國立臺灣大學醫學院物理治療學系暨研究所

碩士論文

School and Graduate Institute of Physical Therapy

College of Medicine

National Taiwan University

Master Thesis

作業優先性對姿勢-上姿勢作業與大腦活動的影響：年齡效應

The Effects of Task Prioritization on Postural-suprapostural Task and Cortical Activity: Age-related Differences

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中華民國 104 年 7 月

July, 2015

國立臺灣大學碩士學位論文
口試委員會審定書

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本論文係游舒涵君（R02428003）在國立臺灣大學物理治療學系暨研究所完成之碩士學位論文，於民國 104 年 7 月 20 日承下列考試委員審查通過及口試及格，特此證明

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致謝

人生中每一個里程碑的到達都伴隨許多人的協助，而長達兩年的研究所生涯，也同樣接受到很多人的幫助。首先，由衷地感謝指導教授黃正雅老師的協助，從研究架構的形成、實驗基礎的訓練、實驗困境的突破到碩士論文的撰寫，每一個階段都受到老師很大的幫助及引導，總是在身旁給予許多建議及鼓勵，使我的研究之路一直都相當順遂，也從中獲得很多的成就感及收穫。此外，感謝口試委員吳瑞美醫師、周立偉老師、陸哲駒老師和張雅如老師在研究及論文上給予許多寶貴的建議，使我能對於研究有更多不同面向的思考，而使研究與論文都能更臻於完善。

這兩年的研究生活中，感謝好朋友郁婷、甯雅和嘉容提供能夠談心歡笑的時間和空間，紓解準備研究和論文時的煩惱及壓力，也感謝學系老師給予許多的關心與指導，更感謝所有受試者熱心地參與實驗，包含臺大醫院志工阿姨伯伯和醫院員工、其他單位的志工阿姨伯伯、大學部的學弟妹、碩士班和博士班的學長姊，給予相當大的協助與鼓勵而使實驗進度能順利推展。最後，真心感謝父母提供無憂的環境可以專心的進行研究及撰寫論文，這兩年間默默給予強大的支援。

「學問如逆水行舟，不進則退」，感謝過去已無法細數的所有協助，成為了推動的助力，幫助我在學問的逆流中一路前進，而能在今日邁向了新的里程碑。

中文摘要

研究背景與目的：姿勢-上姿勢作業為於維持身體平衡下，同時進行另一項動作或認知活動。由於注意力資源的有限性，適當且有效率的注意力配置，亦即作業優先性選擇，為獲得較佳姿勢-上姿勢作業表現的關鍵因素。此外，隨年齡增長，大腦注意力資源及其注意力配置的能力會逐漸下降，更加突顯作業優先性選擇的重要性。然而，目前關於姿勢-上姿勢控制的作業優先性(姿勢優先、上姿勢優先)探討及其相對應的神經機制仍尚未被仔細探討。因此，本研究的主要目的為探討年輕及老年族群，在使用不同作業優先策略下，對姿勢-上姿勢作業表現及大腦活動的影響。

研究方法：本研究共招募16位健康年輕受試者(平均年齡：24.4 ± 4.6歲)及16位健康年長受試者(平均年齡：69.1 ± 2.7歲)進行姿勢-上姿勢作業測試。實驗中受試者站立於平衡板上維持平衡(姿勢作業)，並同時執行右手大拇指與食指的精準按壓動作(上姿勢作業)。姿勢作業之目標角度設為受試者前傾平衡板最大角度的一半，而上姿勢作業之目標力量設為受試者執行精準按壓最大力量數值的一半。實驗過程中須分別將主要注意力放置於姿勢平衡(姿勢優先)或精準按壓動作(上姿勢優先)來執行姿勢-上姿勢作業。實驗過程中記錄平衡板角度變化、精準按壓力量、右手第一背側指間肌肌電圖，並同步測量受試者之腦電圖。本研究之分

析參數包含：姿勢作業角度誤差、精準按壓力量誤差、平衡板晃動之近似熵(approximate entropy)、精準按壓反應時間及腦電圖事件相關電位(P1, N1, P2)振幅。統計分析使用 2 × 2 混合變異數分析(2 × 2 mixed ANOVA)及最小顯著差異法(least significant difference)進行事後檢定，分析作業優先性與年齡效應對各行為表現參數及事件相關電位的影響。

結果與討論：相較於姿勢優先策略，於使用上姿勢優先策略時，年輕族群與老年族群皆會有較少的姿勢作業誤差，尤其老年族群於上姿勢優先策略時，同時會呈現較高的姿勢近似熵數值與較低的精準按壓力量誤差。於腦電圖事件相關電位振幅結果，在使用上姿勢優先策略時，年輕與老年族群的 N1 振幅皆較使用姿勢優先策略時小，反應上姿勢優先策略可降低姿勢作業所需之注意力資源的需求量，代表上姿勢優先策略是個較有效率的策略。此外，相較於年輕族群，老年族群於 N1 波與 P2 波之前，多呈現 P1 波，顯示老年族群於執行姿勢-上姿勢作業的準備初期會先進行感覺訊息的促進與整合。

結論：在執行姿勢-上姿勢作業時，上姿勢優先策略對健康年輕族群及老年族群皆是較佳的動作控制策略，不但能產生較高的作業精準度且有較佳的大腦注意力資源配置情形。

重要性與預期貢獻：本研究結果可提供健康族群，尤其是老年族群在執行姿勢-上姿勢作業時，一個較適當的動作控制策略，以提升整體動作表現，並可對姿勢-上姿勢控制的神經生理機制有進一步的瞭解。未來將進一步推展至神經疾患之患者，以期提供臨床治療時適當的訓練策略。

關鍵字：作業優先性、姿勢平衡、雙重作業、事件相關電位、年齡效應

Abstract

Background and Purpose: Postural-suprapostural task is defined as achievement of a motor or cognitive task performed simultaneously with successful postural control. Due to limited attentional resource, appropriate task prioritization is required for better performance during postural-suprapostural task, especially in elderly adults, who may have decreased attentional capacity and impaired attentional allocation. However, research on the suitable strategy of task prioritization (posture-first (PF) vs. supraposture-first (SF)) in younger and older adults is limited and lacks direct neural evidences. The purpose of this study was to investigate the effects of task-priority strategies on postural-suprapostural performance and its related cortical activity in younger and older populations.

