Effects of attentional load on postural control mechanism in the choice step reaction

（注意負荷がステップ反応動作時における姿勢調節メカニズムに及ぼす影響）

名古屋大学大学院医学系研究科
リハビリテーション療法学専攻

上 村 一 貴

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名古屋大学大学院医学系研究科

リハビリテーション療法学専攻

(指導：　内山　靖　教授)

上 村 一 貴

主論文の要旨

論文題目　Effects of attentional load on postural control mechanism in the choice step reaction
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氏　　名　上村一貴

Ⅰ．緒言

外的刺激に対する素早い反応動作は、ヒトの持つ重要な機能であり、ステップ反応動作は、知覚・判断、予測的姿勢調節(Anticipatory Postural Adjustment; APA)、実質的運動の3相で分析できる。このうちAPAの潜在的なエラーにより、動作遂行時間全体が遅延することが報告されている。このことから、判断・選択を含む認知的過程は、潜在エラーによりステップ動作全体を遅延させてしまうかどうかを決定づける重要な過程と言える。本研究では、この認知的過程に選択的な注意負荷を加えた際の転倒リスク評価により、潜在的なバランス機能低下や転倒リスクを検出しやすいのではないかと考えた。これまでの転倒リスク評価は、筋力や歩行速度などパフォーマンス評価が多く、動作時の認知的過程に着目したものは少ない。本研究の目的は、注意負荷を生じる視覚課題がステップ動作時における姿勢調節メカニズムに及ぼす影響を、特にAPAに着目して明らかにすることである。本研究では、基礎的な制御機構解明のため、ステップ動作時の姿勢調節に対して、1)注意負荷が及ぼす影響、2)速さと正確性の重視戦略の影響の検討を実施した。

Ⅱ．研究1: 注意負荷がステップ反応動作時における姿勢調節に及ぼす影響

Ⅱ-1. 目的

研究1の目的は、若年者において、選択的注意課題による注意負荷がステップ動作時の姿勢調節に及ぼす影響を明らかにすることとした。

Ⅱ-2. 対象及び方法

対象は健常若年者20名とした。測定課題は、前方のモニターに表示される視覚刺激（矢印）の示す方の足をできるだけ早く30cm前方に踏み出すこととした。視覚刺激は、①基本課題：矢印の向きの足を踏み出す、②選択的注意課題：→→→→→(一致)もしくは→→←→→(不一致)に対して中央の矢印の向きの足を踏み出す、の2条件とした。2枚の重心動揺計（Anima社製）で測定した床反力垂直成分のデータから、ステップ動作時間（開始合図から遊脚側接地まで）を求め、(a)反応相：開始合図から、一側への体重移動開始（体重の5%以上の移動）まで、(b)APA相：体重移動開始から遊脚側離地まで、(c)遊脚相：遊脚側離地から接地まで、の三つに細分化した。指示と逆足を出した場合をステップエラー、APA開始時に通常とは逆に立脚側への体重移動が生じた場合をAPAエラーと定義した。

Ⅱ-3. 結果

APAエラー、ステップ動作時間ともに、基本, 一致条件(11%, 0.89s；10.9%, 0.91s)に比較し、不一致条件(41.7%, 0.95s)で有意に増大した。線形混合モデルによる分析の結果、APA

エラーありの場合に、ステップ動作時間、APA 相は有意に遅延した。APA エラーなしの場合には、反応相、遊脚相は有意に遅延が生じた。APA エラーなしの場合には、より多くの時間を用いて判断するため、反応相が延長したと考えられるが、全体としてのステップ動作時間は潜在エラーありの場合に比べて短かった。

Ⅱ-4. 小括

若年者において動作時の認知的過程への注意負荷（視覚干渉）により、APA エラーやステップ反応の遅延を顕在化することが可能であり、転倒のリスク評価として有用である可能性を示した(Uemura K, et al., *Gait Posture* 2013)。

Ⅲ. 研究 2: ステップ動作時における速さ・正確性の重視戦略が姿勢調節に及ぼす影響

Ⅲ-1. 目的

研究 2 の目的は、反応課題における速さと正確性には、トレードオフの関係性が存在することから、選択的注意課題に対するステップ反応動作に速さと正確性の重視戦略が及ぼす影響について明らかにすることとした。

Ⅲ-2. 対象及び方法

対象は健常若年者 18 名とし、研究 1 と同様の実験課題と評価指標を用いた。速さ、正確性、またはその両方を重視させるような教示を行い、重視戦略による差異を検討した。

Ⅲ-3. 結果

ステップエラー率は、平均 0.86%であり、教示間で有意差はみられなかった。速さを重視した場合、他の教示に比べてステップ動作時間が有意に短縮した。正確性を重視した場合、速さ重視に比較して APA エラー率が減少した。また、すべての教示で、APA エラーの生じた試行におけるステップ動作時間の遅延がみられた。

Ⅲ-4. 小括

ステップ反応において速さを重視した場合、ステップそのもののエラーは増えないものの、潜在的な APA エラーが増加した。このように、立位動作における速さや正確性の重視戦略は、予測的姿勢調節による体重移動という要素が存在することから、その他の姿勢や課題とは異なる影響を及ぼす可能性が示唆された(Uemura K, et al., *Hum Mov Sci* 2013)。

Ⅳ. 結語

本研究の結果より、注意負荷を動作開始時の認知的過程に加えることにより、ステップ動作時の APA の潜在的なエラーが増加し、各時間因子が遅延すること、速さ・正確性の重視戦略によって、エラーやステップ動作時間のパフォーマンスが変化することが明らかになり、転倒リスク評価や姿勢調節機能の評価法の開発に向けた基礎的な情報が明らかになった。今後は、高齢者の転倒リスク評価、ならびに有疾患患者を対象とした機能評価としての妥当性や、有効な介入方法（教示・トレーニング）を検証していく必要がある。

Abstract

Title Effects of attentional load on postural control mechanism in the choice step reaction

（注意負荷がステップ反応動作時における姿勢調節メカニズムに及ぼす影響）

Name Kazuki Uemura

Ⅰ. Introduction

The ability to respond rapidly to environmental stimuli is a vital human sensorimotor function. To effectively minimize such occurrences, the cognitive processing (reaction), postural (weight transfer), and locomotion (step) components must be timed and executed appropriately. Errors in the direction of initial weight transfer, which is defined as anticipatory postural adjustment [APA] errors, account for slow choice step execution because the APA error must be corrected before the step can be safely executed. The present study focuses on cognitive processing during movement initiation; these are critical components that determine the accuracy and speed of step execution. We hypothesized that if visual interference can load the cognitive process and increase the potential deficits in choice step execution, then the selective attention task may increase initial motor program errors (i.e., APA errors), which influence on the prolongation of step execution because of the additional time needed to correct the erroneous APA.

Ⅱ. Study 1: Effect of attentional load on postural adjustment in the choice step reaction

Ⅱ-1. Objective

The purpose of this study was to determine whether visual interference, which would be attentional load on cognitive process, has any effect on the initial motor program and choice step execution and whether the presence of an APA error influences on the response times and step execution in healthy young adults.

Ⅱ-2. Methods

Twenty healthy young subjects were instructed to execute forward stepping as quickly and accurately as possible on the side indicated by a central arrow (←left vs. right→) of a visual cue during a neutral condition. During a flanker condition, participants were additionally required to ignore flanker arrows on each side of the central arrow (→→→→→congruent or incongruent→→←→→). Errors in the direction of the initial weight transfer (APA errors), step execution time, and divided phases (reaction, APA, and swing phases) were measured from the data of vertical force.

Ⅱ-3. Results

In the incongruent condition, the percentage of APA errors and the step execution times were significantly greater than those in the neutral and congruent conditions. A linear mixed model revealed that the step execution time in trials with APA errors was longer than those in trials

without APA errors.

Ⅱ-4. Summary of study 1

The visual interference effect of a flanker task increases initial motor program errors and prolongs step execution time even in young adults (*Uemura K, et al,. Gait Posture 2013*).

Ⅲ. Study2: Effect of speed and accuracy strategy on postural adjustment in the choice step reaction with attentional load

Ⅲ-1. Objective

The purpose of this study was to clarify the speed and accuracy trade-off mechanism during a postural task in an upright position. We examined the effects of a speed or accuracy strategy on initial motor program errors and choice step execution in response to the flanker interference task in healthy young adults.

Ⅲ-2. Methods

Eighteen healthy young participants underwent the stepping tests which were same with Study1 under task instructions that either emphasized on speed or accuracy or both of response.

Ⅲ-3. Results

There was no difference in step error rates among instructions. APA error in response to the flanker task was decreased with an accuracy strategy compared to a speed strategy. Step execution time was shortened with a speed strategy compared to an accuracy strategy.

