# MOVEMENT PLANNING AND POSTURAL ADJUSTMENT IN SINGLE AND MULTIPLE STEPS INITIATON

By

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# DEDICATION

I would like to dedicate this project to my family. Thank you for all your love and care during my graduate journey abroad.

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# ABSTRACT

**Background**: This study was designed to identify possible neurological as well as the cognitive factors on how people program their step and stop. Specifically, we use a simple vs choice condition task, which contains 1 to 3 steps under both conditions, to examine the reaction time and anticipatory postural adjustment (APA) phase duration.

**Methods:** Eight healthy young college students (four female, four male) were enrolled in this study. Each of them performed a simple reaction task and a choice reaction task in response to a visual cue. Each task contained situations to take one or several steps. During the test, ground reaction force and position data were collected to further analyze initiation phase latency. Reaction time, release phase, transition time, double support phase, and the total time will be calculated as our dependent variables. Two-way analysis of variance (ANOVA) with Tukey HSD post hoc testing was used to analyze data.

**Results:** Between simple reaction task and choice reaction task, choice reaction task required significantly longer time to finish in reaction and release phase. However, simple reaction task required significantly longer time to finish in transition and double support phase. Number of steps did not affect reaction time, but release, transition and double support phase were significantly affected by number of steps. Specifically, multiple steps task required more time to perform on release and transition, but single step task required more time on double support phase. All four types of APAs were significantly different from each other with an ascending trend from Correct Trials to Multiple Error Trials in release phase. Transition phase had a descending trend with multiple error trials took the least time to finish.

**Conclusion:** In choice reaction task, planning two or three steps ahead cost more time to initiate compared to planning one step. Single step stepping task evaluation period is an online process with program of "stop" actually occurred during double support phase. Error trials tended to have a compensation effect which means durations after release phase had a descending trend with multiple error trial took the least time to complete.

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# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Falls in the elderly are importantly linked to attention and decision making, so understanding how people program their step and stop during gait initiation will identify the mechanisms responsible for falls and will help to make rehabilitation plans towards neural impairment patient.

Falls are the leading cause of injury-related visits to emergency departments especially among seniors [1-4] and a rapid grasp for external support or a quick step, which serves as postural adjustment to restore center of mass (COM) equilibrium, after loss of balance are broadly accepted as a critical motor skill to prevent a fall from occurring [1-3, 5, 6]. Basically speaking, a fall could happen in two conditions: under static conditions and under dynamic situations. Under static condition, to compensate for a postural perturbation, voluntary stepping may serve an important stabilizing role in light perturbations. Therefore, the speed of voluntary step initiation has been considered as an important predictor for fall detection among the elderly population [6, 7]. Apart from that, falls under dynamic conditions are actually more closed to our real life and the loss of balance at this point usually took place when people came into some urgent situations, such as a running person stepped onto a barrier he did not noticed or a walking person was tripped by a stair. Those situations above still require a quick voluntary step as a key strategy to prevent falls. However, there exists another situation which is also dynamic but focuses more on how to stop instead of how to make a quick step and this situation reflects how decision making affects our balance. An example of this could be best described as a dog running into your way when you are jogging. You predicted and programmed your step trying to

make a stop to avoid the dog and loss of balance just happened at this time point. The purpose to make a stop is to decelerate the speed of COM movement and thus a delayed response to make a stop or a delayed initiation of a voluntary step may well be a marker of increased risk of falling [1]. This delay is a reflect of preparation errors which is caused by failures of response inhibition [3] and it mostly happens when different motor tasks are prepared simultaneously and this turned out to be a burden as central processing factors and attentional capacity are important limitations for postural reactions[1, 8, 9]. Therefore, from the above two situations, we believe a quick voluntary step and an appropriate execution of stop are both significantly important in minimizing the risk of falls. And in order to identify how step and stop are related to falls we need to understand when people program their step and stop when initiating a step or gait.

Based on center of pressure (COP) displacement pattern step or gait initiation can be divided into 3 phases: (1) the reaction phase, (2) the preparatory phase and (3) the stepping phase. Each of these phases are dominated, although not exclusively, by different physiological processes and contains several small time periods (Fig.1). The reaction phase is mainly dependent on peripheral sensory detection and lasts from the stimulus delivery to the onset of COP deviation. During the preparatory phase, APA are executed and can be subdivided into two stages: (i) from the COP onset until the furthest point of postero-lateral COP (MaxCOP) is named as release stage, (ii) and after release comes to the unloading stage which is from the MaxCop to the swing foot toe off (SWTO) the ground. Finally, the stepping phase is mainly dependent on neuro-motor mechanisms related to the build-up of muscle force and power to execute the step. Stepping phase also contains two parts, (i) the single support phase (SSP) lasts from the SWTO to the swing foot initial contact (SWIC) on the ground; (ii) the double support phase (DSP) lasts from the SWIC to the stance foot toe off ground (STTO) [5, 9-14]. In our

study, Reaction phase, Release phase and DSP phase alone are first three dependent variables and unloading plus SSP phase together as another dependent variable. We called the combined phase as transition phase, which shows the duration from COP starts moving after MaxCOP ends until finish of SSP. The reason why we combined SSP into unloading is that we assume the stimulus evaluation process happened at most of the release phase and probably a little part of RT phase. So SSP act more like the start of execution process of the former evaluation and unloading phase act as a preparation of execution process. And they all contains weight shift during these two phases.

**1.2 Statement of the Problem**

The programming for step and walk both happened before movement execution and studies have found that a decrease in single leg postural stability will influence parameters of normal gait, but did not, however, significantly change kinetic or temporal characteristics of initiation, confirmed that step and gait initiation are pre-programmed [15]. But one step, as we assume, contains step and stop, which is two different motor tasks both have the control of cognitive part involved, however, step and walk shares the same part as step but differentiates in walk as walking is controlled lower in spinal cord. So, this study was to investigate the influence of stop on reaction time and the time of following initiation phases. Also, we are interested in examining the effect of task complexity (simple and choice, one step through three steps) on people's APA patterns and how these different APA patterns related to the reaction time. Specifically, the experiment mainly attempted to answer the following questions:

1. Does initiation of one step differentiate in initiation time compared to the initiation of three steps?

2. At what time phase does people program stop when they are performing an already known task?
3. Will the task complexity (simple and choice, one step through three steps) affect initiation time, if not, what is the effect of choice stepping task on gait initiation?
4. In choice stepping task, how does the number of error APAs affect the initiation time?

**1.3 Purpose of the Study**

Due to the vacancy of studies evaluating the different initiation patterns comparing the initiation of one step and gait, this study was designed to identify possible neurological as well as the cognitive factors on how people program their step and stop. Specifically, we use a simple vs choice condition task, which contains 1 to 3 steps under both conditions, to examine the reaction time and APA phase duration. Given the well warranted evidence that step and gait are both central pre-programmed before initiation, we assume that step and stop (one step) will show parameters unlike step and walk (two or three steps).

**1.4 Delimitations**

This study was delimited to:

1. 8 Male and female college-age participants, aged from 18-24 years old, from the Bloomington, Indiana.
2. The Indiana University Neuro-Motor control laboratory's gait and step analysis apparatus.
3. Five dependent variables including reaction time, releasing time, transition time, DSP time, and total time from stimulus to the end of DSP.

4. Several independent variables including stepping task (simple or choice), number of steps (one or two or three), and in CRT task we define the types of APA also as independent (none, posterior shift, 1, 2).
5. Two tasks we performed as simple and choice reaction time task.
6. Data analysis including two-way analysis of variance (ANOVA) with repeated experiment design.

### 1.5 Assumptions

The study was conducted under the following assumptions:

1. The participants were representative of male and female adults with normal reaction time in college students group.
2. The subjects did not anticipate any upcoming stimulus and reacted in advance.
3. The participants were motivated to perform at their best condition during each collecting sessions.
4. The 5 trials of each condition in simple reaction task and 10 trials in choice reaction task provide sufficient practice for all subjects to totally get used to the task procedure and without any learning effect.

### 1.6 Hypotheses

This study contains two stepping tasks and the following null hypotheses were tested in both tasks as a whole group:

1. There were no significant differences between SRT and CRT as main effect in reaction time, release phase, transition time, DSP phase and the total time.

2. There were no significant differences among number of steps as main effect in reaction time, release phase, transition time, DSP phase and the total time.
3. There were no significant differences between either two of the fix factors as interaction effect in reaction time, release phase, transition time, DSP phase and the total time.

The following null hypotheses were only tested in CRT group:

1. There were no significant differences among types of APAs as main effect in reaction time, release phase, transition time, DSP phase and the total time.
2. There were no significant differences between types of APAs and any one of the fixed factors as interaction effect in reaction time, release phase, transition time, DSP phase and the total time.

**1.7 Definitions of terms**

The following terms used in this study were defined to clarify their use:

Center of Mass (COM): In this study the COM refers to the human body COM, it is the point that summation of the positive torques of individual body segments relative to a specified axis equals the torque of the integral of the negative torques relative to the same axis and they cancel each other.

Center of Pressure (COP): COP is the point of application of the ground reaction force vector. In this study, COP was gathered through force plate and we use COP patterns to reflect human body postural adjustment.

Anticipatory Postural Adjustment (APA): APA refers to the changes of postural control related to voluntary movement but happened prior to the onset of movement. The correct APAs

appear as the postero-laterally weight transfer towards the swing foot preceding a step and error APAs appears as the postero-laterally weight transfer towards the stance foot.

Posterior Shift (PS): Unlike either the APA correct condition or the APA error condition, the COP trajectory reflects direct posterior shift before turning toward the swing leg.

Stimulus: The stimulus used in this study was a visual cue with six red blocks marking the target area on the ground that subjects need to step on with their corresponding foot.

Foreperiod: A foreperiod is the time between the presentation of the warning signal by experimenters and the presentation of the stimulus. In this study, the foreperiod varies from 2-5 seconds.

Reaction Time: The interval between the presentation of a stimulus and the initiation of a response. Specifically, in our experiment, we use the speed of COP greater than 3 standard deviations from the baseline value as the cutoff of initiation of a response.

Simple Reaction Time (SRT) task: SRT task refers to a stepping task varies from one step to three steps. In SRT task, the subjects were informed about how many steps they need to perform and which leg they need to use to initiate before each testing block.

Choice Reaction Time (CRT) task: CRT task also refers to a stepping task varies from one step to three steps, however in CRT the subjects had to perform the specific task as the visual cue informed and the six different visual cues will be randomly generated by the computer.

# CHAPTER 2

# REVIEW OF THE LITERATURE

Due to the vacancy of studies evaluating the different initiation patterns comparing the initiation of one step and gait, this study was designed to identify possible neurological as well as the cognitive factors on how people program their step and stop. Specifically, we use a simple vs choice condition task, which contains 1 to 3 steps under both conditions, to examine the reaction time and APA phase duration. Gait initiation has been widely investigated to understand human gait patterns, and simple vs choice stepping task were frequently used in those studies as an independent variable. Currently, researchers' focuses has extended to using gait initiation knowledge to further understand neurological deficits and to detect risks of fall.