Methods: Sixteen younger healthy and sixteen elderly healthy adults were recruited in this study. Each participant was requested to perform a force-matching precision grip task (suprapostural task) while maintaining balance on a stabilometer (postural task) with postural task or suprapostural task as the first-priority task. Both behavioral and cortical data, including task accuracy (postural error and force-matching error), postural ApEn (approximate entropy), reaction time of precision-grip, and event-related potentials (ERPs), including P1, N1, and P2 amplitudes, were recorded.

Results and Discussions: With SF strategy, less postural error was found in both younger and older groups. Furthermore, smaller force-matching error and larger postural ApEn were observed under the SF condition in the older group. ERP results revealed a task priority-dependent N1 response, which was smaller in the SF condition, indicating that SF is an efficient strategy for postural-suprapostural control. In addition, besides N1 and P2 waves, P1 positivity was observed only in the older adults, implying more facilitation of sensory processing was invested in the initial preparation phase of postural-suprapostural performance for older adults.

Conclusion: SF strategy may be the adequate strategy for both healthy younger and older adults, with better postural-suprapostural accuracy and more efficient attentional allocation than PF strategy. Further study is needed to be confident in this conclusion for patients with neurological disease, such as Parkinson’s disease.

Significance and Contribution: The study not only provided an optimal task-priority strategy for healthy adults, especially older adults, to increase their movement quality of postural-suprapostural task, but also gain a better insight to neural correlates of concurrent postural and motor-suprapostural tasks.

Keywords: task prioritization; postural balance; dual task; event-related potential; age effect

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List of Abbreviation

ANOVA	analysis of variance
ApEn	approximate entropy
CV_PPF	coefficient of variance of peak precision grip force
EEG	electroencephalography
EMG	electromyogram
ERP	event-related potential
FDI	first dorsal interosseous
LSD	least significant difference
MMSE	Mini Mental State Examination
MVC	maximum voluntary contraction
PF	posture-first
PPF	peak precision-grip force
RMS	root mean square
RT	reaction time
SA	stabilometer tilting-angle
SF	supraposture-first

TA	target angle
TF	target force

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Chapter 1

Introduction

1.1 Overview of Postural-suprapostural Task

1.1.1 Definition

Postural task is defined as the control of body posture in a stable, upright position in space for the purpose of balance or orientation, such as standing and walking.[1,2] It has been traditionally considered as an automatic controlled task which required little attention, but recent evidences have been found significant attentional requirements for postural control in facilitating multi-sensory integration and generation of motor execution.[1,3] In daily activities, upright stance is rarely undertaken without other tasks. Any task that is superordinate to the control of posture is defined as a suprapostural task.[2,4] The evaluation or behavioral goal of the suprapostural task is different from postural control and information of suprapostural performance cannot be acquired from the value of postural parameter.[4]

Performing a postural-suprapostural task is frequent for human being in daily life, such as using mobile phone while standing on a bus or carrying a bowl of soup while walking. When postural task and suprapostural task are performed together, the two attention-demanding tasks require common attentional resource simultaneously, which challenges the brain for prioritizing the two tasks.[1,5] Thus, the appropriate allocation of attention is important when performing a postural-suprapostural task for better performance of both tasks.

1.1.2 Theoretical Framework of Postural-suprapostural Task

Two theoretical frameworks have been commonly described to explain the allocation of attention in postural-suprapostural task, which are resource-competition model and adaptive resource-sharing model.[6,7] According to the resource-competition model, attention is assumed as a capacity-limited resource. When performing a postural-suprapostural task, postural task and suprapostural task compete for the same attentional resource.[6] With the available attentional capacity, both tasks are well performed. However, when attentional requirements of both tasks exceed the capacity, the concurrent tasks interfere with each other and lead to the adverse effect on the both postural and suprapostural performance.[7]

Similar to resource-competition model, the adaptive resource-sharing model postulates that postural task and suprapostural task share the same capacity-limited resource, but the concept of cost-benefit in the postural-suprapostural sharing situation is included in this model. The central system prioritizes between both tasks during postural-suprapostural task and leads the performance of both tasks to the trade-off results.[6] Furthermore, two possible patterns in the adaptive resource-sharing model are proposed based on some behavioral findings of postural-suprapostural performance, which are autonomous and facilitatory patterns. The autonomous pattern emphasizes that postural control would be acted as the primary task (the task gets more attentional resource) and is engaged in sway minimization automatically no matter which suprapostural task is added to a postural task. In contrast, the facilitatory pattern (also called as facilitatory hypothesis) emphasizes that the postural stability may improve for facilitating the suprapostural performance, especially when the suprapostural task gets more attentional resource.[6,8]

Both resource-competition model and adaptive resource-sharing model imply that the attention is a critical issue for postural-suprapostural control. Specially, how the attentional allocation (or task prioritization) operates the postural task and suprapostural task is a worth issue to study.