Ⅲ-4. Summary of study 2

Speed strategy increased APA errors, but not step errors, in the choice step reaction. As a postural task performed in a standing position requires APA, speed and accuracy trade-off mechanism during a postural task in an upright position was different from other posture or task (*Uemura K, et al,. Hum Mov Sci 2013*).

Ⅳ. Conclusion

We found that the visual interference effect of a flanker task increases initial motor program errors and prolongs step execution time in young adults. It is suggested that attentional load on cognitive process during step initiation may expose the potential deficits in postural control. Additionally, it was also clarified that speed and accuracy strategy affected the accuracy of initial motor program and speed of leg movement in different manners. It may be important to manipulate the level of the speed-accuracy trade-off to improve efficiency and safety. Further research is needed to explore the effects of advancing age, risk of falling and disability on choice step reaction in a speed or accuracy strategy, which will contribute to the development of screening tool of fall risk and exercise program for fall prevention including instruction methods.

Contents

Ⅰ. Introduction

The ability to respond rapidly to environmental stimuli is a vital human sensorimotor function [1]. During everyday locomotion, it is often necessary to quickly initiate a step to avoid potentially threatening situations such as collisions, obstacles, and falls. Delayed initiation and completion of a voluntary step is a marker of an increased risk of falling in older adults [2-4]. To effectively minimize such occurrences, the cognitive processing (reaction), postural (weight transfer), and locomotion (step) components must be timed and executed appropriately [1,4]. Tests that have been previously used for assessing the physical performance, including walking speed and step reaction time, could not evaluate the multiple aspects of postural control deficits and the potential mechanism of movement prolongation.

Anticipatory postural adjustment (APA) was originally defined as a change in postural control associated with voluntary movements; it occurs before the onset of the disturbances of posture and equilibrium resulting from a movement [5]. To prepare for a step, the body weight is normally shifted laterally onto the stepping foot in preparation for shifting weight onto the support leg; this is considered to be the APA during step initiation [6]. APA begins at the time of initiation and ends at the time of completion of the preparatory weight transfer (i.e., foot-off)[6-8]. Inhibition of inappropriate motor responses has been shown to be involved in initiation of the preparatory weight transfer [9]. Cohen et al. [10] reported that errors in the direction of initial weight transfer, which is defined as an APA error, account for slow choice step execution because the APA error must be corrected before the step can be safely executed. Given that an initial motor program error leads to incorrect and prolonged APA, cognitive processing may be vital and critical in determining the accuracy and speed of step execution. It is possible that loading this cognitive process will lead to clarification of potential deficits in postural control during step initiation.

Flanker interference tasks are used as selective attention tasks to measure inhibitory function and visual interference effects [11-13]. In such flanker tasks, subjects are usually required to identify the direction of a central arrow flanked by incongruent or congruent stimulus arrays by manually pressing a button. Flanker task performance (i.e., reaction time) deteriorates with increasing age [13], particularly in patients with mild cognitive impairment and Alzheimer's disease [14,15]. Voluntary upper extremity responses might bear little resemblance to postural reactions for avoiding potentially threatening situations in daily life, such as a stepping reaction. In addition, performance of upper extremity responses, which is hardly divided to several components by individual function, can be evaluated by a single parameter (i.e., reaction time) if they include an incorrect initial impulse. Assessing stepping performance in response to the flanker task may enable us to investigate not only the inhibitory function during movement initiation, but also multiple aspects including processing speed, balance function and physical performance, which can be applied to the assessment of postural control. Additionally, analysis of the individual phase would reveal the contributing factor for movement prolongation with respect to several components such as processing, initial APA, and stepping itself.

The present study focuses on cognitive processing during movement initiation; these are critical components that determine the accuracy and speed of step execution. We hypothesized that if visual interference can load the cognitive process and increase the potential deficits in choice step execution, then the flanker task may increase initial motor program errors (i.e., APA errors), which influence on the prolongation of step execution because of the additional time needed to correct the erroneous APA.

Ⅱ. Study 1: Effect of attentional load on postural adjustment in the choice step reaction

Ⅱ-1. Objective

The purpose of this study was to determine whether visual interference, which would be attentional load on cognitive process, has any effect on the initial motor program and choice step execution and whether the presence of an APA error influences on the response times and step execution in healthy young adults.

Ⅱ-2. Methods

Ⅱ-2-1. Participants

Twenty healthy young subjects participated in this study; these included 8 women and 12 men, age of 22.5 ± 0.9 years; height of 166.0 ± 10.7 cm; and body mass of 58.9 ± 8.4 kg (number show a mean ± SD, respectively). In accordance with the Declaration of Helsinki, the participants were informed of the experimental procedure, and each submitted a written informed consent before participation in the study. The experimental procedure was approved by the local ethics committee (Graduate School of Medicine, Nagoya University, approval no. 11-514).

Ⅱ-2-2. Task and design

During each trial, the participants viewed a display that contained visual cues; they initially stood upright on 2 separate force platforms, with their heels separated mediolaterally by 6 cm so that every trial would begin from the same position. The visual display was set 1 m in front of the participants at eye level (Fig. 1). Before each trial, the participants were required to stand with their weight evenly balanced. If 1-sided weight distribution was detected between each force plate, the participant was instructed to shift the weight to the left or right to achieve an approximately balanced weight distribution (not more than 55% of weight on either foot) before starting the trial. They were instructed to execute forward stepping as quickly and accurately as possible on the side indicated by the central arrow (←, left vs. →, right), moving their foot 30 cm on each step trial. In 1 block (neutral condition), only 1 arrow was shown in the same central location on the display. In the other block (flanker condition), the visual display contained 5 arrows; the participants were asked to indicate the direction the central arrow was pointing while ignoring the 2 flanking arrows on each side. In half the trials, the flanking arrows pointed in the same direction as the central arrow cue (←←←←← or →→→→→; congruent condition), while in the other half, the flanking arrows pointed in the opposite direction (←←→←← or →→←→→; incongruent condition). In the incongruent condition, the flankers provided conflicting information that caused interference, typically resulting in an increase in response errors. The direction of the central arrow and each flanker condition (congruent or incongruent) appeared randomly. The neutral condition contained 8 trials, whereas the flanker condition contained 16 trials, including equal numbers of congruent and incongruent conditions. The 2 conditions were blocked and counterbalanced, with every participant completing 24 trials in total.

Ⅱ-2-3. Instrumentation and data analysis

The vertical force data during the step execution were collected using 2 separate force platforms (Twin-gravicorder G-6100, Anima Co., Tokyo, Japan). The force platform data were sampled at 500 Hz. Specific temporal events were extracted from the step execution data using a program written in MATLAB (MathWorks Inc., Cambridge, MA, USA). Figure 2 shows data for the vertical force under both feet as a percentage of body weight, obtained during the 2 trials of step execution by the right foot. Figure 2A shows a trial in which the initial APA was in the correct direction (i.e., increased force under the swing foot to be lifted). Figure 2B shows a trial in which the initial APA was in the wrong direction (i.e., increased force under the initial stance leg), which delayed the step. The following events were extracted from the vertical force data: (1) APA onset, the first time the difference in vertical force under the 2 feet increased by 5% of the body weight; (2) APA errors, trials in which the participants executed an APA in the incorrect direction and then corrected that APA and stepped with the correct foot [10]; (3) foot-off, the first moment when the vertical force under either foot decreased to zero; (4) foot contact, the first moment the vertical force under the swing leg exceeded 10 N. Step execution time was calculated as the time from cue to foot contact. Individual phases of step execution were calculated according to the following definitions: (a) reaction phase, the time from cue to APA onset (even if it was an error); (2) APA phase, the time from APA onset to foot-off; (c) swing phase, the time from foot-off to foot contact [6]. The mean and SD values were determined using the data from the individual conditions (i.e., the neutral, congruent, and incongruent conditions), which normally included 8 trials each.

Ⅱ-2-4. Statistical analysis

Before performing the analysis, we excluded data from the trials in which the participants (a) initiated an APA sooner than 100 ms after the light cue, indicating that the response was simply guessed [10], and (b) stepped with the wrong foot. This left 474 trials. First, 1-way repeated-measures analysis of variance [ANOVA; task condition (neutral vs. congruent vs. incongruent)] was used to analyze the individual response times and errors employing a general linear model. If main effects were detected, post hoc comparisons were performed. A probability of $p < 0.05$ was considered statistically significant.