For this review, relevant information in this area is demonstrated in the following order:

I. Step and Gait Initiation Patterns and Ways to Explore it.

II. Human Information Processing: SRT vs CRT.

III. Response Planning and Fall Prevention.

IV. Summary

## 2.1 Step and Gait Initiation Patterns and Ways to explore it

### 2.1.1 Muscle Activity during Initiation

Step and Gait is the result of the integration of biomechanical, neuro-physiological and motor control actions [16] and they are the most common things people do every day without too much attention on it. Part of the reason could be that only the initiation component may require cognitive control, which means after people step into walking phase, this motor task will be

modulated by spinal cord. And this is why most of the research work was focusing on the initiation part. But for an SRT task, the process is still a stereotypical and unconsidered transition from stance into walking, with a consistent pattern of muscle activity [17, 18]. The activation of muscle follows a certain sequence and every motor program can be defined as a synthesis of different orders of muscle activation concerning different goals of task [19, 20]. Specifically, for step and gait, Crenna and Frigo [21] comparing gait initiation and taking one step forward to investigate the interaction between the anterior and posterior leg muscles and their pattern of inhibition and facilitation and they found both of the two tasks began with inhibition of tonic soleus (S1) activity followed by the onset of tibialis anterior (TA) of the swing leg [20], although stance leg tibialis anterior onset has been shown to precede that for the swing leg [22]. Also, in gait initiation, Burleigh [23] et al and Elble [18] et al both reported a tendency for continued firing of medial gastrocnemius throughout onset of gait initiation, especially in the swing leg and a failure of medial gastrocnemius to be consistently inhibited at gait initiation onset has been shown to be more common in elderly people [24]. These muscle activities serve as generator of horizontal ground reaction force (GRF) which moves the COP posterolaterally towards the swing foot at first and then rapidly across to the stance foot and finally moves anteriorly under the initial stance limb [18, 25]. This kind of COP shift before COM moving forward is known as the body APA and APA is a significant way to explore and exploit how people program a step under various situations.

### 2.1.2 APA Changes during Initiation

APAs are basically defined as changes in postural control related to voluntary movements and they appear prior to the onset of the movement [3, 4, 26]. MacKinnon et al in 2007 [9] using a startle-like acoustic stimulus (SAS) and transcranial magnetic stimulation (TMS) to examine

the preparation of APAs before forward stepping. In thir findings they stated that APAs generate ground reaction forces (GRFs) that move the COP beneath the feet posteriorly and toward the initial swing limb. This sequence of activity produces the forces and moments necessary to propel the body forward and then toward the single-stance limb for the regulation of whole body balance and posture before and during initiation of the voluntary step. They also found there was an initial phase that helps the person to progressively assemble the sequence of APA and that this early preparation did not involve the corticomotor pathways activated by TMS.

Sun et al [14] recently reviewed the effects of choice on the temporal characteristic of step initiation. They use an audio stimulus with high pitch and low pitch to differentiate two stepping task. They found the evaluation process of making a response continued in APA phase and the posterior shift pattern was identified as a typical postural sway to initiate a fast step.

St George, Melzer, and Mancini [2, 27, 28] tested the time of APA using a choice vs simple reaction task and found APAs associated with step initiation have durations of several hundred milliseconds and can be easily collected through force plates under the feet. Previous studies have found APA as a marker of preparatory movement during step initiation [3, 11] and it is believed to act as stabilizing posture and generating initial momentum needed to start walking. This momentum purposefully uncouple the movement of the COM and COP and counter the perturbation associated with the forthcoming voluntary movement in advance [12, 29].

Jacobs and Horak [30] in 2007 examined the APA situations when subjects cannot pre-select their stepping foot. They choose a predictable condition (subjects knew whether they were to step with their left or right foot) vs unpredictable condition (subjects did not know whether to step with their left or right until targets onset) strategy to see how APA changes under

perturbations. They discovered that subjects either tend to have multiple APAs under unpredictable conditions or only one APA but step with the incorrect leg. Their findings suggest that when people had to select a stepping leg at perturbation onset, they either became more unstable and used multiple APAs to delay stepping in order to provide enough time to select the correct stepping leg, or they stepped earlier to remain stable but often stepped with the incorrect leg.

Another component that contributes to the delay of stepping might be inhibition deficits. Inhibition can be understood as attention creates a focus on some information or action to the exclusion of others. It plays a major role in maintaining postural control, particularly in older adults and elderly people step initiation parameters may provide a robust method for assessing the role of inhibitory function in the control of posture [1, 4, 31]. Patrick [4] and his colleague conducted three groups of experiments, which contains perceptual inhibition and motor inhibition under congruous and incongruous conditions, eager to investigate the role of inhibition during lateral step initiation. In their findings, they stated that delays in onset of the first postural adjustment (PA1) and liftoff (LO) of the step leg during preferred steps progressively increased among the simple, choice, congruous, and incongruous tasks and they also found the onset of PA1 during non-preferred steps was earlier than during the preferred steps. Therefore, they stated that deficits in inhibitory function may detrimentally affect step decision processing, by delaying voluntary step responses.

## 2.2 Human Information Processing: SRT vs CRT.

### 2.2.1 Human Information Processing Model.

Human information processing can be understood as a computer metaphor. In this metaphor, people take in information from outside sources just as a computer takes in

information via input devices. The information then undergoes a transformation process and finally stored in memory, which is similar to how a computer processing the input message. After that, the information will be gathered together with some other information and can result in various kinds of movement, just like a computer displays the results as an output [32].

The basic information processing model is actually as simple as a "black box" model (Fig. 2) and every individual was considered in the black box. Interest of investigating the "black box" was then developed among researchers and the most common approach studying this is to test the latency of these various processing stages in the black box. This chronometric approach [32] introduced Reaction time (RT) into people's sight, which became a chief measure of the subject's processing time between stimulus presentation and onset of human movement.

The information-processing model trying to specify different stages beneath the black box can be traced back to the 1860s when Franciscus C. Donders (1868/1969) studied mental activity in terms of stages of processing between the stimulus and response. Using a subtractive method, Donders was trying to estimate the duration of different information stages involved in stimulus discrimination and response selection. Although flaws were latterly detected, Donders thinking still inspired research work on mental processing and served as the foundation for modern analyses of human information processing.

After Donders' theory, several other researchers examined the fractional reaction time between stimulus onset and start of human motion, which trying to clarify details of the stages in black box. Among them, Marteniuk's [33] feedback model, which included a perceptual mechanism, a decision mechanism and an effector mechanism, and Sanders'[34] seven-stage information-processing model, which subdivided perceptual, decision, and motor stages into

several small timing period, aroused researcher' attention and interest to look into the details of processing period.

Finally, Schmidt and Lee's [32] three-stage information-processing model (Fig.3) became widely accepted as it is simple and clear. In this three stage model, the black box contains stimulus identification, response selection, and response programming periods. Stimulus identification period is for subjects to detect stimulus and recognize stimulus patterns by comparing it to those stored in human memory. For many fast-action sports, the speed of recognizing a specific stimulus pattern accurately is a highly trained skill. During response selection period, there are several factors that will contribute to the duration of this stage which are number of stimulus-response alternatives, stimulus response compatibility (S-R compatibility), and response complexity [32]. S-R compatibility means the stimulus and response have the same orientation or pattern and incompatibility of stimulus and response will always lead to extra processing time. For example, a left arrow stands for a right-hand response and a right arrow indicates a left-hand movement. The S-R incompatibility was used in this experiment as the second step on the right indicates using left foot to initiate and vice versa. Lastly, response programming period was directly influenced by numbers of movement parts, movement accuracy and movement duration. And the above three areas can be synthesized as response complexity. So, honestly, response selection and response programming has some overlapping area and these two factors also contribute most on the initiation time.

### 2.2.2 Reaction Time: SRT Vs CRT

Reaction time was considered as a potentially useful physical way to analyze mental activity since the mid-nineteenth century and it means the time from the onset of stimulus to the initiation of a response. Reaction time is an important dependent variable in the study of human

behavior, especially in the psychomotor domain [35]. It can be subdivided into two parts: simple reaction time and choice reaction time.

Simple reaction time refers to a motor task which the subjects were informed of what they need to perform before each trial. And it is just the time to execute the pre-programed the motor task without any decisions to make after the stimulus onset. In simple reaction time task, subjects' reaction time serves as base line level of a specific motor task and will be used to compare to the choice reaction time.

Choice reaction time refers to a task in which the subjects had to perform the specific movement as the cue informed and subjects will get no information about what is about to coming until the signal cue. The different point compared to SRT is on each trial, subjects had to figure out the correct motor task they need to do and the increased reaction time for CRT task has been revealed to be related to aging issues [3]. Many factors, such as aging, fatigue, exercise training, and stress can affect choice reaction time [35] and besides those subject self-effect, choice reaction time are also affected by the number of stimulus-response (S-R) alternatives. Generally speaking, S-R alternatives choice reaction time increased as the number of S-R alternative increased because the processing of information relevant to the selection of a response requires more time when the number of possible alternatives is larger.

Lord and Fitzpatrick [7] in 2001studied the choice stepping reaction time as a measure of fall risks in older people. Using a CSRT test, which required subjects to step onto one of four panels that were illuminated in a random order, they compared the results between young group and elderly people and investigated the correlation between fall risks and increased CRT reaction time. Totally speaking, a significant delay in choice stepping task among elderly people were found and regression analysis showed slow CSRT was the strongest predictor of falls from an

extensive range of neuropsychological, sensorimotor, and balance measures, which suggests that impaired voluntary stepping may contribute in many falls. Apart from that, Pijnappels and Delbaere [36] in 2010 confirmed the former finding, they discovered that compared to non-fallers, fallers have reduced lower limb strength, slow voluntary reaction time and reduced sensory acuity and balance. Evidence has showed that slow reaction time was independently discriminate between elderly people who have and have not fallen [37].

**2.3 Response Planning and Fall Prevention**

Falls are the leading cause of injury-related visits to emergency departments [1, 2]. Evidence have showed that a rapid step is an important protective postural strategy since it can prevent a fall from occurring [2, 5, 27, 38, 39]. Also voluntary movements impose perturbation of postural and our body APAs are initiated to compensate for these perturbations [21, 40]. However, in real world, people's reaction speed is always affected by different response alternative, which means choice and decision delays the time to make a quick step and let alone to make the correct choice. Incorrect response always lead to postural instability and to avoid a fall, perception of a postural threat is required at the first time and then people had to select an appropriate corrective response and execute the response properly [41]. That is why decision making is so crucial on fall prevention; in other words, people's response planning strategy plays a major role in taking a quick step. The normal response to initiate a forward step is to first shift bodyweight laterally to the stepping foot and then transfer the COP to the stance foot to lift the stepping foot and make a step [9, 10, 24]. Since situations in real world are more complex and changeable, people always facing several choices when they need to initiate a quick step and these additional cognitive load finally turns out to be a freezing of gait and fall. Most of the issues were occurred among elderly and clinical population.

In 2007, St George [2] et al examined the effect of age, fall risks and dual task on choice stepping response. They divided the subjects into three groups which are young group, older person with a low risk of falls and older person with a high risk of falls. Four different stepping tasks were performed considering choice stepping with or without obstacle and a secondary working memory task. From the results, they confirmed that compared with young people, older people have an impaired ability to initiate and execute quick accurate voluntary steps, especially under circumstance that a secondary task was performed simultaneously.

Falls are a common and serious problem among Parkinson's disease (PD). Multiple studies have shown that 35 – 90 % of PD patients suffered from falling and difficulties with step and gait initiation are characteristics of PD, which have been identified as big risk factors for future fall occurrence. Patients often exhibit Freezing of Gait when attempting to begin walking or turning [42]. Several studies among the Parkinson's disease have been done by Bloem et al to investigate freezing of gait [39, 42]. They found step initiation represents a significant transition that is highly related to falls, during which patients with PD exhibit failure to make a step.

Rudzinska [43] in 2008 tested one hundred and four patients with moderately advanced PD and reported that environmental factor leaded postural instability were the most common one. For the reasons why PD patients suffered falls that much, Hass [44] and his colleague examined changes in the translation of the center of pressure during forward and lateral (90 degrees to the side) gait initiation in two populations of older adults with postural instability. They detected an inefficient postural adjustments occurred more severely among aging people with PD and their postural adjustments are more counterproductive to producing enough force to initiate a step.