1.1.3 Age-related Models of Postural-suprapostural Performance

Age-related structural and functional changes have been found in musculoskeletal, neuromuscular, cardiovascular, and sensory system, which affected the ability of postural control.[9,10] To compensate the deterioration of postural control, older adults need more attentional requirement for balance comparing to younger adults, even in simple postural condition.[1,11] However, attentional capacity has been found decreased with aging, leading to greater age-related differences of attentional allocation in postural-suprapostural tasks.[12]

Lacour et al. (2008)[13] summarized three age-related models for explaining the poor postural control in postural-suprapostural task, including the cross-domain competition model, the nonlinear interaction model, and the task-prioritization model. First, the cross-domain competition model assumed that the postural task and suprapostural task shared and competed for the attentional resource, leading to less sufficient resource for postural control.[13,14] The increase of the age enlarges the adverse effect of posture during the competition of the both tasks due to reduced attentional capacity.[13] Second, the linear interaction model proposed that the postural performance depended upon the attentional requirement of the suprapostural task.[3,13] With adding a low demanding suprapostural task, postural task improves in both younger and older adults. However, with adding a high demanding suprapostural task, the beneficial effect of suprapostural task reduces with aging.[13]

Different from the two models, the task prioritization model emphasized the importance of task-priority strategy for older adults while performing a postural-suprapostural task. Due to decreased attentional resource with aging, the older adults may tend to select the safer strategy for postural control, allocating more attentional resource to postural task for responding the age-related decline.[13,15] The model predicts that prioritization of postural control, which is also called “posture-first” strategy, is often selected on postural-suprapostural task in older adults as a compensatory attentional reallocation.[11-13] However, if the “posture-first” is the optimal control strategy for older adults while performing a postural-suprapostural task is not completely lucid.

1.2 Related Literature

1.2.1 Task Prioritization on Postural-suprapostural Performance

In a postural-suprapostural task, accomplishing the suprapostural goal and keeping balance as well is the basic purpose of the task. To achieve the better performance, appropriate task prioritization becomes an important issue in postural-suprapostural task. Recently, some previous studies manipulated participants’ major attention between postural and suprapostural tasks by verbal instruction to examine the effect of attentional allocation. Some studies showed that allocating major attention on suprapostural task would result in better postural-suprapostural performance. For example, in Siu et al.'s study (2007), the participants were requested to perform a visual spatial memory task while standing with feet together with focusing on the memory task or their balance. Participants had significantly shorter response time when prioritizing the memory task compared to prioritizing postural task and no postural sway difference between the two prioritizing conditions.[16] Also, in the research of Jehu et al. (2015), subjects were asked to perform a choice reaction time task while standing on a force platform with prioritizing the choice reaction time task or the postural task. Both less postural sway and shorter reaction time were observed under prioritizing the choice reaction time task.[17] In Kelly et al.'s study (2013),[18] participants were asked to perform a auditory Stroop task while walking. The results showed that with a cognitive-focus instruction, both cognitive and walking performance would not decrease, but with a walking-focus instruction, the performance of cognitive task deteriorated significantly but the walking speed did not improve, indicating focusing on a postural task may not a suitable strategy in a postural-suprapostural task.

However, the study of Yogev-Selignmann et al. (2010) had opposite results, reporting that a worse postural-suprapostural performance was observed under prioritization of a cognitive task.[19] In this study, participants were asked to perform a verbal fluency task while walking with focusing on the verbal fluency task or on walking. The results showed that the number of words generated in verbal fluency task was similar between the two conditions. But with focusing on the verbal fluency task, the walking speed decreased relative to focusing on walking. In addition, in study of Yogev-Seligmann et al. (2012), both word-generation number and walking speed improved when subjects focused on walking.[20] Taken together, the inconsistency in current empirical literature on postural-suprapostural task suggests that the effects of task prioritization on postural-suprapostural performance merits further scrutiny.

1.2.2 Age Difference on Postural-suprapostural Performance

Age-related change on postural-suprapostural dual tasking has been found in clinic and been examined in many studies. In clinic, we may observe that older adults stop walking while talking. In attention-related studies, impaired attention functions and impaired working memory have been evident in older adults.[12] Specially, aging-related declines in attentional capacity and resource processing efficiency are noted in multiple-tasking conditions, such as postural-suprapostural task.[3,21-23] Besides, decreased flexibility and optimality of attentional allocation across tasks are also presented in aging studies.[23,24] For instance, Doumas and Krample (2013)[21] found that when performing a auditory n-back task with standing on a sway-reference platform, the performance of postural task decreased in older adults, but not in younger adults. Huxhold et al. (2006)[3] showed that increased center of pressure displacement was found in older adults when performing more demanding cognitive task with postural task , but not in younger adults. Moreover, it had similar findings while older adults need to walk with performing a suprapostural task. Hollman et al. (2006)[25] found slower gait velocity in older adults than younger adults when spelling five-letter words in reverse and walking across the walkway concurrently. Also, comparing to younger adults, older adults had less word-generation number and less walking distance when performing a word-fluency task concurrent with walking on a narrow track.[19] All these studies showed deterioration of both postural and suprapostural performance in support of the view of more limited attentional capacity and attentional control ability in older adults.

1.2.3 Limitation of Previous Study About Postural-suprapostural Task

The results about task prioritization of postural-suprapostural tasks still exited inconsistency. The inconsistency was probably due to the instruction of how the subjects should focus their attention and the nature of suprapostural task (cognitive-supraposture or motor-supraposture).[26] The lack of specification in instruction of prioritization has been considered a major limitation of postural-suprapostural related studies,[16,19] and little difference of the instruction may significantly affect the performance.[17] Most previous studies only instructed the primary task to subjects, such as “focus on the cognitive task and perform it as quickly and accurately as possible”, or “focus on your posture and keep balance as still as possible”, and even did not tell subjects the focused task is the primary task. Without specific instruction for both primary and secondary tasks, subjects may allocate their attention between the primary and secondary tasks differently and result in inconsistency performance. Hence, the instruction of how to allocate their attention between postural and suprapostural tasks should be more specific and clear to avoid discrepancy in attentional allocation between subjects.

On the other hand, the type of suprapostural tasks is also one of the critical factors that may affect the interaction between postural and suprapostural tasks. Most previous literatures used cognitive tasks to be the suprapostural task, such as Stroop task or verbal-fluency task.[19,27] However, growing literatures suggested that combination of motor task and postural task may increase the sensitivity to detect the attentional resource capacity.[28,29] Due to similar nature of postural control and motor task, motor task and postural task compete for the same input and output resources, resulting in larger interference between postural balance and motor-suprapostural performance compared with a traditional dual tasking with a posture-cognition setup. Moreover, the greater interference between postural task and motor task was found in older adults than in younger adults, due to age-related ability decline to manipulate two similar motor tasks concurrently.[23,30] Thus, postural task combined with motor task may be the proper design to observe the interaction between postural and suprapostural tasks, especially in older adults.