Second, when the trials were divided according to the presence or the absence of an APA error, we had different numbers of trials in each cell. Therefore, we used a linear mixed model approach to determine the effects of the condition and the presence or the absence of an APA error on the step characteristics. By entering data from each trial into each model, we built a model that could account for the different numbers of trials in different cells. To determine the effects of the conditions and the APA errors on step execution time and individual phases, we used a linear mixed model with condition (i.e., neutral, congruent, or incongruent) and APA error (i.e., present or absent) as the fixed factors and the participants as the random factor. Additionally, the relationships between step execution time and divided phases in individual conditions were examined using Pearson's correlations.

Ⅱ-3. Results

Ⅱ-3-1. Influence of condition on APA errors and response times

Table 1 shows all the variables in the neutral, congruent, and incongruent conditions. For combined neutral, congruent, and incongruent conditions, APA errors occurred in 98 trials in total. Significant main effects of condition were observed in the APA errors ($F_{1,18}$ = 36.1, $p < .001$; Fig. 3A), step execution time ($F_{1,18}$ = 20.2, $p < .001$; Fig. 3B), reaction phase ($F_{1,18}$ = 17.1, $p < .001$), APA phase ($F_{1,18}$ = 13.2, $p < .001$), and swing phase ($F_{1,18}$ = 42.1, $p < .001$). There were significantly more APA errors in the incongruent condition (41.7%) than in the neutral (11.2%, $p < .001$) and congruent conditions (10.9%, $p < .001$). The step execution time, reaction phase, and APA phase were significantly longer in the incongruent condition than in the neutral and congruent conditions (step execution time: p < .001, p < .001; reaction phase: p < .001, p = .007; APA phase: p = .002, p = .002, respectively), whereas the swing phase was significantly shorter in the incongruent condition than in the neutral (p < .001) and congruent conditions (p < .001).

Ⅱ-3-2. Influence of APA errors on response times during step execution

Next, we considered the influence of the APA errors on the timing of stepping using a linear mixed model. In Figure 4, the trials are divided according to whether an APA error occurred or not. Inferential statistics are reported in Table 2. The step execution time and APA phase in trials with APA errors were longer than those in trials with correct initial APAs ($F_{1,450} = 22.4$, $p < .0001$; $F_{1,450} = 130.9$, $p < .0001$, respectively). There were no significant interaction between the APA error and the condition in the step execution time and APA phase ($F_{1,450} = 1.7$, $p = .17$; $F_{1,450} = .4$, $p = .68$, respectively).

Conversely, the reaction phase was delayed in trials with correct APAs compared to trials with APA errors ($F_{1,450} = 12.8$, $p < .001$). There was also a significant interaction between the APA error and the condition in the reaction phase ($F_{1,450}$ = 4.8, p < .009), indicating that the reaction phase in trials with correct APAs was particularly delayed in the incongruent condition (Fig. 4B). The swing phase in trials with APA errors was shorter than that in trials with correct APAs ($F_{1,450}$ = 17.5, p < 0.001). There was no significant interaction between the APA error and the condition in the swing phase ($F_{1,450}$ = .9, p = .37).

Ⅱ-3-3. Correlation between step execution time and divided phases in individual conditions

Table 3 shows correlation coefficients between step execution time and divided phases in individual conditions. In the neutral condition, step execution time showed significant correlation with APA phase (r = .93, p < .001) and swing phase (r = .84, p < .001). In the congruent condition, step execution time showed significant correlation with APA phase (r = .86, p < .001) and swing phase (r = .84, p < .001). In the incongruent condition, step execution time showed significant correlation with reaction phase (r = .46, p = .04), APA phase (r = .81, p < .001) and swing phase (r = .79, p < .001). Reaction phase showed higher proportion in the step execution time than APA and swing phases in the all conditions.

Ⅱ-4. Discussion

The results of the general linear model support our prediction that the initial motor program errors (i.e., APA errors), step execution time, reaction phase, and APA phase would significantly increase in the incongruent condition compared to the neutral and congruent conditions. The linear mixed model revealed that the presence or absence of APA errors affects the individual timing of stepping in different ways. In trials with APA errors, step execution times were delayed and APA phases were significantly lengthened for all 3 conditions in a similar manner (Fig. 4A, C), indicating that step execution prolongation, caused by visual interference, mainly derived from initial motor program errors and its correction (i.e., prolonged APA). On the other hand, the reaction phase was lengthened in trials with correct APAs. In addition, interaction between APA error and the condition in the reaction phase indicated that prolongation in trials with correct APAs is predominant in the incongruent condition (Fig. 4B). Accurate performance in the incongruent condition of the rapid reaction task is known to require greater attentional control than that required in the congruent condition of the task because subjects must inhibit the processing and response associated with the distracting flanker stimuli [14,16]. One of the key phenomena in rapid reaction tasks is the speed accuracy trade-off, in which a decision maker can perform faster at the expense of accuracy and vice versa [17,18]. In the incongruent condition, longer time might be necessary for processing visual information in order to make a correct postural preparation. The prolonged mean reaction phase in the incongruent condition might be attributable to cautious responses in trials with correct APAs.

Despite the prolonged reaction phase, the step execution time in trials without APA errors was shorter than that in trials with APA errors. As the result of correlation analysis, APA phase had the highest influence on step execution time in divided phases. The findings of the present study, which focused on stepping performance in response to the flanker task, suggest that a cautious strategy involving a longer response to prevent initial motor program error may paradoxically shorten the total step execution time. Further research is needed to clarify whether instructions attaching importance to accuracy induce faster step execution time.

Attentional load from the visual interference may hamper the suppression of inappropriate motor response and cause the affected postural synergy during APA. It was found that the medial gluteus muscles of the swing and stance legs were sequentially activated before the foot-off of the swing leg during rapid stepping and gait initiation [19]. It was hypothesized that this sequential activation of the medial gluteus muscles serves to shift the weight laterally in preparation for the foot-off [20]. In trials with APA error, it is possible that inappropriate activation of the medial gluteus muscles of the stance legs may start faster than swing leg, which causes errors in the direction of initial weight transfer.

The limitation of the present study is that the instruction to stand with the body weight evenly balanced might have added an additional cognitive load. It is necessary to acknowledge the influence of this cognitive load; however, we needed to prevent 1-sided weight distribution, which would affect the following APA and choice stepping performance itself [21]. In addition, almost all the participants could stand with their weights evenly balanced (not more than 55% of the weight on either foot), and only a few participants were instructed to adjust their weight distribution.

II -5. Summary of study 1

The visual interference effect of a flanker task increases initial motor program errors and prolongs step execution time even in young adults. Furthermore, the step execution time in trials with APA errors was longer than that in trials without APA errors, even though the reaction phase was prolonged in trials with correct APAs. In the future, we should examine the effects of aging on the cognitive process and step execution performance with attentional load and evaluate if this related to the risk of falling.

Main part of this article, table 1,2 and figure 2-4 were published in *Gait Posture*, entitled "*Effects of visual interference on initial motor program errors and execution times in the choice step reaction*" (*Gait Posture* 2013, 38(1):68-72) [22].

Ⅱ-6. Table

Table 1. One-way repeated measures ANOVA on measurement parameters

	Conditions, mean ± SD			Main effect	
	Neutral	Congruent	Incongruent	F	*p*
APA errors (%)	11.2 ± 13.3	10.9 ± 14.8	41.7 ± 13.2††, **	36.1	<0.001
Step execution time (s)	0.89 ± 0.09	0.91 ± 0.09	0.95 ± 0.11††, **	20.2	<0.001
Reaction phase (s)	0.34 ± 0.03	0.35 ± 0.04	0.38 ± 0.05††, **	17.1	<0.001
APA phase (s)	0.31 ± 0.05	0.31 ± 0.05	0.35 ± 0.06††, **	13.2	<0.001
Swing phase (s)	0.25 ± 0.04	0.25 ± 0.04	0.22 ± 0.04††, **	42.1	<0.001

F statistics and *p* values for step execution time, reaction phase, APA phase, and swing phase.

††: Significant difference between the neutral and incongruent conditions (Bonferroni test, $p < 0.01$).

**: Significant difference between the congruent and incongruent conditions (Bonferroni test, $p < 0.01$).

Table 2. Effects of APA error and condition on the timing of stepping

	APA error		Conditions		Interaction	
	F	*p*	*F*	*p*	*F*	*p*
Step execution time	22.4	<0.001	3.1	0.045	1.7	0.17
Reaction phase	12.8	<0.001	13.1	<0.001	4.8	0.009
APA phase	130.9	<0.001	0.3	0.74	0.4	0.68
Swing phase	17.5	<0.001	19.8	<0.001	0.9	0.37

F statistics and p values for step execution time, reaction phase, APA phase, and swing phase as a function of APA error (i.e., present or absent) and condition (i.e., neutral, congruent, or incongruent). A linear mixed model was applied with APA error and condition as the fixed factors and the participants as the random factor.

