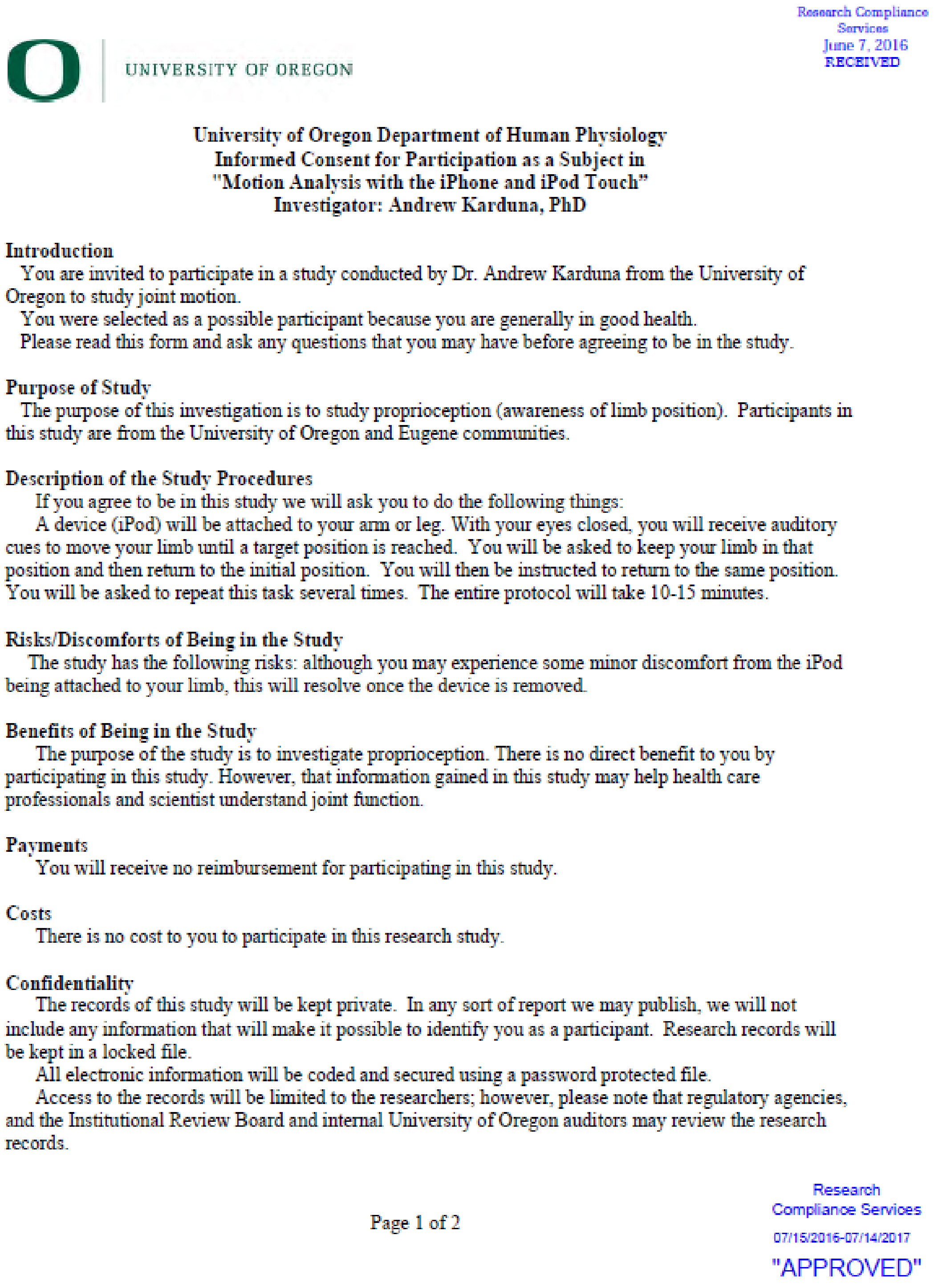
Consent Form



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University of Oregon Department of Human Physiology
Informed Consent for Participation as a Subject in
"Motion Analysis with the iPhone and iPod Touch"
Investigator: Andrew Karduna, PhD

Introduction

You are invited to participate in a study conducted by Dr. Andrew Karduna from the University of Oregon to study joint motion.