Next, most of previous studies about task prioritization of postural-suprapostural control just focused on the behavioral outcome but very were limited to examine the related cortical activation for central resource allocation in a postural-suprapostural task. However, only behavioral evidence is unable to well explain the brain organization for attentional allocation between postural and suprapostural tasks.[31,32] Thus, it appears that the cortical activity and behavioral measurement must be integrated to examine the interaction between postural and suprapostural tasks for providing comprehensive information of postural-suprapostural control.

1.2.4 Characterization of Cortical activity with Event-related Potentials

Event-related potential (ERP), derived from electroencephalogram (EEG), is a common electrophysiological technique for investigating information processing of cognitive or motor task.[33] As a stimulus-locked cortical potential, ERP would be labeled as “N” or “P” waveform for representing negative-going or positive-going component respectively. The number following the label represents the peak latency of the waveform,[34] such as N1 represents the negative waveform which peaks around 100 ms after stimulus and P2 represents the positive waveform which peaks around 200 ms after stimulus. Recently, because of precise temporal resolution, ERP components have been used in dual tasks for investigating attention shift between the two tasks and the stage of neural information processing.[31,32,35-37]

In dual-task paradigm, early ERP (P1, N1, and P2) and late ERP (P300) amplitudes have been known as an index of resource allocation of cognitive processing.[32,35,36] P1 amplitude was reported associated with sensory input to attended task and arousal.[38,39] For postural-suprapostural dual tasking, it was found that N1 amplitude was associated with the information processing of postural control[32,37] and P2 amplitude was related to suprapostural (a precision-grip force-matching task) control.[32] Both Huang and Hwang (2013)[32] and Little and Woollacott (2015)[37] reported that the amplitude of N1 increased when posture demand increased. Besides, P2 amplitude would be modulated by suprapostural difficulty. With high difficulty of suprapostural task, P2 amplitude would be decreased, representing more attentional resource allocated to the suprapostural task.[32] Based on previous studies, P1, N1 and P2 amplitudes were known to play an important role on attention processing in postural-suprapostural task. Therefore, both P1, N1 and

P2 amplitudes were focused in the ERP analysis for representing attentional allocation between postural and suprapostural tasks in the present study.

1.3 Rationales

1. There is inconsistency on advantage and defects between posture-first (PF) strategy and supraposture-first (SF) strategy. It is valuable to realize which task-priority strategy is the suitable strategy when performing a postural-suprapostural task.
2. Because appropriate attentional allocation or attentional shift is a critical factor for successful postural-suprapostural execution, ERP signals could be helpful to identify the neural mechanism of critical level in different task-priority strategies. The understanding of cortical activation of postural-suprapostural execution may facilitate innovative and pertinent treatment strategy for people who are multi-tasking disturbances and prevent them from falling.
3. Comparing to younger adults, older adults may suffer from decreased attentional capacity and impaired attentional allocation,[3] and this may affect the applicability of task-priority strategy between younger and older adults. In this study, both younger and older adults would be included to investigate the effects task prioritization on postural-suprapostural tasks.

4. The instruction affects the way participants allocating their attention in a postural-suprapostural task.[17] Unclear instruction may confuse the participants, leading to different attentional allocation between subjects. In the present study, the “optimum-maximum method”[40] would be used for instructing subjects and enhancing the guidance of task prioritization.
5. Most postural-suprapostural studies use a cognitive task as the suprapostural task. However, a motor-suprapostural task can increase the phenomenon of resource-competition or resource-sharing.[28,29] Besides, a motor-suprapostural task is very common in our daily life, such as cooking on moist floor or texting on the bus. In the present study, we would choose a motor task, precision-grip task, as the suprapostural task.

1.4 Purpose and Significance

The purpose of this study was to investigate the effects of different task prioritization (PF vs. SF) on postural-suprapostural performance and its related cortical activity in younger and older populations. The significance of the present study was addressed in the academic and clinical aspects. In the academic aspect, this study provided a better insight of the behavioral results and neural mechanism of attentional allocation under different task prioritization in both younger and older populations. Especially, through this study, we could clarify the applicability of “facilitatory hypothesis” or “posture-first principle” with behavioral and cortical evidences (Figure 1). In clinical aspect, the results may provide the clinical value for the physical therapists to instruct older adults who have multi-tasking difficulty with a suitable movement strategy in their daily life and prevent them from falling.

1.5 Hypotheses

1. Both postural and suprapostural performance are different between a postural-suprapostural task with PF or SF strategy. In addition, the suitable task-priority strategy for younger and older adults is different. These hypotheses would be systematically tested by postural and suprapostural accuracy, postural regularity and reaction time of the suprapostural task. We expected that optimal postural-suprapostural overall performance was found with SF strategy in younger adults, whereas optimal postural-suprapostural overall performance was found with PF strategy in older adults.
2. Attentional resource allocation between postural and suprapostural tasks is different depending the participants performing a postural-suprapostural task with PF or SF

strategy. This hypothesis would be tested by P1, N1, and P2 amplitudes of ERP signals, for representing the allocated attention for posture and supraposture respectively. We expected that P1, N1, and P2 amplitudes were significantly affected between PF and SF strategies. Moreover, frontal area was found related to information processing of working memory under dual-task condition and motor-type suprapostural task was found related to parietal area.[32,41,42] Therefore, significant effects were expected found in frontal and parietal areas when adopting PF and SF strategies.

Chapter 2

Methods

2.1 Participants

Thirty two healthy right-handed volunteers (16 younger adults, mean age: 24.4 ± 4.6 years; 16 older adults, mean age: 69.1 ± 2.7 years) without history of neurological, vestibular, orthopedic, or cardiovascular disorders were recruited in this study. All subjects had normal or corrected-to-normal vision. For older subjects, they were able to ambulate independently without walking aids and had no history of falling. Besides, Mini Mental State Examination (MMSE) score was measured for older adults and only the subjects with more than 24 points were included (Appendix 1). Because the subjects were asked to perform an suprapostural task while standing on a stabilometer (67-cm length × 50-cm width × 24-cm height, anterior-posterior tilting angle: 0-100 degrees), the subjects who were pregnant, had prior experience with tasks, unable to maintain balance on the stabilometer for at least 80 seconds, or took any medications that could affect balance were excluded from this study. Telephone interview with the subjects was done before recruiting. Table 1 is the demographic data of both younger and older groups.