Table 3. Correlation coefficient between step execution time and divided phases in individual conditions

			Reaction phase	APA phase	Swing phase
Step execution time	Neutral	r	0.29	0.93***	0.84***
		Proportion (%)	38	34	28
	Congruent	r	0.38	0.86***	0.84***
		Proportion (%)	38	34	28
	Incongruent	r	0.46*	0.81***	0.79***
		Proportion (%)	40	37	23

Note. Pearson's correlation coefficients and proportions each phase in step execution time were indicated (%).

*: Significant correlation ($p < 0.05$).

***: Significant correlation ($p < 0.001$).

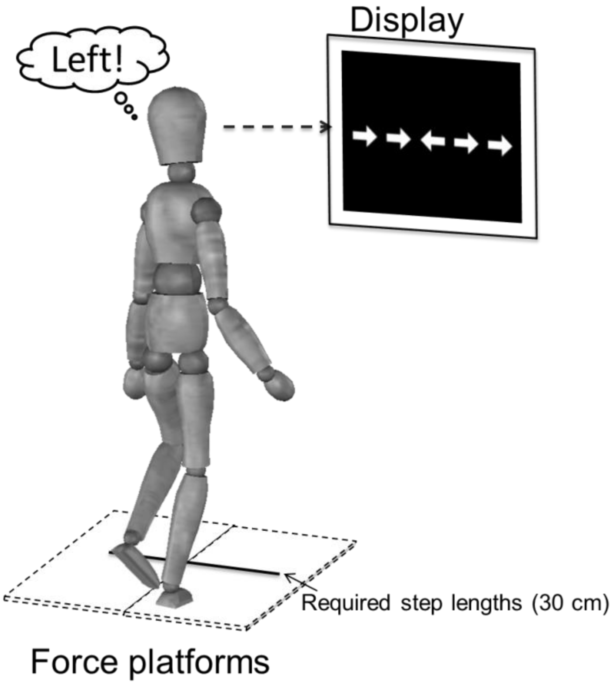

Figure 1. Schematic representation of choice stepping test

Participants initially stood upright on a separate force platform (heels were separated 6 cm mediolaterally so that every trial would begin from the same position). The visual display was set 1 m in front of participants at eye level.

II -7. Figure

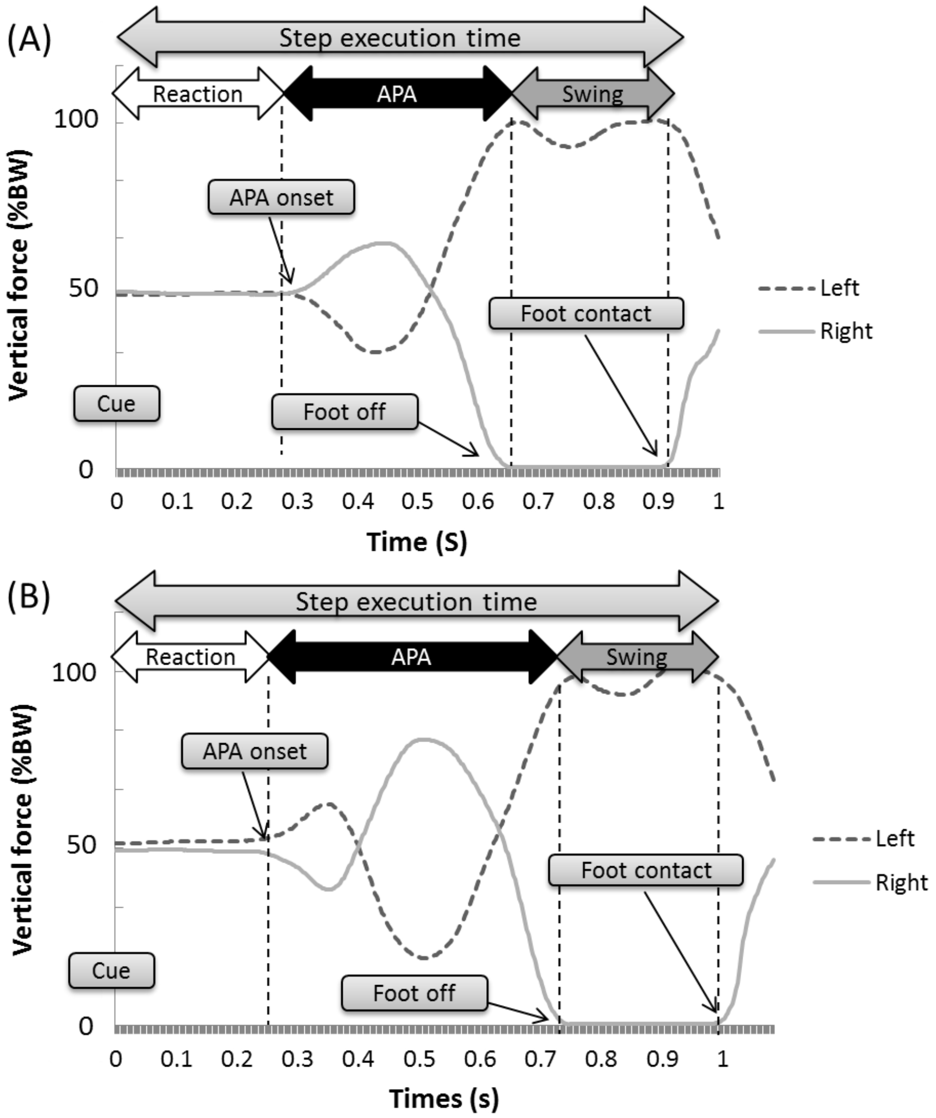

Figure 2.

Two example data of the step execution trials with the right foot, with vertical force expressed as a percentage of body weight. (A) A trial with a correct initial APA. (B) A trial with an initial APA error. The following events were extracted from the vertical force data: (1) APA onset, the first time the difference in vertical force under both feet increased by 5% of the body weight; (2) APA errors, trials in which the participants executed an APA in the incorrect direction, subsequently corrected that APA, and stepped with the correct foot; (3) foot-off, the first moment the vertical force under either foot decreased to zero; (4) foot contact, the first moment the vertical force under the swing leg exceeded 10 N. BW, body weight.

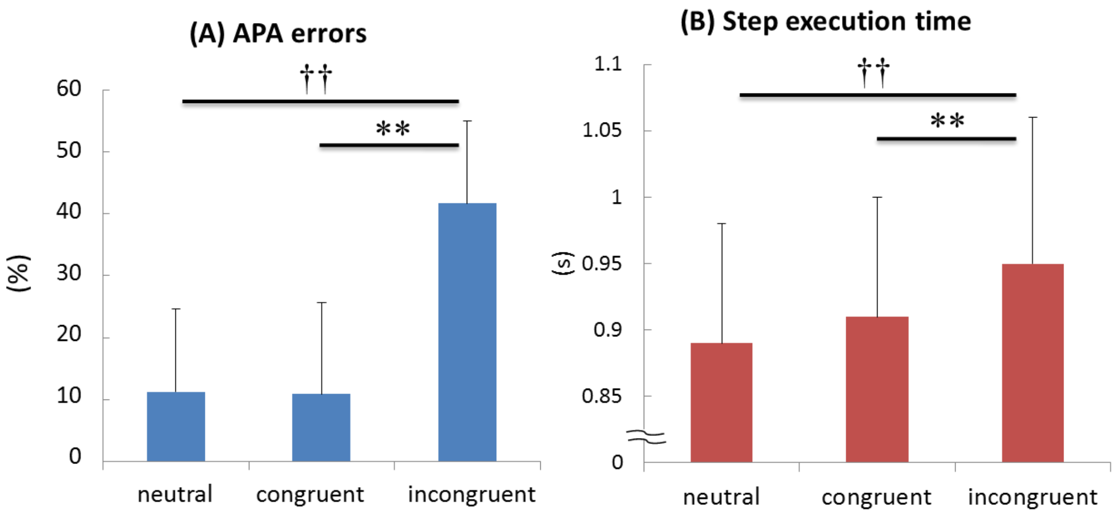

Figure 3.

Mean of the measurement parameters, (A) APA error rates, and (B) step execution time, in different task conditions: neutral, congruent, and incongruent condition.

††: Significant difference between the neutral and incongruent conditions (Bonferroni test, $p < 0.01$). **: Significant difference between the congruent and incongruent conditions (Bonferroni test, $p < 0.01$).