## 2.4 Summary

Falls are a common issue with elderly people particularly among the clinical population. Studies have shown that falls can be prevented efficiently by making a quick step or grasp for external support. Thus, understand the programming of step and gait initiation will identify the mechanisms responsible for falls. Choice stepping task has been reported as a valid measure to examine whether people are able to initiate a quick and correct step under various situations. Specifically, by analyzing the APA patterns of different stepping tasks we will gain a better understanding about how people react to an unknown stimulus and how they program their response to make a proper step or stop.

# CHAPTER 3

# METHODOLOGY

## 3.1 Participants

Eight healthy young college students (four females, four males) were enrolled in this study (Table.1). All subjects are physically healthy which is defined as a person who does not have a history of orthopedic injury, musculoskeletal, vestibular, neurological disorders or stroke according to self-report. Subjects were recruited from the School of Public Health fitness specialist courses as well as the motor learning course and were all between 18 to 24 years old.

All subjects will be given an informed consent form prior to participating in any testing and this study was approved by the Institutional Review Board of Indiana University for the protection of human subjects.

## 3.2 Experiment Equipment

The eight camera Qualisys motion capture system will be used to gather position data from passive reflective markers on each participant's lower limbs and ankles.

Two force plates will be used to analyze the shift of center of pressure.

A pressure mat was put on top of the first force plate to monitor the balance conditions prior to initiate a step.

An HD screen will be used to show instruction of stepping and walking corresponding to different testing phases.

Four wooden boards were built connected to the second force plate as a walking platform that allows the subjects to take several steps on them.

### 3.3 Task Design and Procedure

This study is a laboratory experiment based quantitative study aims to build models for analyzing initiation parameters in step and walk. And within subjects repeated measures design will be used in this study.

Before testing, subjects will complete a medical history questionnaire and the informed consent form. Subjects will be asked to dress in shorts in order to expose their lower limbs; after that, 12 reflective markers will be used to label different components of lower limbs. All participants in this study will perform step and walk in two phases: simple reaction time task (SRT) and choice reaction time task (CRT). In the SRT task phase, subjects will conduct 6 different blocks described as: Block 1 (L1) asks the participants to take one step ahead which initiate and land both with left foot; Block 2 (L2) asks the participants to take two steps ahead which use right foot to initiate but finally land with left foot; Block 3 (L3) asks the participants to take three steps ahead which, like L1, use left foot both to initiate and land; Block 4 (R1) asks the participants to take one step ahead which initiate and land both with right foot; Block 5 (R2) asks the participants to take two steps ahead which use left foot to initiate but finally land with right foot; Block 6 (R3) asks the participants to take three steps ahead which, like R1, use right foot both to initiate and land. Each block contains 5 practice trials to get the subjects familiar with the task in this block and 10 regular trials to record the data. In each trial, subjects were instructed to stand upright without shoes on the first force plate with two feet 25cm apart. To ensure the consistent stance and initiation position of each trial, two small rectangular marks were taped on the force plate to let the subjects' feet aligned within the two boxes. During the entire trial, subjects looked straight ahead with eyes fixing on screen placed 4 meters ahead at eye level (Fig.4) Subjects were told to maintain the balance before any stimulation occurs and

the position of center of pressure generated by pressure mat was used to decide whether the subjects are balanced and once the center of pressure are stable, the experimenter will tell the subjects to get ready to the upcoming stimuli displayed on the screen as a visual cue. This visual cue displayed on the screen has six white squares with three on each side suggesting one to three steps ahead of the subjects and every time one of the six squares will become red indicating the subjects has to land on that square (e.g. The second square one the left (L2) becomes red means the subject should initiate with right foot so that he or she can land with left foot at the second step) (Fig.5). After a warning signal and a random foreperiod between 2-5 seconds, subjects will receive this visual cue and then perform the task corresponding to the visual cue as quickly as possible. The visual cue remained on the screen during the entire trial and data collection lasted 10 seconds. In the SRT condition, the subjects were informed that a specific block will be record in the next 10 trials, which means the subjects knows what the visual cue will be showed up on the screen and knows the specific foot he will use to initiate and land in advance. The CRT condition and SRT condition shares the same setup and preparation process, but in the CRT phase, there is only one block that contains all 60 trials. Those 6 different initiation and landing conditions vary from L1 to L3 and R1 to R3 will randomly split these 60 trials, so technically, there are still approximately 10 trials for each condition. In CRT phase, the participants were informed that, during each trial, the visual cue was equally likely to signal all these six conditions so the subjects had to figure out what is the corrected foot to initiate after the stimuli showed up. The order of the six blocks testing in SRT condition was randomly chosen and counterbalanced with every participant. Subjects sat and rested for 5 minutes every 2 blocks in SRT phase and every 20 trials in CRT condition.

### 3.4 Data Acquisition and Analysis

A Tekscan HR MAT Pressure Mat (Tekscan Inc.) was placed on the first force plate (AMTI). This pressure mat as stated above allowed the experimenter to monitor the weight distribution under the feet and ensure that with no more than 51% of weight on either foot before generate any stimulation [3].

All ground reaction forces (GRFs) and moments will be collected through two AMTI force plates (OR-6-7000, Advanced Mechanical Technology.Inc, MA, USA) at 1000 Hz and COP data will be derived from the forces and moments [14]. COP and force data will be low pass filtered at 50Hz.

A Qualisys motion tracking system (Qualisys AB, Sweden) will be used to gather position data from 24 passive reflective markers on the subject's trunk, head and limbs. The motion tracking data will be sampled at 100 Hz.

The visual stimulus will be delivered and synced with the motion tracking system through a customized MATLAB (MathWorks.Inc.) program with Psychtoolbox.

Fractional timing of step initiation was calculated for each trial from the COP data [10]. The subjects' movement onset was defined as when COP velocity was greater than 3 standard deviations from the baseline value calculated from the stance period before stimulus onset [9]. Also, from the COP data, several key time points were identified and described as below: (1) MaxCOP time point was named as the point when maximum lateral COP shift towards the swing leg was reached; (2) SWTO time point was defined as the end time of the COP mediolateral shift toward the stance leg; (3) SWIC time point was determined using the obvious increase of ground reaction force on the second force plate because the weight of swing leg has shifted on the second force plate now and (4) STTO time point was the last one which represents the point

when ground reaction force under the first force plate dropped below 10 N level. All the key time point and the period between them were calculated through a customized code written in Matlab.

### 3.5 Statistical Analysis

#### 3.5.1 Data cleaning

The Qualisys Motion Capture system gathered all reflective markers' data and the COP data from force plate will also be transported into Qualisys. A matlab file that contains all the kinetic and kinematic data will then be generated and this is how we access our raw data for each subject. Before analyzing data, we excluded trials based on the following criteria: (1) the movement onset (initiation of APA) was sooner than 100 ms after the visual cue showed up [3], (2) failed to step within 1000 ms after the visual cue showed up, (3) initiated with wrong foot as of the visual cue indicated. After eliminating the abnormal trials, there are 920 trials (470 CRT, 450 SRT) left in total, on average 115 trials per person (out of 120).

#### 3.5.2 Data Analysis

COP displacement, velocity and acceleration will be calculated to further determine the MaxCOP, SWTO, SWIC, and STTO. And then reaction time, release phase, transition time, DSP phase, and the total time will be calculated as our dependent variables. For analysis, a two-way analysis of variance (ANOVA) with the repeated measures design was firstly performed with all subjects and conditions together on each dependent variable, in which stepping task (SRT vs CRT) and number of steps were set as fixed factors and subjects as random factor. After that, to determine how APA responses affected the timing of each step initiation phase, another two-way analysis of variance (ANOVA) was performed only in the CRT group on each dependent variable as we assume the SRT data should not contain enough multiple APA trial. This time we define APA patterns, number of steps, and initiating leg as fixed factors. We also use the post

hoc testing (Tukey HSD) to further investigate how the specific numbers of steps and role of different APA types affect the timing of each stepping initiation phase. Effect size will be examined using Partial Eta Squared ($\eta^2$). A priori Alpha level was set at $p<.05$ for all analyses.

# CHAPTER 4

# RESULTS

All 8 participants completed 120 trials as the requirements informed so we have 960 trials in total. Based on our experimental settings and former studies on SRT and CRT tasks, we excluded 6 errors stepping trials and 34 outliers (22 late reaction trials and 12 anticipatory trials). Also, as all the SRT trials were determined as correct trials, we excluded 27 posterior shift trials in the SRT task. All the data analysis work was based on the left 893 trials (423 SRT, 470 CRT). For different number of steps, Mean and Standard Deviation of the duration in each stepping stage are summarized in Table.2. We examined the COP spatial evolution during CRT task and identified four different COP patterns:

1) Correct APA Trial (CT): COP moves backward and towards the initial swing limb, then cross over to the stance foot;
2) Posterior Shift Trial (PST): COP moves backward for a relatively longer time than Correct Trial which is at least 50ms prior to lateral COP velocity onset;
3) Error APA Trial (ET): COP initially shifts postero-laterally toward the stance leg, and then turning back to the swing leg;
4) Multiple Error APAs Trial (MET): The shifting direction of COP changes several times (more than one) between swing and stance foot before it reaches MaxCOP. Usually, this happened in multiple steps choice reaction tasks and it is less in number.

Totally, in CRT condition, we identified 220 Correct APA Trial, 129 Posterior Shift Trial, 82 Error APA Trial, and 39 Multiple Error APAs Trial. Table.3 showed the mean and standard deviation of the duration in each stepping stage based on different APA types.

**4.1 Changes in response times induced by stepping task (SRT, CRT) during gait initiation.**

Significant main effects of the two different stepping tasks (SRT, CRT) were found (Fig. 6) on RT, F (1, 880) = 385.0, $p < .001$, $\eta^2 = 0.30$; Release phase, F (1, 880) = 400.83, $p < .001$, $\eta^2 = 0.31$; Transition phase, F (1, 880) = 19.0, $p < .001$, $\eta^2 = 0.02$; DSP phase, F (1, 880) = 9.66, $p < .01$, $\eta^2 = 0.01$. The Total Time of all the 5 stages above was also significant with a 225.4ms quicker response in SRT than CRT, F (1, 880) = 909.1, $p < .001$, $\eta^2 = 0.51$. Among all the significant effects, RT and Release time had a lot longer time durations in CRT than SRT, however, Transition and DSP showed slightly longer durations in SRT. Also, RT, Release and Total Time all had a large effect size, $\eta^2 > 0.26$, compared to the effect size of Transition time and DSP, $\eta^2 < 0.02$. This indicated that more reliable and meaningful time increasing changes in CRT group were caused by RT and Release Time.

**4.2 Changes in response times induced by number of steps (1 to 3) during gait initiation.**

Reaction time was not significantly affected by number of steps, F (2, 880) = 2.12, $p > .05$. Significant main effects of number of steps (1 to 3) were found (Fig.7) on Release Time, F (2, 880) = 60.60, $p < .001$, $\eta^2 = 0.12$; Transition time, F (2, 880) = 27.08, $p < 0.001$, $\eta^2 = 0.06$; DSP phase, F (2, 880) = 250.63, $p < .001$, $\eta^2 = 0.36$; Total time, F (2, 880) = 48.32, $p < 0.001$, $\eta^2 = 0.10$. The Tukey Post Hoc test of number of steps showed significant differences among all dependent variables except RT. These differences were between one step and two or three steps, however, differences between two and three steps were not observed. Notably, among release,

transition and total time, durations of one step was shorter than two or three steps; however DSP phase is remarkably opposite with one step required longer time to finish (Fig.7 (B)).