The protocol was approved by the research ethics board at the National Taiwan

University Clinical Trail Center (Appendix 2). Study procedure was explained by the researcher for each subject and an inform consent was signed by the subjects prior to participating in this experiment.

2.2 System Set-up and Data Recording

The experiment consisted of postural task and suprapostural task. Participants were requested to perform a force-matching precision grip task with their right index and thumb (suprapostural task) while standing on a stabilometer (postural task) (Figure 2). For the postural task, participants were asked to maintain their balance on the stabilometer (67-cm length × 50-cm width × 24-cm height, anterior-posterior tilting angle: 0-100 degrees) with an inclinometer (Model: FAS-A, MicroStrain, USA) mounted on the center of the stabilometer plate to measure the tilting angle of the stabilometer. The maximal anterior tilting was recorded for each participant before the experiment and the 50% of the maximal anterior tilting angle was set as the target angle for the postural task. For the suprapostural task, participants were asked to execute a force-matching task, and the level of force output was recorded with a load cell (15-mm diameter × 10-mm thickness, net weight = 7 grams; Model: LCS, Nippon Tokushu Sokki Co., Japan). Maximum voluntary contraction (MVC) of precision grip was also recorded before the experiment and the

50% of the MVC force was set as the target force for the suprapostural task. The participants needed to execute the thumb-index precision grip task in response to auditory cues. The auditory cues consisted of 80-second sequences of tone pips, with a total of fifteen warning-executive signal pairs. The interval between a warning tone (frequency: 800 Hz, duration: 100 ms) and an executive tone (frequency: 500 Hz, duration: 100 ms) was 1.5 seconds for the first three warning-executive pairs, but was random presented at different intervals of 1.5, 1.8, 2.1, 2.4, 2.7 or 3.0 seconds form the fourth to fifteenth warning-executive pairs. The interval between the executive tone and the next warning tone was 3.5 seconds. Participants performed a quick thumb-index precision grip (force impulse duration < 0.5 second) to couple the peak precision force with the force target when receiving the executive tone. In order to determine the reaction time (RT) of force-matching, the initial activation of the first dorsal interosseous (FDI) muscle was recorded with surface electromyogram (EMG) in a bipolar arrangement (Ag/AgCl, 1.1 cm in diameter, Model: F-E9M-40-5, GRASS) and an AC amplifier (gain: 5000, cut-off frequency: 1 and 300 Hz; Model: QP511, GRASS).

For recording cortical activation, electroencephalogram (EEG) data was recorded from a 32 Ag-AgCl scalp electrodes with a NuAmps amplifier (NeuroScan, EI Paso, TX). The placement of the EEG electrodes was according to the 10-20 International System at the following locations: $Fp_{1/2}$, F_z, $F_{3/4}$, $F_{7/8}$, $FT_{7/8}$, FC_z, $FC_{3/4}$, $FC_{7/8}$, C_z, $C_{3/4}$, CP_z, $CP_{3/4}$,

P_z, $P_{3/4}$, $T_{3/4}$, $TP_{7/8}$, O_z, and $O_{1/2}$. The ground electrode was placed along the midline ahead of F_z and the recording references were placed on the mastoids of the both sides. In addition, two electrodes were attached above the arch of the left eyebrow and below the eye to monitor eye movements and blinks. The impedances of all electrodes were maintained below 5 kΩ, and data was recorded with a band-pass filter set at 0.1 to 100 Hz with a notch filter at 60 Hz to remove the noise from the environment. Both behavioral and cortical signals, including stabilometer movement, precision grip force, EMG of FDI muscle, and EEG data, were synchronized with a sampling rate of 1 kHz.

2.3 Experimental Conditions and Procedures

This study was conducted in two separate days with one-week apart. Participants in both age groups were randomly assigned to either PF or SF conditions in the first day and to the other in the second day (Figure 3). In each experimental day, participants were requested to perform three experimental tasks, including one postural-suprapostural task, and two corresponding control tasks (a single corresponding postural task and a single corresponding suprapostural task). There were six trials for each experimental task.

In most previous researches related to task prioritization, the lack of specification instruction for how participants directing their attention when performing dual tasks was a major limitation.[16] For the better improvement of task prioritization instruction, a procedure derived from “optimum-maximum method” proposed by Navon (1990) was used in this study for manipulating task prioritization.[40] The optimum-maximum method was used to guard subjects’ attention with specific instruction for both high-priority and low-priority tasks.[23,43] With this method, the high-priority task was designed the “to-be-optimized” task, and low-priority task was the “to-be-maximized” task. Participants were instructed to execute the high-priority task with their “optimum” level and to perform their best on the low-priority task. Such a procedure required participants to optimize the high-priority task and not to “give up” on the low-priority task. Besides, individually determined performance standard and performance feedback were provided in the high-priority task but not for low-priority task. Therefore, in this study, visual feedback about the target and performance of stabilometer movement or force-matching task was used for enhancing the prioritization of the attention (Figure 4). For example, participants in the PF condition were instructed to pay their primary attention on the postural task with maintaining the tilting angle of the stabilometer at the target angle precisely, and to maximize the precision of force-matching task. Visual feedback of stabilometer target angle and instantaneous stabilometer tilting angle was provided in the PF condition, but visual information about the force-matching target and force output was not provided. Because the visual feedback was only provided for postural performance, the corresponding control tasks of the PF condition were that 1) performing the postural task on the stabilometer with visual feedback and did not execute the force-matching task, and 2) performing the force-matching task without visual feedback on a stable box (67-cm length × 50-cm width × 24-cm height). In contrast, participants in the SF condition were instructed to pay their major attention on the precision grip task with coupling the force peak with the target precisely, and to maximize the precise tilting angle of the stabilometer. Visual feedback of the force-matching target and force output was provided in the SF condition, but visual information about the stabilometer and its target angle was not provided. The corresponding control tasks of the PF condition were that 1) performing the postural task on the stabilometer without visual feedback and did not execute the force-matching task, and 2) performing the force-matching task with visual feedback on a stable box (67-cm length × 50-cm width × 24-cm height). Besides, in order to remind the force-matching target for the PF condition and the tilting angle target for the SF condition, the visual feedback about the first 3 force-matching performances and the first 10-second stabilometer tilting angle with their target was provided in each trial for the PF and the SF conditions, respectively. All the visual information was displayed on a 22-inch computer monitor with 60 cm in front of the subjects at eye-level.