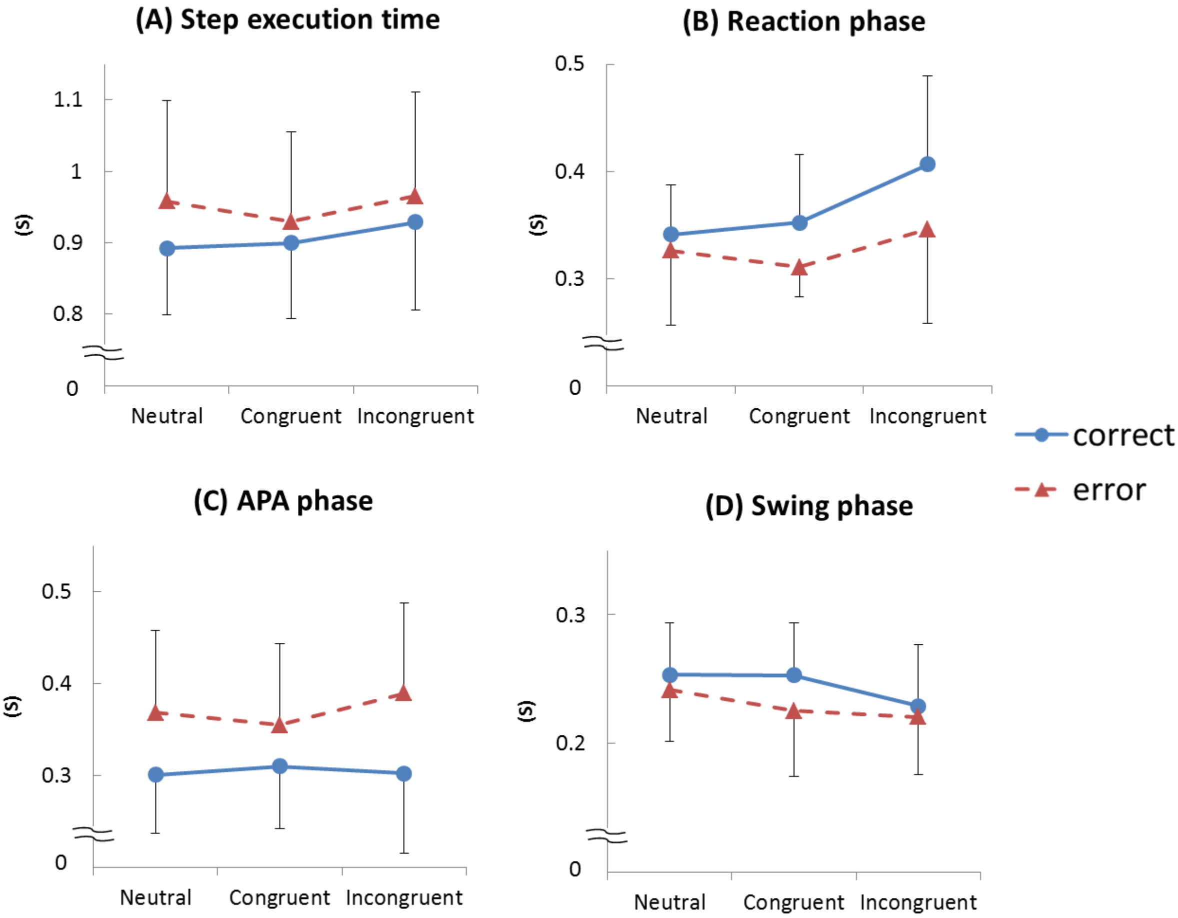

Figure 4.

Effect of APA errors on individual timing of step initiation: (A) the step execution time, (B) reaction phase, (C) APA phase, and (D) swing phase. Circles connected to solid lines: the mean values from the trials with correct APAs. Triangles connected to dashed lines: the mean values from the trials with APA errors. The inferential statistics are reported in Table 1.

Ⅲ. Study2: Effect of speed and accuracy strategy on postural adjustment in the choice step reaction with attentional load

Ⅲ-1. Background and Objective

One of the key phenomena in rapid reaction tasks is the speed-accuracy trade-off in which a decision-maker performs faster at the expense of accuracy and vice versa [17,18]. People can often control their level of the speed-accuracy trade-off, that is, select or change their position along a continuum of speed versus accuracy to suit the task requirements [23]. Individuals can approach a task by focusing on the speed of performance (often at the expense of making more errors), or on the accuracy of performance (often at the expense of slowing reaction time). It is important to strike a reasonable balance between the competing demands of speed and accuracy in order to improve efficiency [18]. Reaction time studies covering a wide range of information processing, including perception, have been conducted [24-26]. Many of these studies used tasks that required upper-limb extremity responses via the fingers or hands in a seated position [17,18,23,27]. It is possible that a speed-accuracy trade-off also underlies postural movements in a standing position that consist of more complex cognitive and motor processes than those of upper-limb extremity responses. A postural task performed in a standing position requires the maintenance of balance during the entire motion and places constraints on its completion, thus interfering with the classical speed-accuracy trade-off reported by the experiment based on upper-limb extremity responses [28]. While many experiments based on postural tasks include the typical instruction to "be as fast and accurate as possible," no study has investigated the effects of a strategy emphasizing a focus on either speed or accuracy and manipulating the priority between them. Finger-press reaction performance, which is hardly divided to several components by individual function, can be evaluated by a single parameter (i.e., reaction time) if an incorrect initial impulse is included. Conversely, analysis of the individual phase during step execution would reveal a contributing factor of movement prolongation with respect to several components (such as processing, initial APA accuracy, and stepping itself), which may clarify the trade-off mechanism in more detail.

Flanker task is considered to be ideal for investigating the interaction between interference control and speed and accuracy strategy [29], which has been investigated using finger-press reaction time. We found that flanker task, used as visual stimulus, increases APA errors during choice step execution (~30%), which prolongs duration of APA and step execution (~ 0.05 s) even if stepping on the correct side is ultimately executed (Study 1) [22]. Visual interference of a flanker task complicates the initial motor program, which is critical for step execution performance; this may influence the speed and accuracy trade-off mechanism. Therefore, we used a flanker task as the visual stimulus for the choice stepping task to investigate the interaction between visual interference and speed-accuracy strategy. It is possible that accuracy should be emphasized in order to prevent excessive APA errors and the associated prolongation of step execution time in choice stepping with the flanker task rather than simple choice stepping.

It should be noted that subjects might not necessarily show the maximum level of efficiency in the standard condition, where they were not instructed to focus on a particular factor, such as speed or accuracy [30]. Therefore, we believe that modification and manipulation of the priority or balance between speed and accuracy by instruction or coaching may contribute to improvements in the efficiency and safety of postural movement for frail elderly and disabled persons with incorrect movement strategy. First, in order to develop efficient instructional methods for clinical use, it is necessary to investigate the effects of the speed and accuracy strategy on the performance of locomotion in healthy subjects. We wished to examine whether shifting the level of the speed-accuracy trade-off by instructing participants to focus on one or the other would affect performance in choice step execution. The purpose of this study was to clarify the speed and accuracy trade-off mechanism during a postural task in an upright position. We examined the effects of a speed or accuracy strategy on initial motor program errors and choice step execution in response to the flanker interference task in healthy young adults. This was done in order to provide preliminary data on the trade-off mechanism during a postural task. We hypothesized that if visual interference from a flanker task complicates the initial motor program, the speed-emphasis instruction will increase APA errors, especially in choice stepping with the flanker task rather than simple choice stepping.

Ⅲ-2. Methods

Ⅲ-2-1. Participants

Eighteen healthy young subjects participated in this study, of whom 8 were women and 10 were men, age of 21.9 ± 1.5 years; height of 166.1 ± 9.4 cm; and body mass of 55.9 ± 7.9 kg (number show a mean ± SD, respectively). All the participants were free of neurological and musculoskeletal impairments. In accordance with the Declaration of Helsinki, the participants were informed of the experimental procedure, and each submitted a written informed consent before participating in the study.

Ⅲ-2-2. Task and design

Main task and setting were same with Study1, which can be referred to Methods section of Study 1 (Ⅱ-2-2). Participants were instructed to execute forward stepping by moving their foot by 30 cm on the side indicated by the arrow in the center of the display (←, left vs. →, right) in each step trial (Study1-Fig. 1). The emphasis placed in the instructions was changed in 3 ways. For the control instruction, participants were instructed to execute choice forward stepping as quickly and accurately as possible. For the accuracy instruction, participants were instructed to focus on making an accurate response without losing too much speed. For the speed instruction, participants were instructed to focus on speeding their responses and be less concerned about making errors, but not to the point of simply guessing a response [31]. The order of the 3 instructions was randomized.