**4.3 Changes in response times induced by interaction effects.**

The ANOVA evaluating interaction effects of simple vs choice and number of steps revealed significant difference on Release, $F(2, 880) = 26.24$, $p < 0.001$, $\eta^2 = 0.06$; Transition, $F(2, 880) = 8.35$, $p < 0.001$, $\eta^2 = 0.02$; DSP, $F(2, 880) = 19.53$, $p < 0.001$, $\eta^2 = 0.04$; Total time, $F(2, 880) = 27.15$, $p < 0.001$, $\eta^2 = 0.06$. Reaction time was not significantly affected by the interaction effects $F(2, 880) = 0.08$, $p > 0.05$.

**4.4 Changes in response times induced by types of APAs among only CRT groups.**

Fig.8 showed significant differences on Reaction time, $F(2, 880) = 11.16$, $p < 0.001$, $\eta^2 = 0.07$; Release time, $F(2, 880) = 137.79$, $p < 0.001$, $\eta^2 = 0.48$; Transition phase, $F(2, 880) = 17.84$, $p < 0.001$, $\eta^2 = 0.11$; Total time, $F(2, 880) = 39.38$, $p < 0.001$, $\eta^2 = 0.21$. DSP phase was not significantly affected by types of APAs among CRT groups $F(2, 880) = 0.21$, $p > 0.05$, $\eta^2 = 0.01$. Test of Post Hoc for RT showed significant differences between CT and PST ($p < 0.01$), CT and ET ($p < 0.05$), MET and PST ($p < 0.01$), and between MET and ET ($p < 0.05$). As for release time, all four types of APAs are significantly different from each other with an ascending trend from CT to MET. However, transition time in Post Hoc Test has a descending trend from CT to MET, which is opposite from release phase. Homogeneous Subsets indicates that CT and PST are in the same group, but ET and MET are two separate groups. Significance were found between CT and ET ($p < 0.001$), CT and MET ($p < 0.001$), PST and ET ($p < 0.05$), PST and

MET ($p < 0.001$), and between ET and MET ($p < 0.01$). Total time is consistent with release time which also has a rising tendency from CT to MET with significant differences between all four types of APAs.

# CHAPTER 5

# DISCUSSION

This study mainly attempted to figure out how people program their stop by comparing one step initiation and three steps initiation. We are also interested in how task complexity affects different phases of people's initiation time.

From the results we got, SRT and CRT groups showed significant differences all four phases and the total initiation time with CRT group costs 225.4ms longer than SRT. This was consistent with Sun et al study[14] which found RT, Release, Unloading and DSP phase were quite sensitive to additional processing in stimulus evaluation and response selection. Among the four phases, RT and Release phase had pretty large time consuming differences between CRT and SRT with CRT always required longer time to complete than SRT. This can be explained as the very first two parts of initiation phase worked together to figure out what kind of stepping task you will perform. However, unlike RT and Release phase, we found SRT group had longer time duration than CRT group during transition and DSP phases even though the delayed time between SRT and CRT was relatively small and so was the effect size. This indicated that at the finishing part of step initiation, stimulus evaluation of stepping task (simple or choice) might not play a major role any more. The prolonged time in SRT group was probably caused by the shorten of CRT group, which means SRT were still using the normal time to finish Transition and DSP but CRT tend to have a quicker move to shorten the last two phases. This was because our subject were told to react as soon as possible after cue onset so in CRT condition the

cognitive part of our brain, which have already detected that too much time were used in RT and Release to evaluate stepping task, tend to speed up our physical movement to compensate for the former time loss. We defined this as a compensation effect during choice reaction task. And this was consistent with our findings on APA errors during gait initiation.

APAs occurred prior to the onset of human movement and the equilibrium from the movement [3, 26, 45]. The correct APA sequence to prepare a step is to shift body weight laterally onto the initiation foot to get ready to the weight shifting from the stepping leg to the support leg. After that, body weight is shifted to the support leg and we can initiate with our stepping leg to make a step. However, at some situations, weight shift goes to the wrong direction and this must be corrected before initiation and mostly this happened among seniors and choice reaction task. APA is so important because it works to make sure we initiate our step safely, and errors in APA usually cause a loss of balance which may lead to a fall. Choice reaction task is widely used in gait and stepping experiment to trigger error APAs, and in our study we characterized four types of APA in CRT: Correct APA Trial which COP went directly to the stepping foot and then crossover to the support foot; Posterior Shift Trial which the COP neither tended to move right nor left, instead it chose a medial way to move backward; Error APA Trial which COP moved towards support foot first and then corrected itself after some time; Multiple Error APA Trial which COP pattern tended to have two or more correction turning curves (Fig.9) before it moved to the stepping leg. Most MET trials had two errors and only very few of the trials got three. As we have already known that, with one error happened, the person's COP moved to the direction of support leg first so two-error trials should have a pattern with correct initiation direction which is to the stepping leg but mistakenly evaluated the situation and corrected itself to the support leg and then figured out the last correction was wrong

with a changing of direction again to the stepping leg. Interestingly, this was reflected in Fig.10 (A) with CT group and MET group had no significant difference during RT phase but they all had significant difference towards PST and ET. The reason behind it could be CT and MET used almost the same time to react to get COP moving towards stepping foot but MET group then regretted and re-evaluated the situation for a second time and that was the reason why MET group's duration on Release Phase was so long. Back to Fig.8 (A), PST and ET tended to have a relatively shorter reaction time and this ws also consistent with the Sun and Guerra's study [14] which found PST and ET had shorter reaction time compared to CT. This might be related to the goal of making a fast step. From Fig.8 (B~C), we can obviously see the time changing trend from ascending to descending with MET toking the longest time in Release phase and inversely toking the shortest time in Transition phase. This phenomenon proved our deduction about the compensation effect on SC task, which suggesting the task differences (simple vs choice) can be roughly reflected in APA analyzing. Slightly different thing between SC and APA analyzing was the time duration in DSP phase. The four types of APA did not show any difference between each other in DSP phase and this means the situation evaluation which were highly related to APA was no longer a major factor of time consuming during DSP. Total time was still a rising trend from CT to MET and this was mainly due to a big variance in Release Phase. Importantly, the variance in Release Phase was not only caused by simple vs choice reaction task but also affected by the task of how many steps to take. Actually, CRT was about how many steps one will take and 1 to 3 steps represents the task complexity.

Analyzing the factor of number of steps on time duration in both simple and choice groups have found significant differences in Release, Transition, and DSP phase but RT did not show any difference among 1~3 steps. This result in RT and the following phases indicated the

situation evaluation pattern was to initiate first and then evaluate the task during the following phases. From Fig.7 (B) we found Release Phase was the actual time period that cost to evaluate the correct initiation of a task with one step significantly shorter than two and three steps. But two and three steps did not have significant differences. This is understandable because one step is used to be understood as easier to figure out which foot to initiate with and indeed it was as reflected by Fig.7 (B). However, in DSP phase which did not show many differences in S/C and APA, one step task was significantly longer than two and three steps with a very large effect size ($\eta^2 > 0.3$). This prolonged one step duration in DSP phase suggested that subjects were making decisions at that time period and the decision would mostly be whether he should stop after the step or keep walking because DSP phase is the last phase of a single step. This finding answered our study question of when did people program stop. And to further prove this, we analyzed the effect of number of steps by split simple and choice groups. Result in Fig.10 (D) revealed that both simple and choice group showed significant difference between one and two or three steps. Specifically, one step was not only longer in choice reaction task but also in simple reaction task. Simple reaction task is a stepping task that subjects have already known how many steps they will perform in advance which means all the initiation work were all pre-programed. Findings in our study indicated that the pre-programed work for step initiation did not include when and probably how to make a stop, the whole stepping task evaluation period is an online process which subjects tended to quickly initiate after cue onset and then kept evaluating and eventually programmed a stop.

Apart from the stop programming time point, we found another interesting fact that in simple reaction task the total time for two steps is significant higher than one and three steps and this only happened in SRT. This happened because in our experiment design the second step

contained a stimulus-response incompatibility as the target square on the left but subjects had to initiate with right foot or the target on the right but initiates with left foot. Former researchers [32] had found S-R incompatibility will contribute to the duration of response selection stage and that is why in SRT two steps had prolonged time duration of total initiation time. However, this was not reflected in the choice reaction task and no significant differences were found between two and three steps. This was different from our guess as we thought two steps will take longer time in both SRT and CRT. The possible reason for that could be in CRT people spend most time evaluating which foot to initiate with correspond to different steps and also in this study the task complexity was another part which contributes a lot to the time duration. So, at this point of view, the prolonged time for two steps is probably due to the S-R incompatibility and the prolonged time for three steps might be mainly caused by task complexity as subjects had to plan three steps ahead.

**Limitations and Areas of Further Research**

One limitation was that during testing period, we asked the subjects to react as fast as possible but observed several subjects showed anticipate moving towards upcoming stimulus and this kind of anticipating trial showed a different COP pattern which we have to eliminate from the trial pool. Another limitation was that the wooden platform for step and gait was narrow in width, which might probably trigger a relatively short step length and abnormal gait pattern. At last, the testing time for each subject was different which varies from morning to afternoon and this caould be a potential issue for reaction time difference as we cannot guarantee the participants were at their best condition to perform the motor task.

As we have already observed some abnormal gait patterns during ET and MET trials like: short step length during second step and hesitation release with heel off on both feet, future study

can investigate more of the biomechanical data of one step to three steps. Also, body sway during step and gait in choice reaction task is another part which would be interesting to further study because it is highly related to risk of falls and probably could have relationship with short step length and hesitation release. Last but not least, visual reality can be used to study motor coordination during fatigue, injury, and complex skill learning and also can be used to investigate how people maintain their dynamic stability during barrier avoidance processes.

# CHAPTER 6

# CONCLUSION

This study was designed to evaluate different initiation patterns comparing the initiation of one step to three steps and identify possible time period on how people program their step and stop. Based on the findings above, three conclusions can be drawn from this study:

1. In choice reaction task, planning two or three steps ahead required more time to initiate compared to planning one step. However, due to the existence of S-R incompatibility in two step planning, three steps, which was the longest planning task in our study, did not show differences from two step planning.

2. The fact that the "stop" command of step initiation was programmed during Double Support Phase suggested that the whole stepping task evaluation period was an online process which subjects tended to quickly initiate after cue onset and kept evaluating and eventually programmed a stop.

3. In choice reaction task, most evaluation work for initiation happened during release phase, and the more error a trial got during Anticipatory Postural Adjustment, the more time it will cost in release as well as in the total initiation time. But error trials tended to have a compensation effect which means durations after release phase had a descend trend with multiple error trial took the least time to finish.