You were selected as a possible participant because you are generally in good health.

Please read this form and ask any questions that you may have before agreeing to be in the study.

Purpose of Study

The purpose of this investigation is to study proprioception (awareness of limb position). Participants in this study are from the University of Oregon and Eugene communities.

Description of the Study Procedures

If you agree to be in this study we will ask you to do the following things:

A device (iPod) will be attached to your arm or leg. With your eyes closed, you will receive auditory cues to move your limb until a target position is reached. You will be asked to keep your limb in that position and then return to the initial position. You will then be instructed to return to the same position. You will be asked to repeat this task several times. The entire protocol will take 10-15 minutes.

Risks/Discomforts of Being in the Study

The study has the following risks: although you may experience some minor discomfort from the iPod being attached to your limb, this will resolve once the device is removed.

Benefits of Being in the Study

The purpose of the study is to investigate proprioception. There is no direct benefit to you by participating in this study. However, that information gained in this study may help health care professionals and scientist understand joint function.

Payments

You will receive no reimbursement for participating in this study.

Costs

There is no cost to you to participate in this research study.

Confidentiality

The records of this study will be kept private. In any sort of report we may publish, we will not include any information that will make it possible to identify you as a participant. Research records will be kept in a locked file.

All electronic information will be coded and secured using a password protected file.

Access to the records will be limited to the researchers; however, please note that regulatory agencies, and the Institutional Review Board and internal University of Oregon auditors may review the research records.

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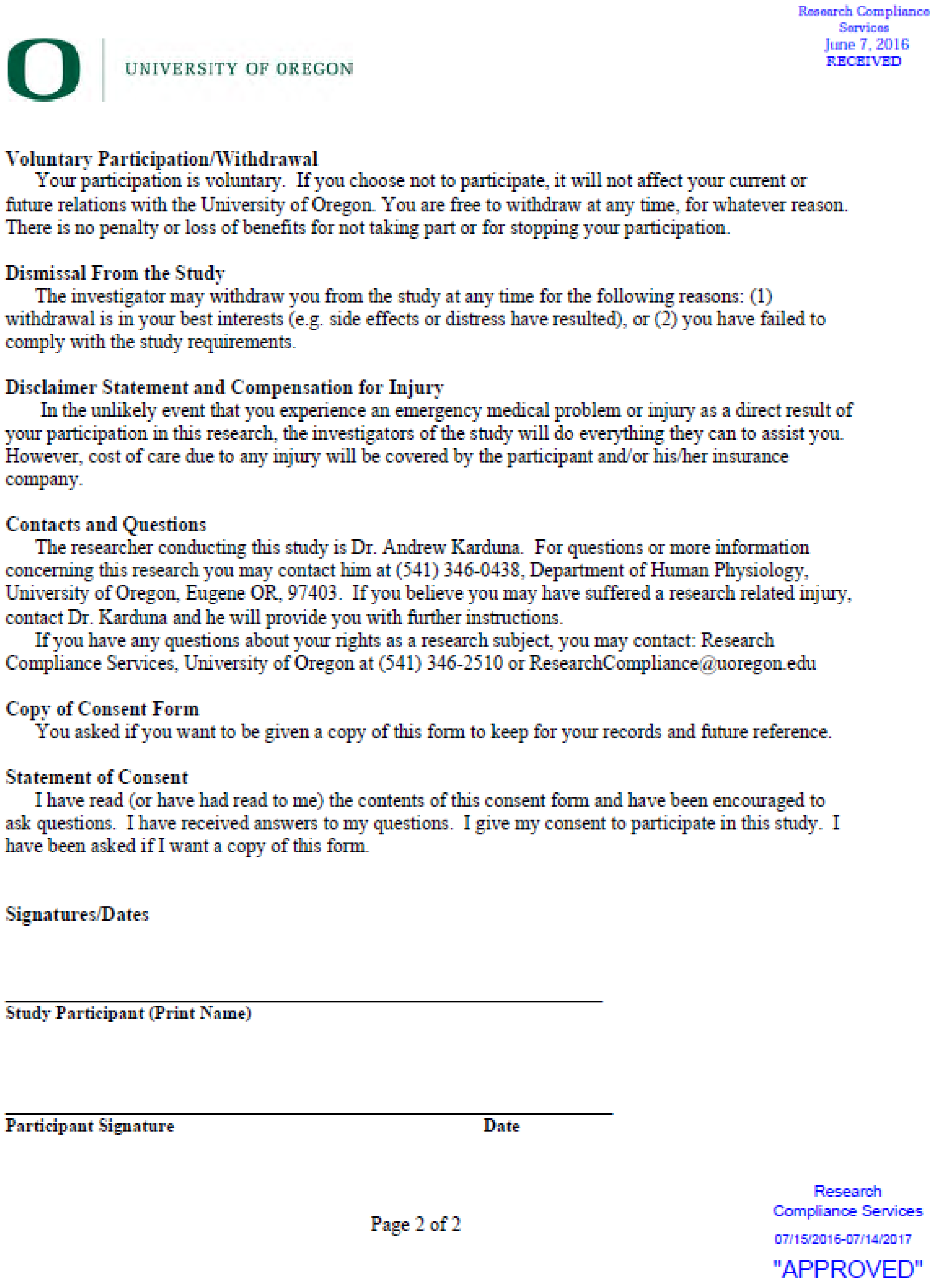