The manipulation of visual stimulus included 2 conditions, which were blocked and counterbalanced. In 1 block (neutral condition), only 1 arrow was shown in the same central location in the display. In the other block (flanker condition), the visual display contained 5 arrows and the participants were asked to follow the direction in which the central arrow was pointing while ignoring the flanking arrows. In half the trials, the flanking arrows pointed in the same direction as the central arrow cue (←←←←← or →→→→→; congruent condition); in the other half, the flanking arrows pointed in the opposite direction (←←→←← or →→←→→; incongruent condition). In the incongruent condition, the flankers provided conflicting information that caused interference, typically resulting in an increase in response errors. The direction of the central arrow and the flanker condition (congruent or incongruent) appeared randomly. There were 8 trials for each condition of the flanker manipulation (i.e., neutral, congruent, and incongruent), with these 24 trials then crossed with the 3 conditions of the instruction manipulation (i.e., control, speed, and accuracy), resulting in a total of 72 trials. Participants were allowed to sit and rest for approximately 5 minutes between blocks.

Ⅲ-2-3. Instrumentation and data analysis

Instrumentation and data analysis methods were mostly same with Study1, which can be referred to Methods section of Study 1 (Ⅱ-2-3). Accuracy was measured with percentage of step error (i.e., stepped with the wrong foot) and APA error for each condition and instruction. The mean and SD values of timings of step initiation were determined using the data from trials without step error for each condition (i.e., neutral, congruent, and incongruent) and instruction (control, speed, and accuracy), which normally included 8 trials if no step error occurs. For individual parameters, flanker effects (i.e., interference effects of the selective attention task) are calculated using the following formula: incongruent – congruent [31]. A larger flanker effect indicates that visual interference increases APA error or prolongs response times during step execution more greatly.

Ⅲ-2-4. Statistical analysis

A two-way repeated-measures analysis of variance (ANOVA; instruction [control vs. speed vs. accuracy] × task condition [neutral vs. congruent vs. incongruent]) was used to analyze the individual timings (step execution time, reaction, APA, and swing phase) and error rates (step and APA error). A one-way repeated-measures ANOVA (instruction [control vs. speed vs. accuracy]) was used to analyze the flanker effects. Post hoc comparisons (Bonferroni test) were performed to assess differences due to instruction methods in the individual condition. A p value of less than .05 was considered statistically significant.

If the trials were divided according to the presence or the absence of an APA error, we would have different numbers of trials in each cell. Therefore, a linear mixed model approach was used to determine the effects of the condition and the presence or the absence of an APA error on the step characteristics in individual instructions. By entering the data from each trial individually into each model, we built a model that could account for the different numbers of trials in different cells. Before analyzing the data, we removed the trials stepped with the wrong foot. This left 1283 trials. To determine the effects of conditions, instructions, and APA errors on step execution time, we used a linear mixed model with condition (i.e., neutral, congruent, or incongruent), instructions (control, speed, or accuracy), and APA error (i.e., present or absent) as the fixed factors and participants as the random factor. APA errors for the combined neutral, congruent, and incongruent conditions occurred in 100 trials for control instruction, 124 trials for speed instruction, and 63 trials for accuracy instruction. We did not observe shifts in weight greater than 5% of each participant's body weight earlier than 100 ms after the cue.

Ⅲ-3. Results

Ⅲ-3-1. Influence of instruction and condition on error rates during step execution

Table 1 shows error rates during step execution in the neutral, congruent, and incongruent conditions for individual instructions. An interaction was observed between instruction and condition for APA error rates ($F_{1,16} = 2.7$, $p = .042$; Fig. 1(a)). Significant main effects of instruction and condition were observed in the APA error rates ($F_{1,16} = 11.6$, $p < .001$; $F_{1,16} = 104.9$, $p < .001$). The main effect was qualified by the interaction. Post hoc comparisons showed that APA error rates were significantly larger when speed was emphasized than when accuracy was emphasized in the neutral and incongruent conditions ($p < .01$; $p = .01$, respectively); however, there was no significant difference between the emphasis on speed and accuracy in the congruent condition ($p = .84$).

There was no significant interaction for step error rate ($F_{1,16} = .4$, $p = .81$).

There were extremely few step errors (<1.4%) in all conditions, with no significant main effects of instruction or condition ($F_{1,16}$ = .38, p = .69; $F_{1,16}$ = 2.3, p = .11).

Ⅲ-3-2. Influence of instruction and condition on response times during step execution

Table 2 shows response times during step execution in the neutral, congruent, and incongruent conditions for individual instructions. No significant interaction was found between instruction and condition for step execution times ($F_{1,16}$ = .8, p = .52; Fig 1(b)). Significant main effects of instruction and condition were observed in step execution times ($F_{1,16}$ = 23.9, p < .001; $F_{1,16}$ = 32.5, p < .001). Post hoc comparisons showed that step execution times were significantly shorter in the speed instruction compared to the control and accuracy instruction conditions (p < .01; p < .01, respectively).

A significant interaction between instruction and condition was detected in the reaction phase ($F_{1,16}$ = 3.9, p = .006). Significant main effects of instruction and condition were observed in the reaction phase ($F_{1,16}$ = 11.8, p < .001; $F_{1,16}$ = 22.8, p < .001). The main effect was qualified by the interaction. Post hoc comparisons showed that the reaction phase was significantly shorter for the speed instruction than for the accuracy instruction in all conditions (p < .01). The reaction phase was also significantly shorter for the control instruction than the accuracy instruction in the congruent condition (p = .02), but there was no significant difference in the neutral and incongruent conditions (p = .07; p = .14, respectively).

A significant interaction between instruction and condition was detected in the APA phase ($F_{1,16}$ = 2.9, p = .047). Significant main effects of instruction and condition were observed in the APA phase ($F_{1,16}$ = 11.5, p < .001; $F_{1,16}$ = 39.4, p < .001). The main effect was qualified by the interaction. Although the APA phase was shorter for the speed instruction than for the control and accuracy instructions in the neutral and congruent conditions (p < .01), there was no significant difference in the incongruent condition between the speed and accuracy instructions (p = .17).

No significant interaction effect was found between instruction and condition for the swing phase ($F_{1,16}$ = .39, p = .81). Significant main effects of instruction and condition were observed in the swing phase ($F_{1,16}$ = 29.1, p < 0.001; $F_{1,16}$ = 80.9, p < .001). Post hoc comparisons showed that the swing phase was significantly shorter in the speed instruction than the control and accuracy instruction conditions (p < .01; p < .01, respectively).

Ⅲ-3-3. Influence of instruction methods on flanker interference effects during step execution

Significant main effects of instruction were observed on the flanker effect, as measured by APA error rate ($F_{1,16}$ = 4.4, p = .019; Fig. 2(a)), reaction phase ($F_{1,16}$ = 4.2, p = .023; Fig. 2(c)), and APA phase ($F_{1,16}$ = 6.0, p = .006; Fig. 2(c)). However, there were no significant main effects of instruction on flanker effects of step execution time ($F_{1,16}$ = .38, p = .68; Fig. 2(b)) and swing phase ($F_{1,16}$ = .41, p = .67; Fig. 2(c)). The flanker effect indicated by APA error rate was significantly larger for the speed instruction than the accuracy instruction (p = .035; Fig. 2(a)). The flanker effect observed in reaction phase was significantly smaller for the speed instruction than the control and accuracy instructions (p = .05; p = .032; Fig. 2(c)). Conversely, the flanker effect observed in APA phase was significantly larger for the speed instruction than the control and accuracy instructions (p = 0.031; p = 0.042; Fig. 2(c)).

Ⅲ-3-4. Influence of APA errors on response times during step execution in individual instructions

Next, we considered the influence of APA errors on the timing of stepping by using a linear mixed model. In Fig. 3, the trials were divided according to whether an APA error occurred. There was no interaction effect between APA error, condition, and instruction ($F_{1,1281}$ = .53, p =.71); between APA error and condition ($F_{1,1281}$ = .86, p =.49); between APA error and instruction ($F_{1,1281}$ = .79, p =.45); and between condition and instruction ($F_{1,1281}$ = 1.04, p =.41). However, step execution time was prolonged in trials with APA errors relative to trials with correct initial APA for all instruction methods ($F_{1, 1281}$ = 117.3, p <.001). In the neutral condition, similar step execution times were observed in trials with correct initial APA and APA errors.