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## LIST OF TABLES

Table.1. Means and standard deviations of demographics

| | Age | Height (cm) | Weight (kg) |
|---|---|---|---|
| M ± SD | 21.1 ± 0.6 | 169.5 ± 8.0 | 72.0 ± 11.7 |

Table.2. Summary of temporal characteristics of simple and choice stepping task.

| | SRT, mean ± SD (ms) | | | CRT, mean ± SD (ms) | | |
|---|---|---|---|---|---|---|
| Steps | 1 | 2 | 3 | 1 | 2 | 3 |
| RT | 306.1 ± 73.3 | 303.7 ± 86.1 | 293.2 ± 65.9 | 405.3 ± 98.6 | 412 ± 108.1 | 396.7 ± 96.3 |
| Release | 320.2 ± 48.6 | 347.8 ± 70.1 | 342.9 ± 57.4 | 390.7 ± 82.9 | 509.1 ± 129.7 | 530.1 ± 189.7 |
| Transition | 603.2 ±57.6 | 641.9 ±73.6 | 633.3 ± 61.8 | 603.4 ± 59.8 | 612.3 ± 73.8 | 624.4 ± 72.5 |
| DSP | 206.7 ± 22.8 | 173.1 ± 21 | 169.7 ± 171 | 191.7 ± 27.1 | 171.3 ± 19.7 | 171.6 ± 16.1 |
| Total | 1436.1 ± 10.5 | 1466.5 ± 156.8 | 1439.1 ± 105.3 | 1591 ± 105 | 1704.8 ± 145.5 | 1723.3 ± 205.6 |

Table.3. Summary of temporal characteristics among different types of APA groups.

| | CRT, mean ± SD (ms) | | | |
|---|---|---|---|---|
| APA Types | 0 | 0.5 | 1 | 2 |
| RT | 415.6 ± 104.5 | 387.1 ± 93.1 | 390.1 ± 93 | 433.1 ± 113.5 |
| Release | 370.6 ± 78.6 | 507.6 ± 89.0 | 572.4 ± 100.2 | 763.1 ± 178.6 |
| Transition | 625.7 ± 69.3 | 615.2 ± 65.5 | 597.2 ± 67.8 | 569.4 ± 63.1 |
| DSP | 183.9 ± 25.7 | 174.9 ± 20.5 | 173.7 ± 19.1 | 167.5 ± 21.4 |
| Total | 1595.7 ± 132.5 | 1684.9 ± 128.4 | 1733.5 ± 130.3 | 1933 ± 196.2 |

## LEGEND OF FIGURES

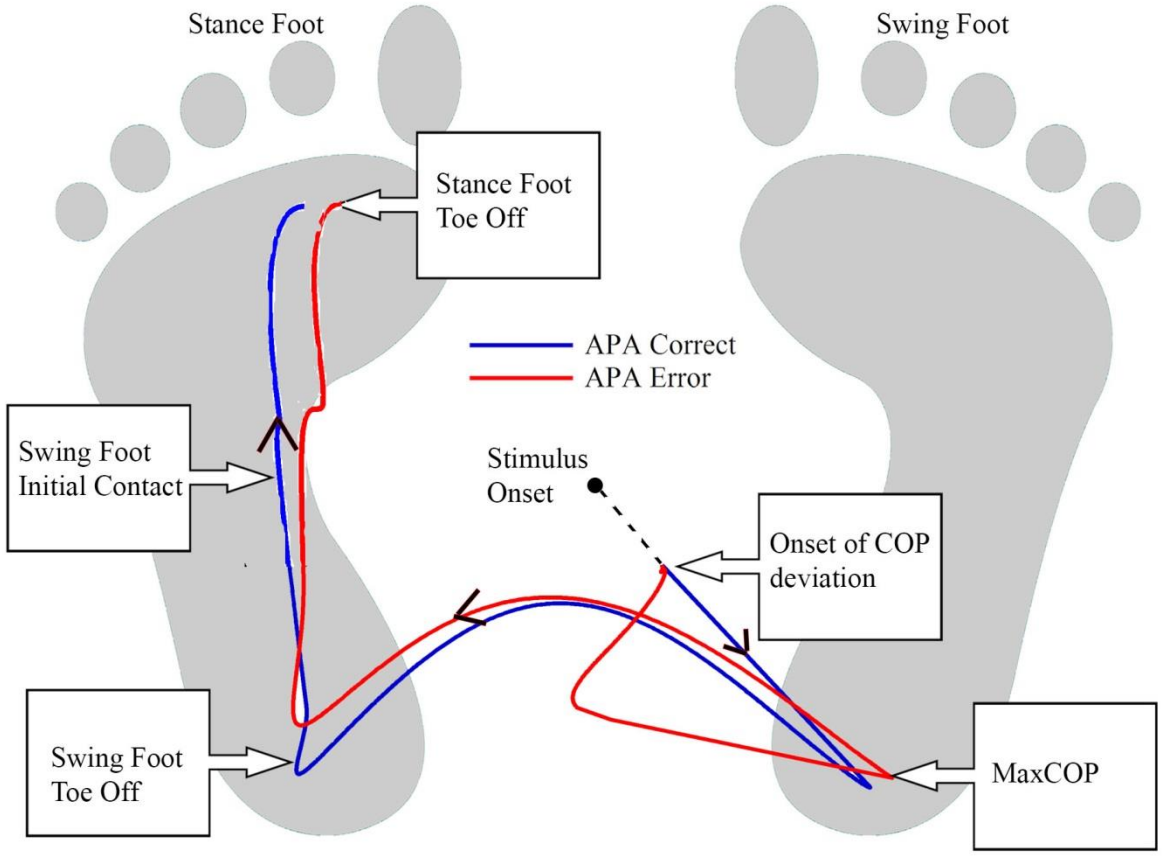


Figure1: COP displacement during step initiation in APA correct and error trials. (Reaction Time is from stimulus onset to the onset of COP deviation; Release Phase is starts from the onset of COP to lateral MaxCOP; Unloading Phase is the time between Swing Foot Toe Off and MaxCOP; Single Support Phase begins after Swing Foot Toe Off and ends at Swing Foot Initial Contact; At last is the Double Support Phase which is the time duration rom Swing Foot Initial Contact to Stance Foot Toe Off)

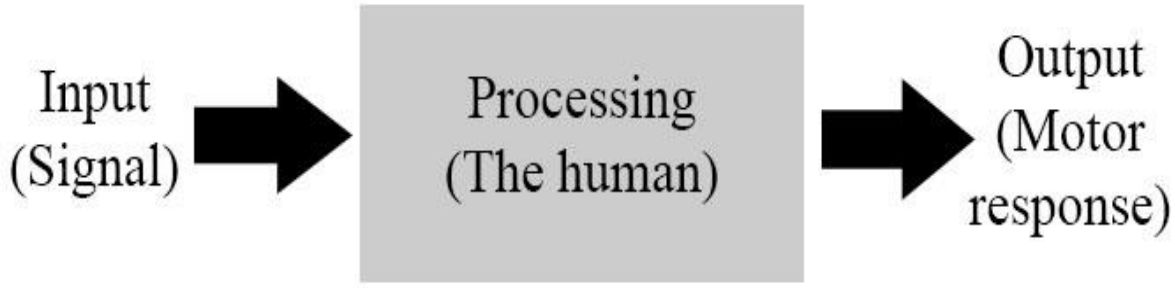


Figure2: Black Box information processing model.

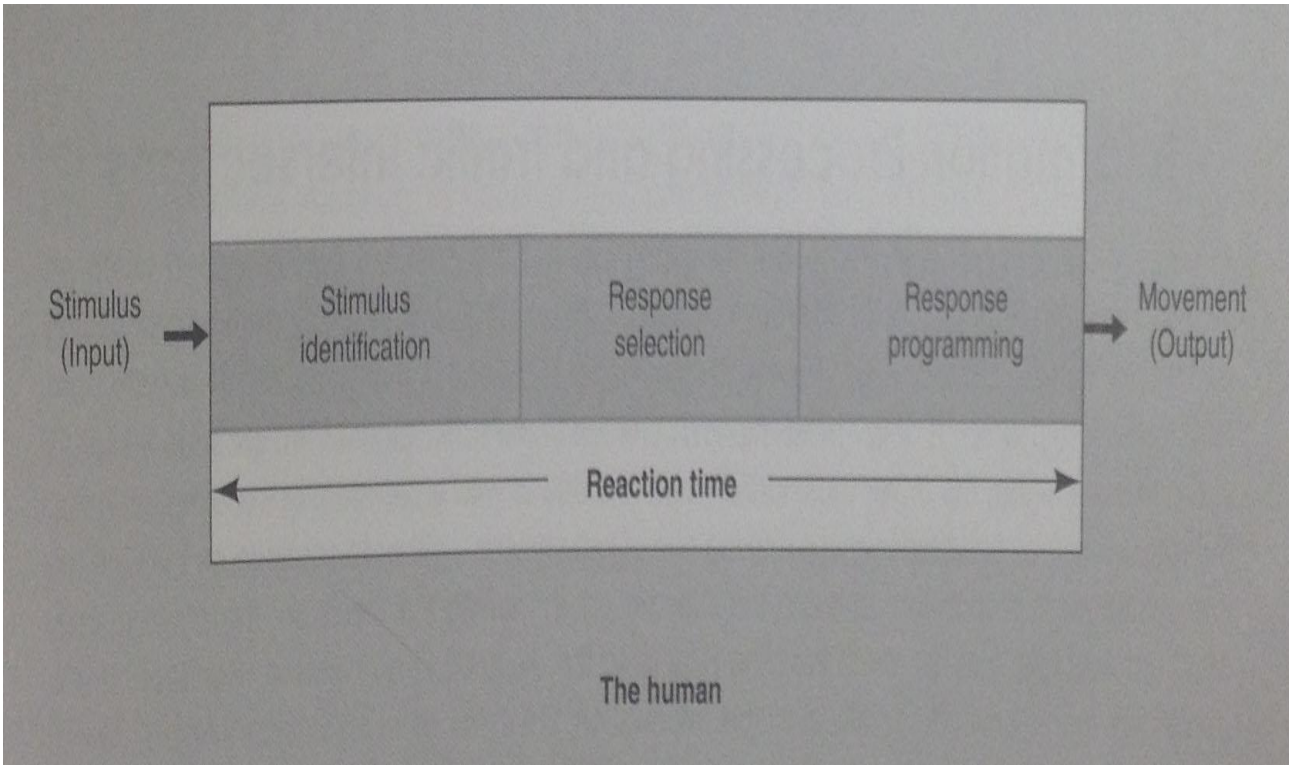


Figure3: A three-stage information-processing model.