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Voluntary Participation/Withdrawal

Your participation is voluntary. If you choose not to participate, it will not affect your current or future relations with the University of Oregon. You are free to withdraw at any time, for whatever reason. There is no penalty or loss of benefits for not taking part or for stopping your participation.

Dismissal From the Study

The investigator may withdraw you from the study at any time for the following reasons: (1) withdrawal is in your best interests (e.g. side effects or distress have resulted), or (2) you have failed to comply with the study requirements.

Disclaimer Statement and Compensation for Injury

In the unlikely event that you experience an emergency medical problem or injury as a direct result of your participation in this research, the investigators of the study will do everything they can to assist you. However, cost of care due to any injury will be covered by the participant and/or his/her insurance company.

Contacts and Questions

The researcher conducting this study is Dr. Andrew Karduna. For questions or more information concerning this research you may contact him at (541) 346-0438, Department of Human Physiology, University of Oregon, Eugene OR, 97403. If you believe you may have suffered a research related injury, contact Dr. Karduna and he will provide you with further instructions.

If you have any questions about your rights as a research subject, you may contact: Research Compliance Services, University of Oregon at (541) 346-2510 or ResearchCompliance@uoregon.edu

Copy of Consent Form

You asked if you want to be given a copy of this form to keep for your records and future reference.

Statement of Consent

I have read (or have had read to me) the contents of this consent form and have been encouraged to ask questions. I have received answers to my questions. I give my consent to participate in this study. I have been asked if I want a copy of this form.