Ⅲ-4. Discussion

We investigated the influence of instruction emphasis on response conflict resolution during choice step execution. This is the first study to clarify the speed and accuracy trade-off mechanism during a postural task while participants were in an upright position. We found that step execution time was shortened when task instructions emphasized speed compared to accuracy regardless of condition, which is in line with previous studies that used finger-press reaction time [23,29]. On the other hand, step error rate remained unchanged, although APA error rate increased notably when speed was emphasized compared with accuracy strategy. When a standing person produces a movement that can potentially disturb postural equilibrium, the movement is preceded by APA—changes in the activity of postural muscles that lead to early changes in mechanical variables [5,32]. Step reaction needs APA as a means of generating forces and moments of force that counteract the predicted mechanical effects of the planned action on the postural task [33]. Therefore, as foot-off and stepping itself start after the complete shifting of body weight to the stance leg, errors in the initial direction of APA might be corrected before foot-off in many cases. Thus, in the trade-off for the choice step task, step execution time was shortened with the speed strategy and APA error was decreased with the accuracy strategy, although step errors remained unchanged. Increased initial motor program errors and unchanged step errors under a speed strategy could only be detected during a postural task requiring a preparatory weight shift to compensate for gravitational effects, unlike upper-limb tasks performed in a seated position.

The flanker interference effect on total reaction time (i.e., step execution time) is equivalent in the 3 instructions. However, phase analysis revealed that the mechanism and the factor responsible for delayed step execution are different. Step execution was divided into 3 components; reaction phase (processing), APA phase (weight transfer for postural preparation), and swing phase (step itself) [6]. For the control instruction condition, the flanker effect suggests that both the reaction and APA phases were prolonged in the incongruent condition, which led to an extension of step execution time. Accurate performance in the incongruent condition of the rapid reaction task is well known to require greater attentional control than that required in the congruent condition because subjects must inhibit the processing and the response associated with the distracting flanker stimuli [14,16]. Thus, in a standard strategy (i.e., control), the reaction phase would be prolonged in order to react accurately to the distracting visual stimulus [22]. A similar response was seen when accuracy was emphasized. However, an emphasis on speed did not increase processing duration but increased APA error and APA phase compared to the other instruction conditions. It is thus possible that hasty strategy specifically leads to an increase in initial motor program errors and prolongation of the APA duration.

In response to visual interference in the incongruent condition, the speed instruction increased the APA error more so than other instructions, as indicated by a flanker interference effect on APA error rates. The linear mixed model revealed that the presence of APA errors delays step execution time for all instruction methods. Cohen et al. [10] reported that older adults are more likely to have APA errors, which might explain the apparent slowing of choice reaction time with age. In older adults, speed instructions may prominently increase APA errors in response to visual information, including interference effects. Additionally, it is reported that older adults need to move more slowly for maintaining accuracy in postural reaction task than young adults [34]. Thus, an emphasis on speed may have an adverse effect on frail older adults (such as prolonged step execution time through increased APA error or increased step error) that could influence on falling; if so, therapists should instruct them to prioritize accuracy over speed during postural movement. Since the present study provided preliminary data based on healthy young adults, further research is needed to explore the effects of advancing age and disability (e.g., neurological disorders) on response conflict resolution during choice step reactions in a speed-accuracy trade-off in order to develop appropriate clinical methods. This study provides preliminary data of a speed and accuracy trade-off mechanism during a choice step task, which could be used to assess older adult or clinical samples. In the future, this knowledge should be applied to the development of efficient instructional methods for clinical use such as coaching and rehabilitation for disabled persons with incorrect movement strategy.

Ⅲ-5. Summary of study 2

To our knowledge, this is the first detailed study of the effect of speed or accuracy emphasis instructions on the accuracy of initial motor program and speed of leg movement in standing human subjects. APA error was increased in response to the flanker task and step execution time was shortened with a speed strategy compared to an accuracy strategy. Furthermore, in response to visual interference of the flanker task, speed instructions increased APA errors more than other instructions. The present experiment provides quantitative support for the use of speed or accuracy emphasis instruction to manipulate the priority or balance between speed and accuracy to improve the efficiency and safety of postural movement. In clinical rehabilitation, therapists should instruct patients on emphasis and manipulate the level of the speed-accuracy trade-off in frail elderly and disabled persons with incorrect movement strategy, such as a hurried person with limited mobility. In terms of the preliminary data obtained in the present study, we should examine the interaction effects between aging/disability and the effects of a speed or accuracy strategy on the cognitive process and step execution performance in response to a flanker task.

Main part of this article, table 1,2 and figure 1-3 were published in *Human Movement Science*, entitled “*Effects of speed and accuracy strategy on choice step execution in response to the flanker interference task*” (*Hum Mov Sci* 2013, 32(6):1393-403) [35].

Ⅲ-6. Table

Table 1. Results of the two-way repeated measures ANOVA on error rates during step execution

	Instructions	Conditions, mean ± SD			Main effect (instruction)		Main effect (condition)		Interaction (instruction × condition)	
		Neutral	Congruent	Incongruent	F	*p*	F	*p*	F	*p*
Step error rate (%)	Control	0.7 ± 2.9	1.4 ± 4.0	1.4 ± 4.0	0.38	0.69	2.3	0.11	0.4	0.81
	Speed	0.7 ± 2.9	0.7 ± 2.9	1.4 ± 4.0						
	Accuracy	0	0	1.4 ± 4.0						
APA error rate (%)	Control	11.1 ± 14.1	12.8 ± 16.1	44.7 ± 21.4	11.6	< 0.001	104.9	< 0.001	2.7	0.042
	Speed	18.3 ± 14.9**	11.1 ± 9.4	58.2 ± 21.9**						
	Accuracy	3.4 ± 7.1	7.4 ± 9.9	31.9 ± 19.2						

**Significant difference between accuracy and speed instructions (Bonferroni, p < .01).

Table 2. Results of the two-way repeated measures ANOVA on response times during step execution

	Instructions	Conditions, mean ± SD			Main effect (instruction)		Main effect (condition)		Interaction (instruction × condition)	
		Neutral	Congruent	Incongruent	F	*p*	F	*p*	F	*p*
Step execution time (s)	Control	0.90 ± 0.09	0.92 ± 0.10	0.96 ± 0.11	23.9	< 0.001	32.5	< 0.001	0.8	0.52
	Speed	0.81 ± 0.08[a]**	0.82 ± 0.08[a]**	0.86 ± 0.08[a]**						
	Accuracy	0.94 ± 0.08	0.97 ± 0.09	1.00 ± 0.1						
Reaction phase (s)	Control	0.32 ± 0.09	0.33 ± 0.09	0.36 ± 0.1	11.8	< 0.001	22.8	< 0.001	3.9	0.006
	Speed	0.32 ± 0.08*	0.33 ± 0.08**	0.33 ± 0.09**						
	Accuracy	0.35 ± 0.09	0.36 ± 0.09[b]	0.39 ± 0.1						
APA phase (s)	Control	0.29 ± 0.09	0.3 ± 0.1	0.33 ± 0.1	11.5	< 0.001	39.4	< 0.001	2.9	0.047
	Speed	0.24 ± 0.07[a]**	0.25 ± 0.07[a]**	0.33 ± 0.11						
	Accuracy	0.3 ± 0.08	0.32 ± 0.09	0.35 ± 0.11						

	Control	0.24 ± 0.07	0.24 ± 0.07	0.21 ± 0.07						
Swing phase (s)	Speed	0.19 ± 0.06[a]**	0.19 ± 0.57[a]**	0.17 ± 0.05[a]**	29.1	< 0.001	80.9	< 0.001	0.39	0.81
	Accuracy	0.24 ± 0.07	0.24 ± 0.07	0.22 ± 0.06						

[a]Significant difference between control and speed instructions (Bonferroni, $p < .01$). *Significant difference between accuracy and speed instructions (Bonferroni, $p < .05$). **Significant difference between accuracy and speed instructions (Bonferroni, $p < .01$). [b]Significant difference between control and accuracy instructions (Bonferroni, $p < .05$).