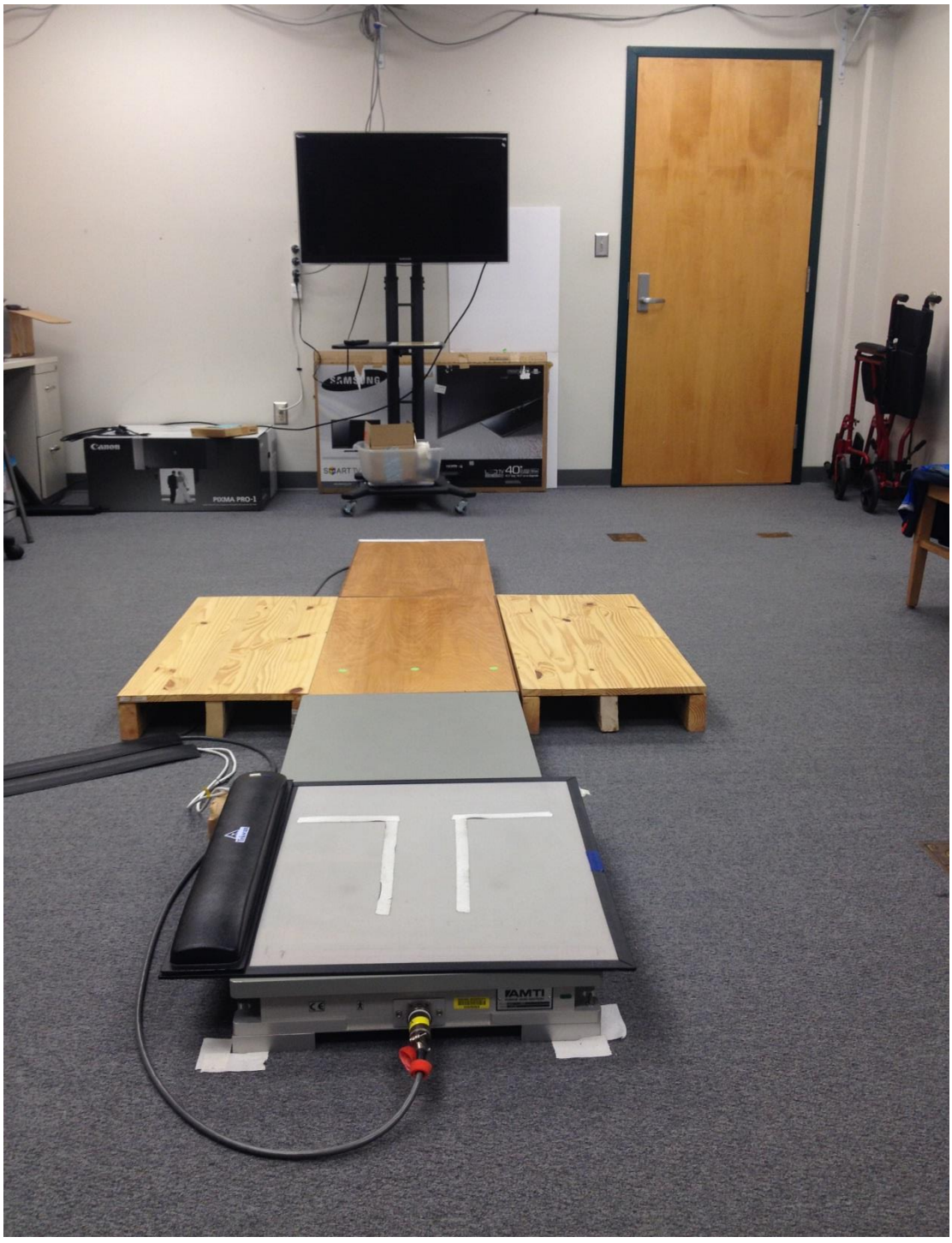


Figure4: Lab equipment settings.

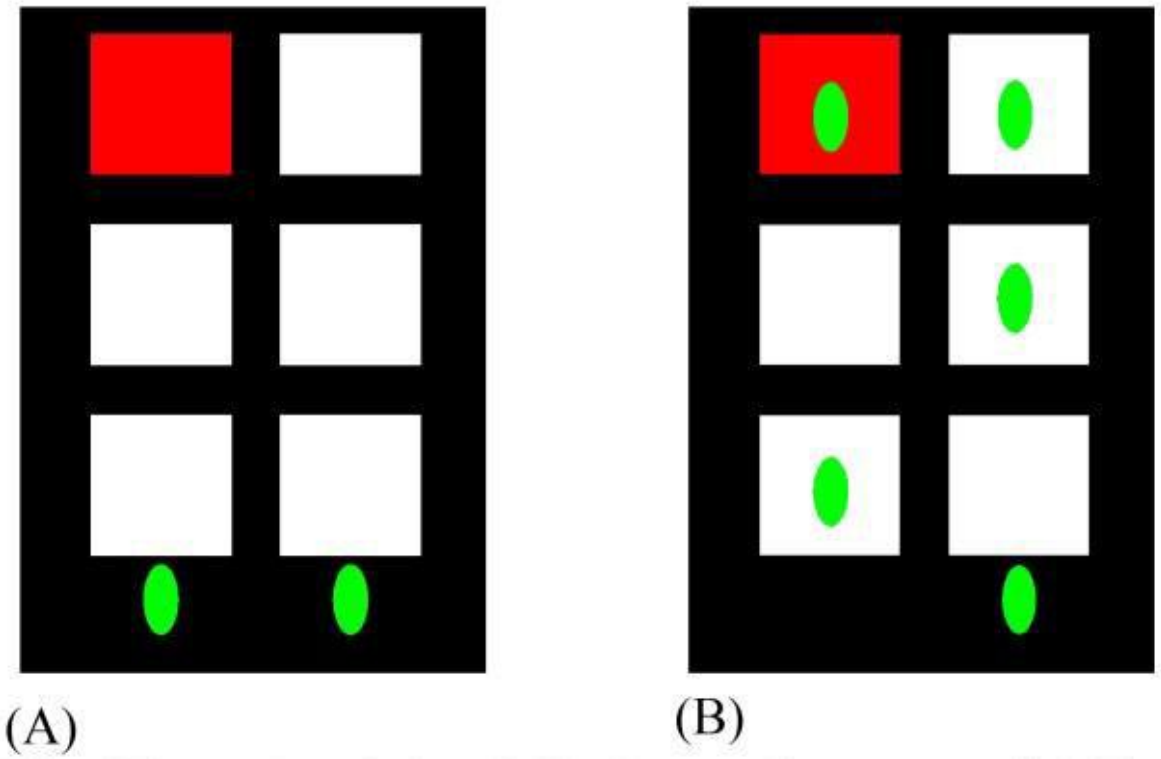


Figure5: Example of visual display on the screen. (A) Top left square was painted red indicating subject need to initiate 3 steps, with the third step stepping onto the red square. (B) Green footprint shows the correct planning and execution strategy to finish the task in A.

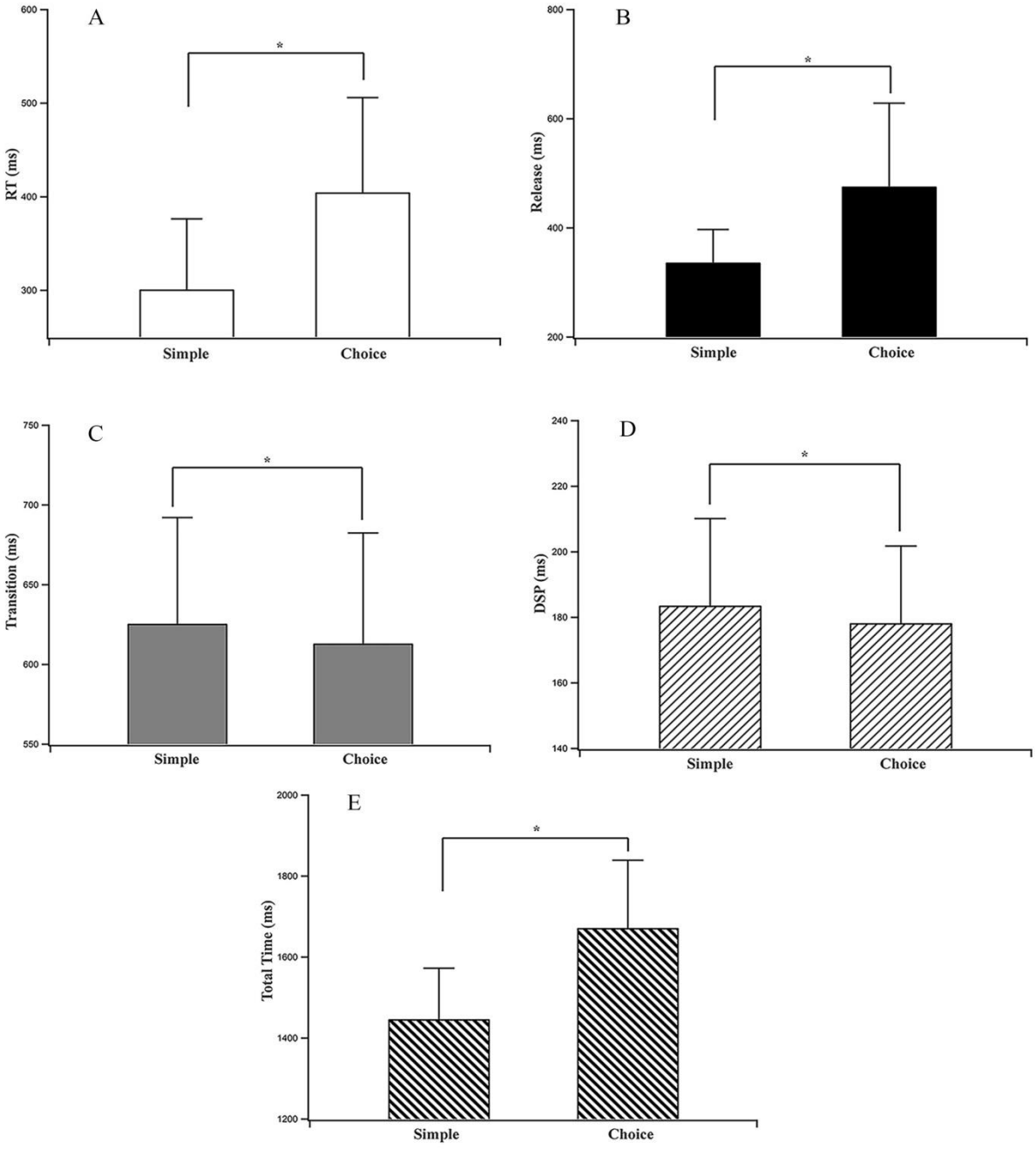


Figure6: Effect of SRT vs CRT on temporal characteristic of step initiation. ( * Significant effect located in All phases between simple reaction task and choice reaction task with choice reaction)

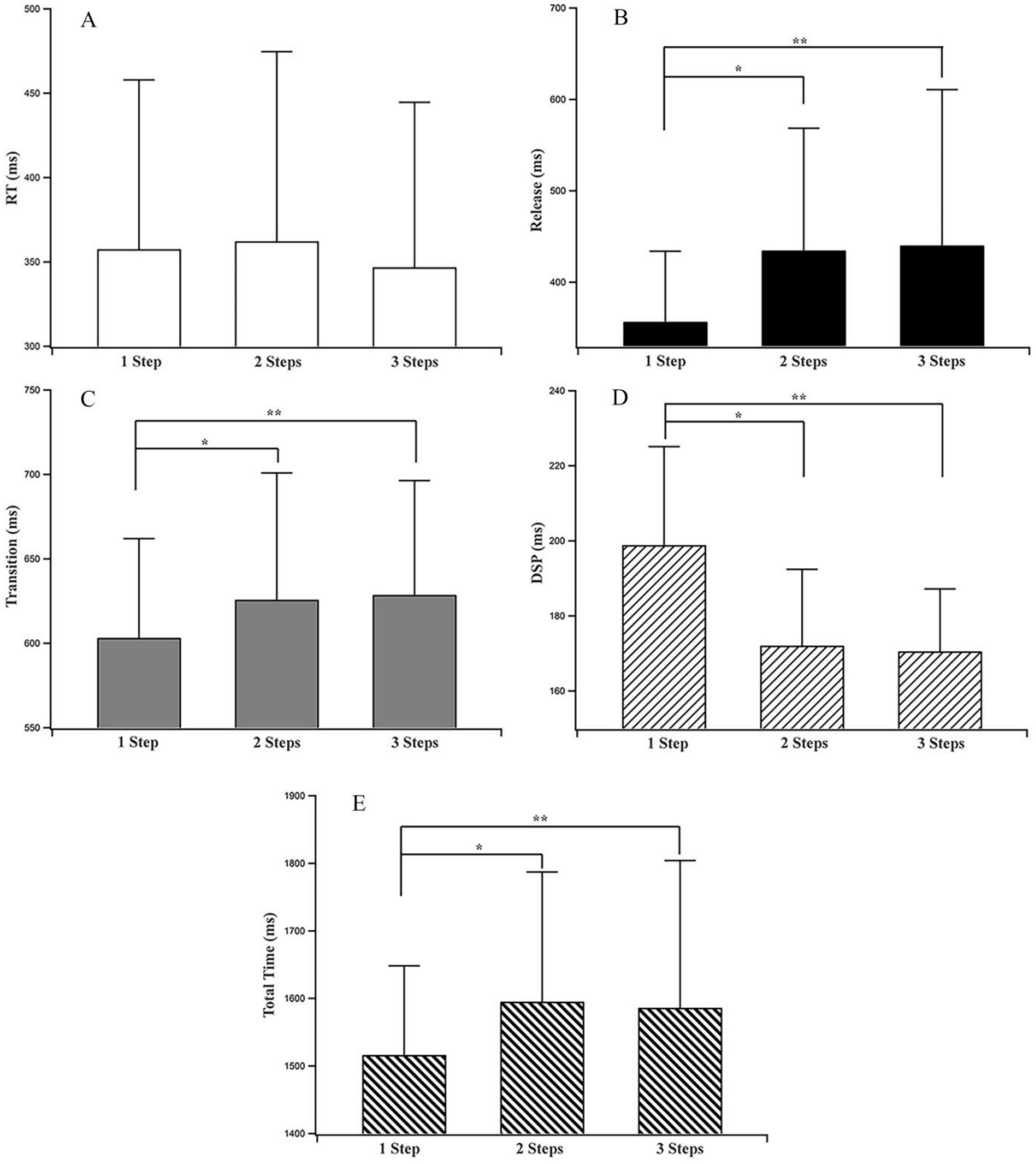


Figure7: Effect of Number of steps on temporal characteristic of step initiation. ( *, ** Significant differences were found in Release, Transition, DSP and Total Time Phases among 1, 2 and 3 steps motor task with 1 step always different from 2 and 3. But no significant effect were found between 2 and 3 steps.)