2.4 Data Analysis

2.4.1 Behavioral Data

For postural performance, the inclinometer data was conditioned with 6-Hz low-pass filter and the units were converted to degrees. The inclinometer data from every executive tone to next warning tone was selected for calculation of absolute postural error and absolute postural approximate entropy (ApEn). The absolute postural error was presented by calculating the root mean square (RMS) of the mismatch between the target angle and the stabilometer tilting angle and then divided by the target angle, presenting as $\frac{\text{RMS(SA-TA)}}{\text{TA}}\times 100\%$ (SA: stabilometer tilting-angle, TA: target angle). The absolute postural ApEn of the stabilometer tilting angle's trajectory was used to represent the variability property of the postural performance. According to previous study, the calculation of postural ApEn was calculated after the trajectory of stabilometer tilting angle normalized with standard deviation of time series, presenting as ApEn (m, r) = $\log[C_m(r)/C_{m+1}(r)]$.[44] Where m represents the length of the compared time windows and r represents the tolerance range of the regularity.[44-46] If a completely predictable time-series with high regularity, value of $C_m(r)$ will be very close to $C_{m+1}(r)$, yielding a log-probability (ApEn) of zero.[44] In this study, m equaled 2 and the tolerance range of r was 0.15× the standard deviation of the time series[44]. The value of the ApEn was between 0 and 2. An ApEn value of closer to 2 represented higher irregularities, or larger complexity of the postural movement changes. In contrast, an ApEn value of closer to 0 represented greater regularity.[47]

For suprapostural performance, the absolute force-matching error was presented as $\frac{|\text{PPF-TF}|}{\text{TF}} \times 100\%$ (PPF: peak precision-grip force, TF: target force). The absolute force-matching RT of suprapostural task was recorded by calculating the time delay from the presentation of executive tone to the EMG onset of FDI muscle. All behavioral parameters of postural-suprapostural task were normalized in reference to its corresponding control task.

$$normalized\ value = \frac{absolute\ value_{\_postural\text{-}suprapostural}}{absolute\ value_{\_corresponding\ control}} \times 100\%$$

2.4.2 ERPs Data

The manipulation of Event-related potentials (ERPs) data mainly referred to the previous ERP study.[32] The recorded EEG data was processed with NeuroScan’s 4.3 software (NeuroScan Inc., EI Paso, TX, USA) and the off-line analysis was used for the analysis. The DC shift of each channel on entire EEG data was corrected with third-order correction. The eye movements and blinks were removed from the EEG data. After eye movements were removed, the EEG data was low-pass filtered with cut-off frequency of 40 Hz (48 dB/octave), and segmented into epochs of 700 ms, including a 100 ms before the onset of executive signals. The 100 ms-data prior the executive signals was used for the baseline correction of each EEG epoch. A visual inspection for each epoch was applied, and those epochs with artifacts, including excessive drift, eye movements or blinks, were removed from analysis. Those epochs with adequate responses were averaged. ERPs from the six trials of each task were group averaged separately at each condition for each subject. According to the previous ERP studies, P1 amplitude was reported associated with sensory input to attended task[38], N1 was associated with the attention modulation related to postural control, and P2 was associated with the attention modulation related to perceptual-motor suprapostural task,[32,44] Therefore, in the present study, we analyzed the peak amplitudes of P1 (70-110 ms), N1 (80-150 ms), and P2 (150-240 ms) components across all EEG electrodes to characterize the attention allocation between postural and precision-grip tasks.

2.5 Statistical Analysis

The task prioritization conditions (PF condition, SF condition) and age groups (younger group, older group) effects on behavioral and electrophysiological parameters of postural and suprapostural tasks, including the normalized force-matching error, normalized force-matching RT, normalized postural error, normalized postural ApEn, and ERP amplitudes of P1, N1, and P2 components were compared with 2×2 mixed analysis of variance (ANOVA). When necessary, *post hoc* least significant difference (LSD) comparisons were performed. The level of significance was set at $p < 0.05$. Signal processing of behavioral data and statistical analysis was completed by using MatLab v. R2008a (Mathworks, Natick, MA, USA) and the statistical package for SPSS statistics v. 17.0 (SPSS Inc., Chicago, IL, USA).