Ⅲ-7. Figure

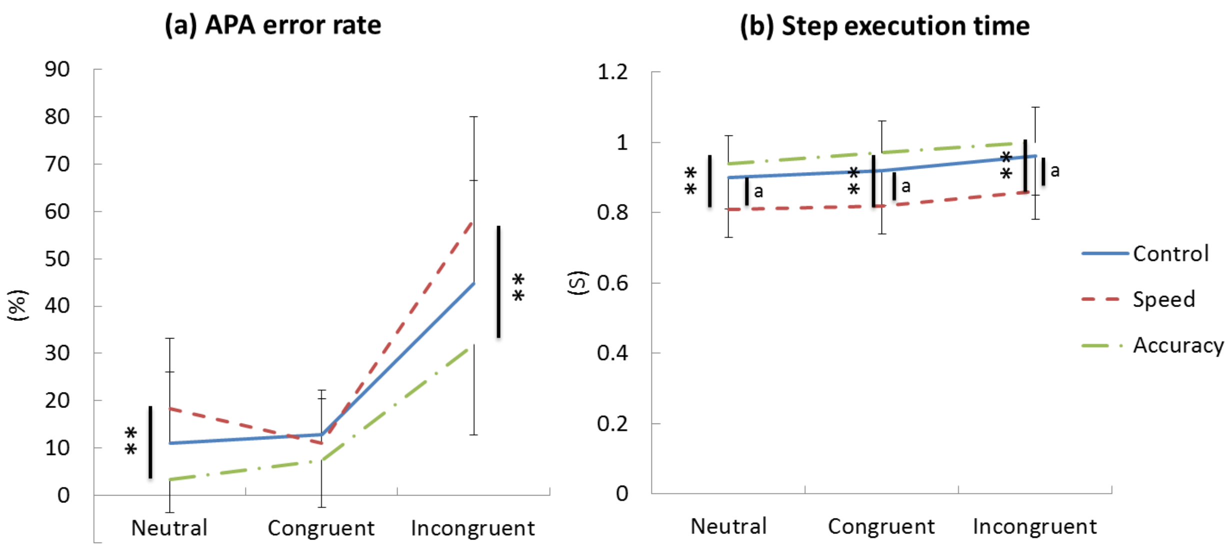

Figure 1.

Mean of the measurement parameters, (a) APA error rate and (b) step execution time, in different task conditions—neutral, congruent, and incongruent condition—with different instructions: control, speed and accuracy. [a]Significant difference between control and speed instructions (Bonferroni, $p < .01$). **Significant difference between accuracy and speed instructions (Bonferroni, $p < .01$).

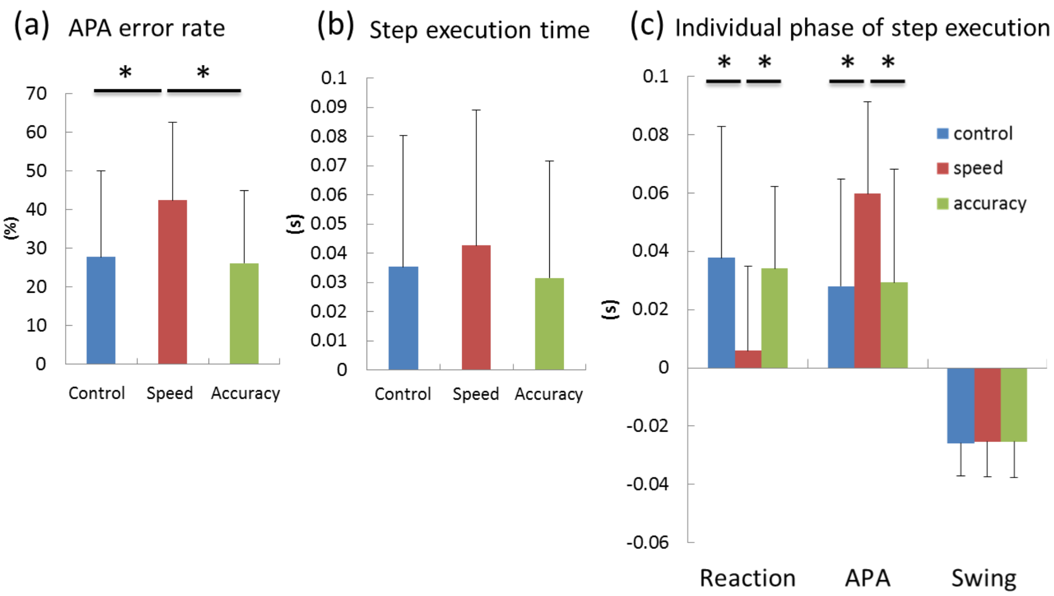

Figure 2.

Interference effects of the flanker task on (a) APA error rate, (b) step execution time, and (c) individual phase of step execution.

*Significant difference (Bonferroni, $p < .05$).

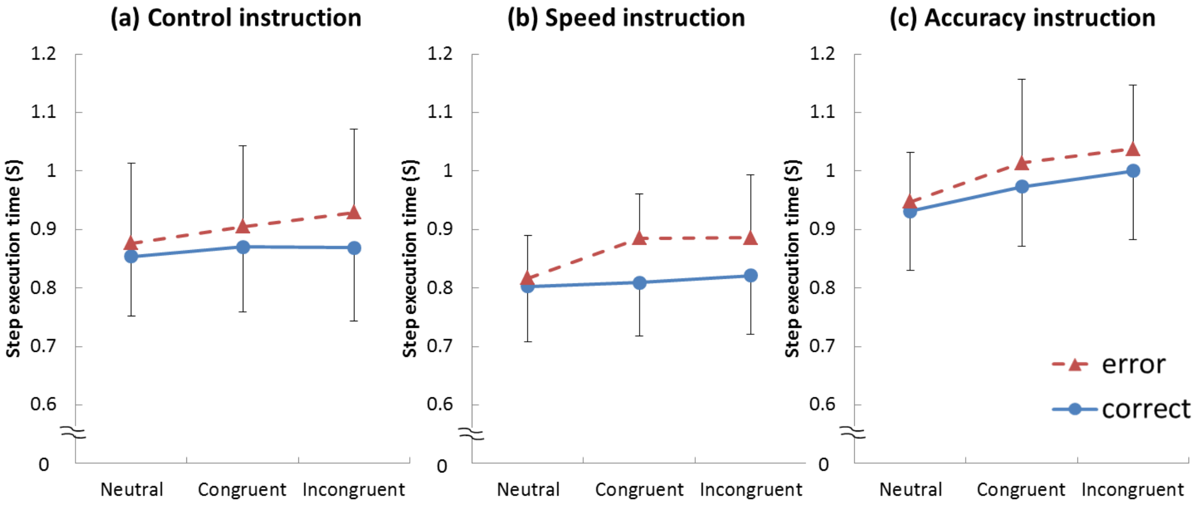

Figure 3.

Effect of APA errors on step execution time in individual instruction: (a) control instruction, (b) speed instruction, (c) accuracy instruction. Circles connected to solid lines: the mean values from the trials with correct APAs. Triangles connected to dashed lines: the mean values from the trials with APA errors.

Ⅳ. General discussion

The present study explored effects of attentional load caused by visual interference on initial motor program errors and execution times in choice step reaction, and also examined the speed and accuracy trade-off mechanism of those in healthy young adults. We focused on APA error and response times in choice step reaction as indicators of postural control deficits in this study. On the other hand, step error itself (i.e., stepped with the wrong foot) is not focused on because error rate and response time of the upper extremity responses to the flanker task are enough to assess inhibitory function itself. Response times of choice step reaction with attentional load reflect multiple aspects including processing speed, balance function and physical performance, which can be applied to the assessment of postural control.

Assessing stepping performance with attentional load may help predict the risk of falls in older adults. Cognitive dysfunction is a responsible factor to falls in older adults [36]. However, the precise mechanisms through which impaired cognitive abilities cause deficits in postural control or reaction are not completely understood [37]. In an fMRI study, Liu-Ambrose and colleagues reported that older adults who experienced falls showed hypofunctioning in the cerebellum during a selective attention task (i.e., flanker task by manual response) [38]. However, there is a lack of research on quality of cognitive process during movement or postural control in which older adults are likely to fall. The results of the present study revealed that attentional load of a flanker task increases potential errors in postural preparation and total execution times in choice step reaction, even if stepping on the correct side is ultimately executed, which will lead to clarification of potential deficits in postural control during step initiation. It is suggested that prolonged step execution time along with increased initiation of an incorrect motor program may increase the likelihood of falling in the elderly.

Ⅴ. Conclusion

We found that the visual interference effect of a flanker task increases initial motor program errors and prolongs step execution time even in young adults and the step execution time in trials with APA errors was longer than that in trials without APA errors. It is suggested that attentional load on cognitive process during step initiation may expose the potential deficits in postural control. Additionally, it is also clarified that speed and accuracy strategy affects the accuracy of initial motor program and speed of leg movement in different manners, which provides quantitative support for the use of speed or accuracy emphasis instruction to manipulate the priority or balance between speed and accuracy to improve the efficiency and safety of postural movement. Clarification of those control mechanism will contribute to the development of assessment method of postural control addressing cognitive process. Further research is needed to explore the effects of advancing age, risk of falling and disability on choice step reaction in a speed or accuracy strategy, which will contribute to the development of screening tool of fall risk and exercise program for fall prevention including instruction methods.

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