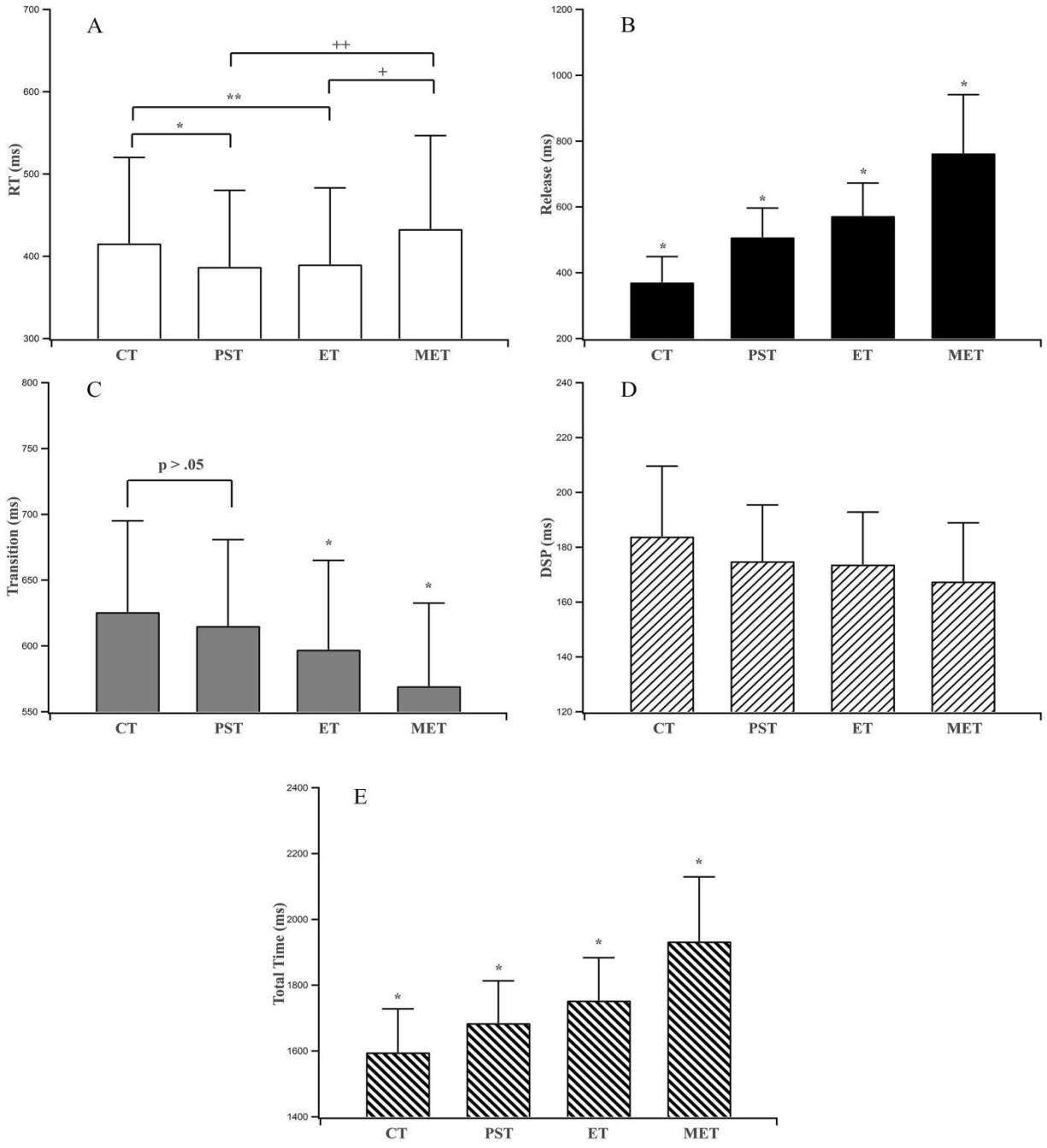


Figure8: Effect of types of APA on temporal characteristic of step initiation. ( *, **, +, ++ Significant effect were found between CT and PST, CT and ET, MET and PST, MET and ET in RT phase; * Significant effect were found between all four types of APA in Release and TotalTime; No Significant effect were found in DSP)

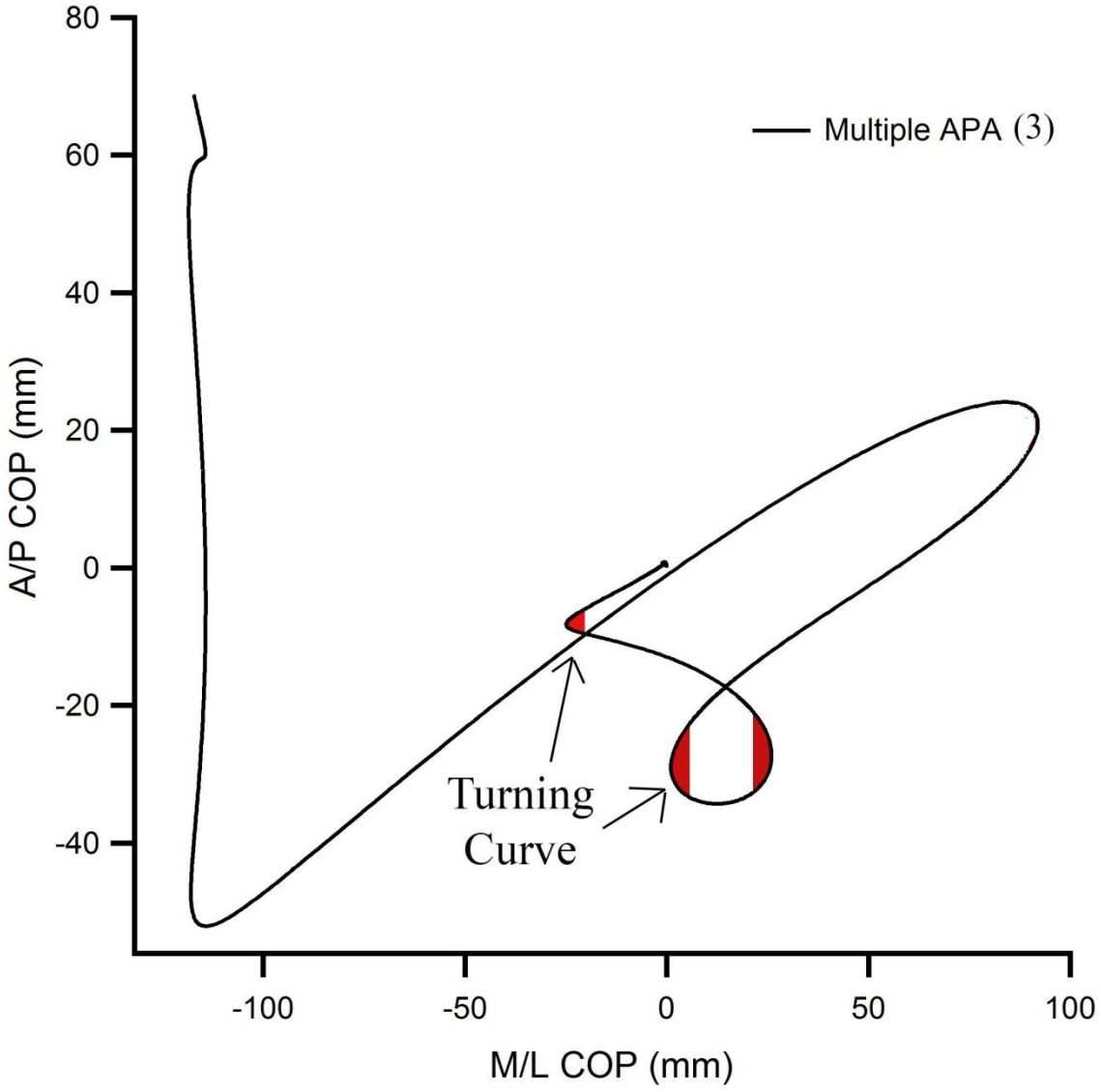


Figure9: Turning Curve on Multiple Error APA Trial. (The red painted area suggested that subjects changed the direction of COP movement by evaluating the task requirements. Each turning curve before MaxCOP stands for an APA error)