Chapter 3

Results

3.1 Behavioral Performance

3.1.1 Error and Regularity of Postural Performance

Figure 5 shows the absolute and normalized postural error of SF and PF conditions in the younger and older groups. ANOVA results suggested that normalized postural error was subject to task prioritization ($F_{1, 30} = 12.99$, $p < 0.01$) and age difference ($F_{1, 30} = 11.28$, $p < 0.01$) without interaction ($F_{1, 30} = 0.30$, $p = 0.59$). Larger normalized postural error was observed in the PF condition than that in the SF condition for both younger and older groups ($p < 0.05$). Besides, normalized postural error was larger in the older group than that in the younger group across task prioritization conditions ($p < 0.05$). The normalized postural error of SF condition in the younger group was below 100% (84.51 ± 3.86%), but the others were above 100%, indicating that younger adults had better postural performance during the postural-suprapostural dual-task condition than that during the single postural task condition. For postural regularity, Figure 6 displayed the absolute and normalized postural ApEn results of SF and PF conditions in the younger and older groups. ANOVA results showed a significant main effect of task prioritization ($F_{1, 30} = 4.41$, $p < 0.05$) and age difference ($F_{1, 30} = 18.82$, $p < 0.001$) on the normalized ApEn values without a significant interaction ($F_{1, 30} = 2.21$, $p < 0.15$). *Post-hoc* testing showed a larger normalized ApEn in the younger group than that in the older group (PF condition: younger (102.87 ± 1.58%) > older (92.16 ± 1.65%)), $p < 0.01$; SF condition: younger (103.87 ± 1.70%) > older (97.99 ± 2.12%), $p < 0.05$), indicating that younger adults had higher postural irregularity when performed a postural-suprapostural task than older adults. Also, we noted that normalized ApEn was above 100% in the younger for both PF and SF conditions, but was below 100% in the older group, indicating that addition of the force-matching task led to an opposite effect on postural regularity between younger and older groups. On the other hand, the task prioritization effect on normalized ApEn was only shown in the older group with larger value in the SF condition than that in the PF condition ($p < 0.05$).

3.1.2 Error and Reaction Time of Force-matching Task

For suprapostural performance, force-matching error of PF and SF conditions in younger and older groups is shown in Figure 7. ANOVA results suggested that normalized force-matching error was subject to task prioritization ($F_{1, 30} = 12.31$, $p < 0.01$), but not to age effect ($F_{1, 30} = 2.25$, $p = 0.14$) with no significant interaction effect ($F_{1, 30} = 1.69$, $p < 0.20$). *Post-hoc* evaluation revealed that normalized force-matching error in older group was higher in PF condition than that in SF condition ($p < 0.05$). Besides, all normalized force-matching errors were above 100% (younger group: PF condition = 118.90 ± 5.63%, SF condition = 103.16 ± 5.49%; older group: PF condition = 139.88 ± 11.57%, SF condition = 105.65 ± 5.31%), indicating that force-matching error tended to increase when subjects were requested to perform a force-matching task and kept their balance on a stabilometer concurrently compared to perform the force-matching task in a stable posture (stand on a stable box).

Figure 8 displays the RT of force-matching task of PF and SF conditions in younger and older groups. Similar as force-matching error, all normalized force-matching RT values were above 100% (younger group: PF condition = 110.79 ± 3.50%, SF condition = 107.70 ± 1.87%; older group: PF condition = 102.51 ± 4.12%, SF condition = 102.36 ± 2.80%), indicating that RT would be longer when subjects were requested to perform a force-matching task and kept their balance on a stabilometer concurrently compared to perform the force-matching task in a stable posture. However, the RT of force-matching did not vary with either task-priority strategy or age difference (task-priority effect: $F = 0.48$, $p = 0.50$; age effect: $F = 3.15$, $p = 0.09$).

3.2 ERP Amplitudes

Figure 9 displays the typical ERP waveforms of younger group and older group in postural-suprapostural tasks. It is interesting to find that the ERP characteristics were different between the younger and older groups. In the younger group, only the N1 and P2 waves presented after the presentation of the executive signals across postural-suprapostural conditions (Figure 9(a)); however, the P1, N1, and P2 waves were all observed in sequence after the presentation of the executive signals in the older group (Figure 9(b)). Therefore, for statistical analysis of ERP amplitude, N1 and P2 amplitudes were analyzed via a 2 (task prioritization: PF vs. SF) × 2 (age: younger vs. older) mixed ANOVA, with repeated measure on the first variable, while P1 amplitudes was analyzed via a paired t-test to examine the task prioritization effect for the older adults.

3.2.1 Task Prioritization Effect on ERP Amplitudes

Figures 10(a-e) are typical ERP recordings showing the effects of task prioritization P1, N1, and P2 amplitudes. ANOVA results suggested that in the younger group, the N1 amplitudes of most electrodes around left frontal (F_3: $F_{1,30} = 9.34$, $p < 0.01$; FC_3: $F_{1,30} = 9.05$, $p < 0.01$), central (C_3: $F_{1,30} = 8.93$, $p < 0.01$) and parietal (CP_3: $F_{1,30} = 21.26$, $p <$

0.001; P_3: $F_{1, 30} = 16.36$, $p < 0.001$) cortices, and midline electrodes (FC_z: $F_{1, 30} = 4.37$, $p < 0.05$; C_z: $F_{1, 30} = 6.61$, $p < 0.05$) were subject to a significant task prioritization effect. *Post-hoc* analysis further indicated that the N1 amplitudes on these electrodes (F_3, FC_3, FC_z, C_3, C_z, and CP_3,) in the PF condition was generally greater than that in the SF condition ($p < 0.05$)(Figure 11(a)). On the other hand, a significant supraposture effect on P2 amplitude was noted in the left temporal (T_5: $F_{1, 30} = 6.32$, $p < 0.05$) and parietal (P_z: $F_{1, 30} = 4.68$, $p < 0.05$) cortices. Besides, some electrodes had significant interaction between task prioritization and age factors on P2 amplitudes (T_5: $F_{1, 30} = 4.90$, $p < 0.05$; P_3: $F_{1, 30} = 4.28$, $p < 0.05$; O_1: $F_{1, 30} = 4.47$, $p < 0.05$). Further *post-hoc* analysis indicated that P2 amplitudes on T_5, P_3, P_Z, and O_1 electrodes were greater in the SF condition than that in the PF condition ($p < 0.05$)(Figure 11(b)).