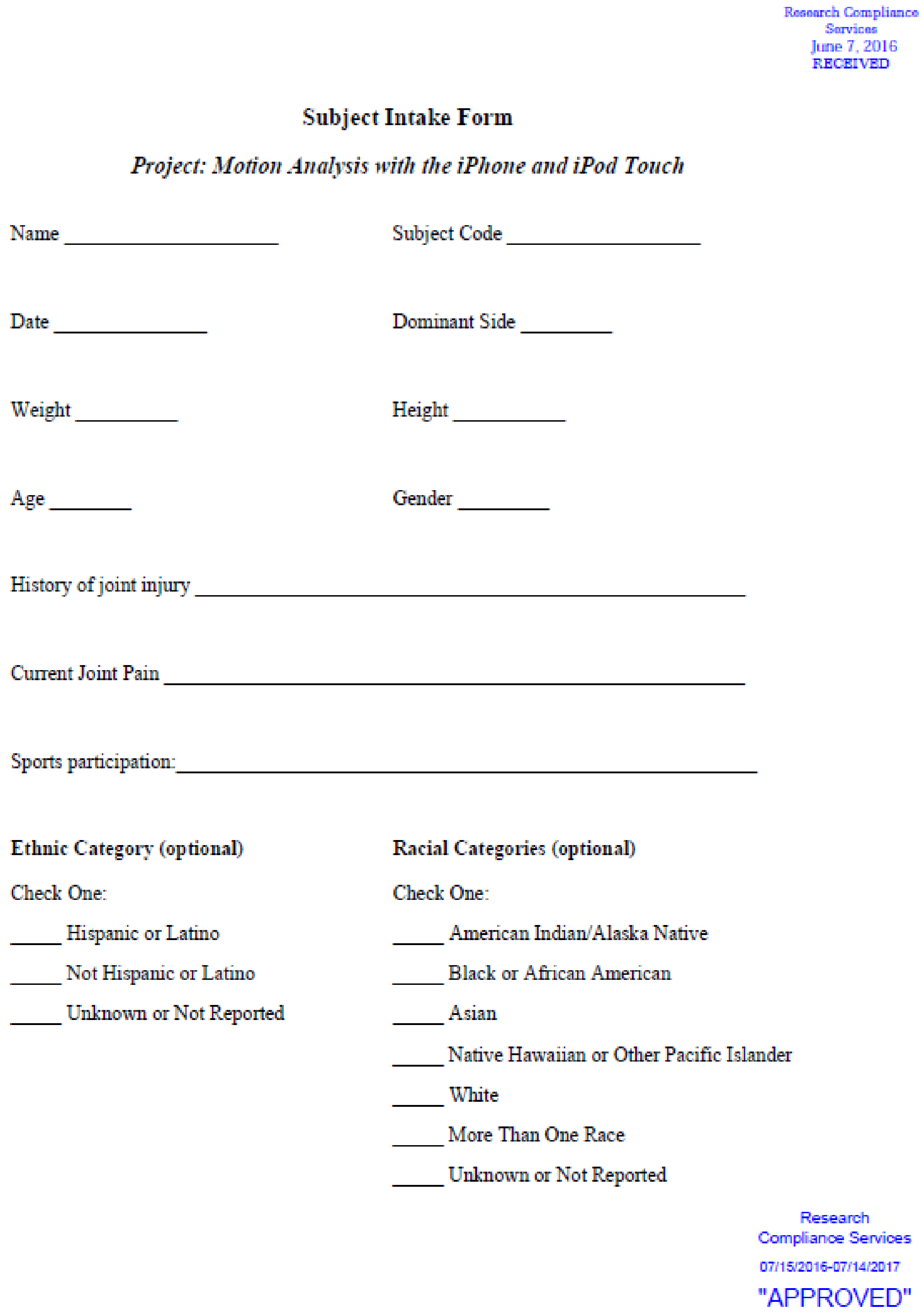
Signatures/Dates

____
Study Participant (Print Name)

____
Participant Signature **Date**

Page 2 of 2

Subject Intake Form



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Subject Intake Form

Project: Motion Analysis with the iPhone and iPod Touch

Name ____________________

Subject Code __________________

Date ______________

Dominant Side ________

Weight _________

Height __________

Age _______

Gender ________

History of joint injury ____

Current Joint Pain ____

Sports participation:____

Ethnic Category (optional)

Check One:

_____ Hispanic or Latino

_____ Not Hispanic or Latino

_____ Unknown or Not Reported

Racial Categories (optional)

Check One:

_____ American Indian/Alaska Native

_____ Black or African American

_____ Asian

_____ Native Hawaiian or Other Pacific Islander

_____ White

_____ More Than One Race

_____ Unknown or Not Reported

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