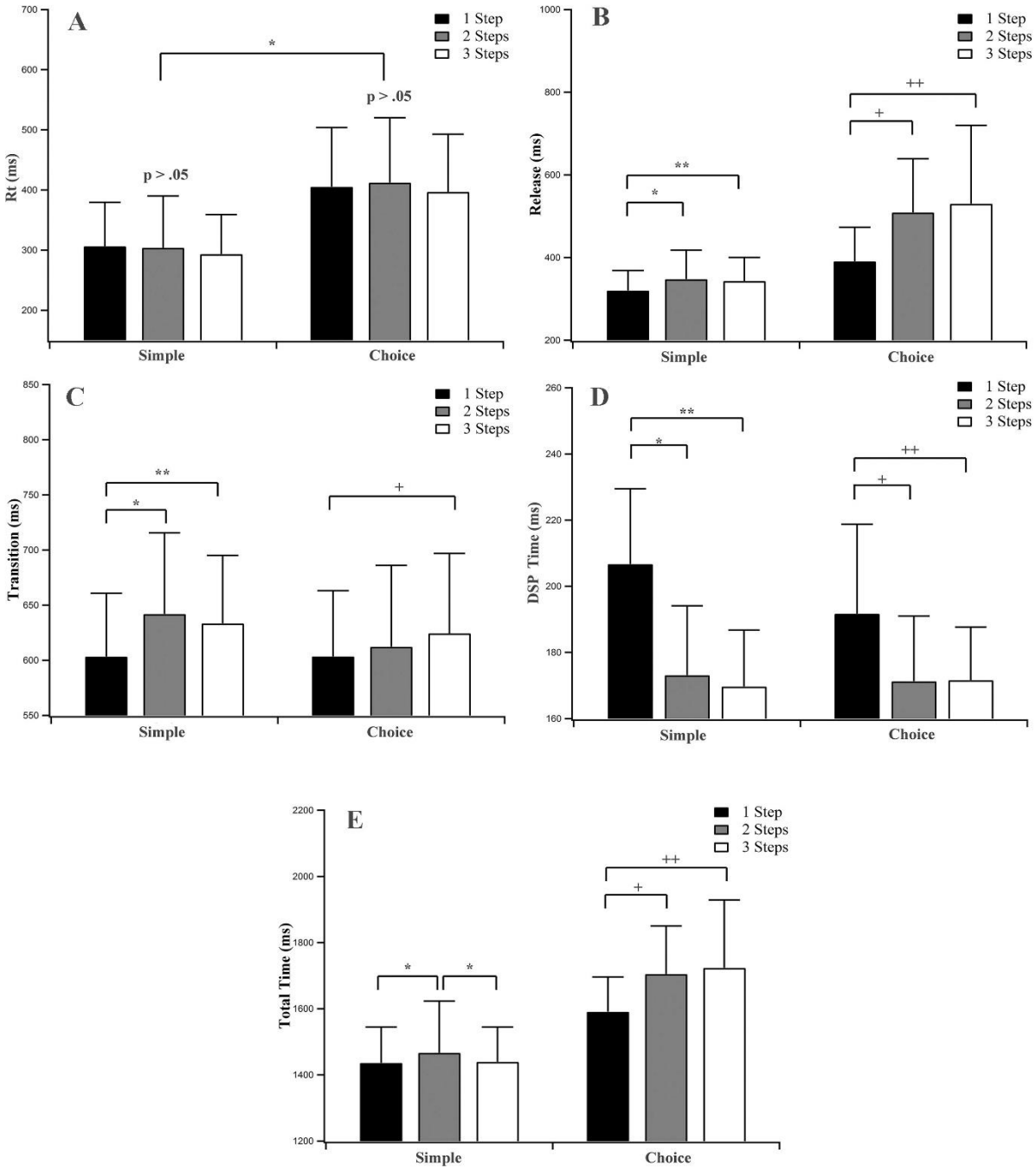


Figure10: Effect of Number of Steps on temporal characteristic in Simple and Choice step initiation task separately. ( *, **, +, ++ Significant effect was consistent with Fig.7 except Total Time under simple reaction task. Total Time under SRT had the largest time duration in two steps task and is significantly different from one and three steps task)

# APPENDIX

## Appendix-A Human Subject Approval & Consent Form

**INDIANA UNIVERSITY INFORMED CONSENT STATEMENT FOR**

**Response Planning and Execution in Step and Gait Initiation.**

You are invited to participate in a research study of the investigation of the time measured from an auditory stimulus to the start of a step. You were selected as a possible subject because of your reply to the recruiting script delivered during one of your classes. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

The study is being conducted by Dr. John Shea in the Department of Kinesiology.

**STUDY PURPOSE**

The proposed research is designed to comparing the processes underlying the initiation of one step and walk using an auditory stimulus and measuring the time it takes to response and execute among normal healthy young subjects.

**NUMBER OF PEOPLE TAKING PART IN THE STUDY**

If you agree to participate, you will be one of **10** subjects who will be participating in this research.

**PROCEDURES FOR THE STUDY**

If you agree to be in the study, you will do the following things:

You will be participating in an investigation of step and gait initiation. Your participation in this investigation will require that you to perform one step or walk (several steps) with a reaction task. Prior to participation, you will be asked for normal vision and any known mental or physical complication impacting vision or memory (e.g. stroke, multiple sclerosis, or paralysis) will be allowed to participate. Additionally, while performing the task, you will be videotaped with a motion analysis system, and the force and pressures underneath your feet and will be measured.
These procedures will be conducted at the Indiana University Neuro-Motor Learning Lab within the Department of Kinesiology. Your participation requires 1 visit to the Neuro-Motor Learning Lab and will require approximately 60 minutes of your time.

**RISKS OF TAKING PART IN THE STUDY:**

There is a risk of falling.
.

**BENEFITS OF TAKING PART IN THE STUDY**

You are not expected to benefit from participating in this study.

**CONFIDENTIALITY**

Efforts will be made to keep your personal information confidential. We cannot guarantee absolute confidentiality. Your personal information may be disclosed if required by law. Your identity will be held in confidence in reports in which the study may be published and all databases storing video tape recordings, motion analysis, survey information, assessment results and study data will be stored with identity confidence and secured with passwords that only the study investigators will have access to. All

documentation collected during this study will be destroyed via a paper shredder three years after completion of the investigation.

Organizations that may inspect and/or copy your research records for quality assurance and data analysis include groups such as the study investigator and his/her research associates, the Indiana University Institutional Review Board or its designees, and (as allowed by law) state or federal agencies, specifically the Office for Human Research Protections (OHRP), who may need to access your research records.

**PAYMENT**

You will not be paid for participation in this study.

**COMPENSATION FOR INJURY**

In the event of physical injury resulting from your participation in this research, necessary medical treatment will be provided to you and billed as part of your medical expenses. Costs not covered by your health care insurer will be your responsibility. Also, it is your responsibility to determine the extent of your health care coverage. There is no program in place for other monetary compensation for such injuries. However, you are not giving up any legal rights or benefits to which you are otherwise entitled. Because you are participating in research which is not conducted at a medical facility, you will be responsible for seeking medical care and for the expenses associated with any care received.

**CONTACTS FOR QUESTIONS OR PROBLEMS**

For questions about the study or a research-related injury, contact the Co-Investigator researcher Tianyu Zhao at 812-349-8769 or Ruopeng Sun at 718-753-3256, or Principal Investigator Dr. John Shea at 812-856-6045. If you cannot reach the researcher during regular business hours (i.e. 8:00AM-5:00PM), please call the IU Human Subjects Office at (812) 856-4242 or (800) 696-2949. After business hours, please call 812-525-9329.

In the event of an emergency, you may contact Tianyu Zhao at 812-369-0116.

For questions about your rights as a research participant or to discuss problems, complaints or concerns about a research study, or to obtain information, or offer input, contact the IU Human Subjects Office at (812) 856-4242 or (800) 696-2949.

**VOLUNTARY NATURE OF STUDY**

Taking part in this study is voluntary. You may choose not to take part or may leave the study at any time. Leaving the study will not result in any penalty or loss of benefits to which you are entitled. Your decision whether or not to participate in this study will not affect your current or future relations with Indiana University.

**SUBJECT'S CONSENT**

In consideration of all of the above, I give my consent to participate in this research study. I have the option to withdraw from this study at any time I choose without penalty.

I will be given a copy of this informed consent document to keep for my records. I agree to take part in this study.

**Subject's Printed Name:**_____

**Subject's Signature**:_____**Date**:_____

(Must be dated by the subject)

**Printed Name of Person Obtaining Consent:**_____

**Signature of Person Obtaining Consent**:_____**Date**:_____

# IRB Approval Letter

INDIANA UNIVERSITY

OFFICE OF THE VICE PRESIDENT FOR RESEARCH

Office of Research Compliance

**To:** John Shea
KINESIOLOGY

Ruopeng Sun
KINESIOLOGY

Tianyu Zhao
RECREATIONAL SPORTS

**From:**

Chair - IRB-IUB
Human Subjects Office
Office of Research Compliance – Indiana University

**Date:** November 10, 2014

**RE:** **NOTICE OF EXPEDITED APPROVAL - NEW PROTOCOL**

Protocol Title: Response planning and execution in step and gait initiation.

Study #: 1410613793

Funding Agency/Sponsor: None

Review Level: Expedited

Status: Approved | Active - Open to Enrollment

**Study Approval Date:** November 10, 2014

**Study Expiration Date:** November 09, 2016

The Indiana University Institutional Review Board (IRB) IRB00000222 | IRB-IUB recently reviewed the above-referenced protocol. In compliance with (as applicable) 21 C.F.R. § 56.109 (e) and 46 C.F.R. § 46.109 (d), this letter serves as written notification of the IRB's determination.

**The study is approved under Expedited Category (4)** Category 4: Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) (7) Category 7: Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies. (NOTE: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(2) and (b)(3). This listing refers only to research that is not exempt.)

Approval of this study is based on your agreement to abide by the policies and procedures of the Indiana University Human Research Protection Program and does not replace any other approvals that may be required. Relevant policies and procedures governing Human Subject Research can be found at: http://researchadmin.iu.edu/HumanSubjects/hs_guidance.html.

IRB approval is required prior to implementing any changes or amendments in the protocol, regardless of how minor, except to eliminate immediate hazards to subjects. No changes to the informed consent document may be made without prior IRB approval.

If you submitted and/or are required to provide participants with an informed consent document, please ensure you are using the most recent version of the document to consent subjects.

The initial approval period is noted above. Continued approval is contingent upon the submission of a renewal application to the Human Subjects Office in a timely fashion. Failure to submit the renewal notice in a timely fashion may result in the expiration and subsequent suspension of all protocol activities. **Failure to receive notification from the Human Subjects Office will not relieve you of your responsibility to ensure compliance with Federal Regulations regarding annual review [as applicable, 21 C.F.R. § 56.109(f) and 45 C.F.R. § 46.109(e)]**

You should retain a copy of this letter and all associated approved study documents for your records. Please refer to the assigned study number and exact study title in future correspondence with our office. Additional information is available on our website at http://researchadmin.iu.edu/HumanSubjects/.

**If your source of funding changes, you must submit an amendment to update your study documents immediately.**

If you have any questions or require further information, please contact the Human Subjects Office via email at irb@iu.edu or via phone at (317)274-8289 (Indianapolis) or (812) 856-4242 (Bloomington).

You are invited, as part of ORA's ongoing program of quality improvement, to **participate in a short survey** to assess your experience and satisfaction with the IRB related to this approval. We estimate it will take you approximately **5 minutes to complete the survey.** The survey is housed on a Microsoft SharePoint secure site which requires CAS authentication. This survey is being administered by REEP; please contact us at reep@iu.edu if you have any questions or require additional information. Simply click on the link below, or cut and paste the entire URL into your browser to access the survey: https://www.sharepoint.iu.edu/sites/iu-ora/survey/Lists/Compliance/IRB_Survey/NewForm.aspx.

/enclosures

## Appendix-B Subject Health Form

**Does the participant have a medical or surgical history, current or resolved, of any of the following?**

| MEDICAL HISTORY | Yes / No | Unknown | If Yes, Explain | Current / Resolved |
|---|---|---|---|---|
| **1. Head, Eye, Ear, Nose, Throat** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **2. Respiratory** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **3. Cardiovascular** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **4. Gastrointestinal** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **5. Genitourinary** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **6. Musculoskeletal** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **7. Neurological** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **8. Endocrine-Metabolic** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **9. Blood/Lymphatic** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **10. Dermatologic** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **11. Psychiatric** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **12. Allergy** | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |
| **13. Other, specify:** _____ | ☐ Yes ☐ No | ☐ | | ☐ Current ☐ Resolved |

## Appendix-C Data Collection Form

# Gait Initiation Study Test Sheet

Subject ID: _____ Date of Testing: _____

Age: _____ Male Female

Height: _____ Weight: _____

| Test Order | Experiment Condition | Practice Trail | | Trails Collected | | Notes |
|---|---|---|---|---|---|---|
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| 2 | SRT L 2 | 1 | | 1 | | |
| | | 2 | | 2 | | |
| | | 3 | | 3 | | |
| | | 4 | | 4 | | |
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| | | 9 | | 9 | | |
| | | 10 | | 10 | | |
| 3 | SRT L 3 | 1 | | 1 | | |
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| | | 4 | | 4 | | |
| | | 5 | | 5 | | |
| | | 6 | | 6 | | |
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| 4 | SRT R 1 | 1 | | 1 | | |
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