For the older group, paired t-test revealed that compared to with PF strategy, P1 amplitudes were larger at frontal (FC_3 and F_8), central (C_3 and C_Z), parietal (CP_3, CP_Z, P_Z and P_4), and right temporal (FT_8 and T_4) areas with SF strategy ($p < 0.05$)(Figure 11(c)). ANOVA results suggested that the N1 amplitudes of the electrodes around parietal (CP_3: $F_{1, 30} = 21.26$, $p < 0.001$; CP_Z: $F_{1, 30} = 8.97$, $p < 0.01$; P_3: $F_{1, 30} = 16.36$, $p < 0.001$; P_Z: $F_{1, 30} = 7.39$, $p < 0.05$) and temporal (T_5: $F_{1, 30} = 10.81$, $p < 0.01$) areas were subject to a significant task prioritization effect. *Post-hoc* testing showed that N1 amplitudes on these electrodes (T_5, CP_3, CP_Z, P_3, and P_Z) were larger in the PF condition than that in the SF condition ($p < 0.05$)(Figure 11(d). On the other hand, the P2 amplitudes of electrode FT_8 had a significant main effect of task prioritization ($F_{1, 30} = 5.16$, $p < 0.05$). Besides, some electrodes showed significant interaction effect between task prioritization and age factors around right frontal (F_8: $F_{1, 30} = 4.39$, $p < 0.05$; FT_8: $F_{1, 30} = 5.26$, $p < 0.05$) and temporal (T_4: $F_{1, 30} = 4.63$, $p < 0.05$) areas. Further *post-hoc* analysis indicated that F_8, FT_8, and T_4 electrodes had larger P2 amplitudes in the PF condition than that in the SF condition ($p < 0.05$)(Figure 11(e)).

3.2.2 Age Effect on ERP Amplitudes

The age effect on N1 and P2 amplitudes is displayed in Figures 12(a)-(b). For the PF condition, ANOVA results revealed a significant main effect of age difference on N1 amplitudes at frontal (F_3: $F_{1, 30} = 5.60$, $p < 0.05$; FC_3: $F_{1, 30} = 4.86$, $p < 0.05$), central (C_3: $F_{1, 30} = 5.14$, $p < 0.05$), and parietal (CP_3: $F_{1, 30} = 4.86$, $p < 0.05$; CP_Z: $F_{1, 30} = 4.22$, $p < 0.05$; P_3: $F_{1, 30} = 4.95$, $p < 0.05$) areas. *Post-hoc* evaluation showed that the N1 amplitude of these electrodes (F_3, FC_3, C_3, CP_3, CP_Z, and P_3) in the older group was generally greater than that in the younger group ($p < 0.05$)(Figure 12(a)). However, the P2 amplitude was independent of the age effect for all cortical areas in the PF condition ($p > 0.05$)(Figure 12(b)).

For the SF condition, ANOVA results revealed the a significant main effects of age groups difference on N1 amplitudes at left fronto-parietal cortex (F_3: $F_{1, 30} = 5.60$, $p < 0.05$; FC_3: $F_{1, 30} = 4.86$, $p < 0.05$; C_3: $F_{1, 30} = 5.14$, $p < 0.05$; CP_3: $F_{1, 30} = 4.86$, $p < 0.05$; P_3: $F_{1, 30} = 4.95$, $p < 0.05$) with larger N1 amplitudes in the older group (Figure 12(c)). On the other hand, ANOVA results showed a significant main effects of age difference on P2 amplitudes at occipital area (O_1: $F_{1, 30} = 4.40$, $p < 0.05$; O_z: $F_{1, 30} = 6.94$, $p < 0.05$; O_2: $F_{1, 30} = 4.55$, $p < 0.05$) and a significant interaction between task prioritization and age factors at P_z electrode ($F_{1, 30} = 4.47$, $p < 0.05$)(Figure 12(d)). *Post-hoc* analysis indicated that P2 amplitudes on these electrodes (P_Z, $O_{1/2}$, and O_z) were greater in the younger group than that in the older group ($p < 0.05$).

Figure 13 displays the topological plots of the younger and older groups in each postural-suprapostural condition. It seems that task prioritization affected the activation duration of N1 and P2 waves in the younger and older groups respectively. In the younger group, with activation duration of N1 wave was shorter in the SF condition and P1 activation of the older group seemed earlier in the SF condition than in the PF condition. In addition, the age difference also affected the activation of N1 and P2, with greater activation intensity and area of N1 wave in the older group but greater activation intensity and area of P2 wave in the younger group.

Chapter 4

Discussions

4.1 Improved Task Accuracy with SF Strategy

The results showed significant task prioritization effect on postural and suprapostural tasks in both younger and older adults. First, better postural/ suprapostural performance was found in both age groups when paying major attention on force-matching task in postural-suprapostural task (Figures 5, 7), which in line with some studies related to task prioritization.[17,48] Burcal et al. (2014) showed greatest postural improvements when focusing on suprapostural task compared with focusing on balance and no focusing instruction.[48] Jehu et al. (2015) also reported that less postural sway was observed when prioritizing reaction time task than prioritizing posture.[17] These researches suggested that focusing on suprapostural task allowed attention shifted attention away from control of posture, leading to more automatic and efficient postural control. The results may also support the constrained-action hypothesis, which proposed that consciously controlling posture or movement close to the body may interfere with the automatic control processes and thus negatively affected postural performance.[49] In addition, the postural improvement with SF strategy was also consistent with the facilitatory pattern in adaptive-resource sharing model, which proposed that postural stability may get improved in order to facilitate suprapostural performance.[6,8] The facilitatory effect was especially dominant in the older adults, because both force-matching error and postural error was less in the SF condition than that in the PF condition (Figures 5, 7). However, Yogev-Seligmann et al.'s study (2010) reported the opposite results.[19] In the study, subjects (younger and older adults) were requested to perform a cognitive task (verbal fluency task) during walking with different attention instruction, including no specific prioritization instructions, prioritization of gait and prioritization of the verbal fluency task. They found that gait speed was reduced when prioritization was given to the verbal fluency task in both age groups, indicating that SF strategy might decreased postural performance. The discrepancy between our results and Yogev-Seligmann et al.'s finding may result from different type of suprapostural task. With a motor suprapostural task, such as force-matching, attentional resource would be enforced to integrate for optimal outcome.

On the other hand, postural performance was found to be significantly better in the younger group than that in the older group for both PF and SF conditions. Age-related decline of postural performance in older adults may represent the inability to adequately allocate attentional resource between two tasks and inefficient postural control in older adults.[15,50] With aging, overall structural and functional decline resulted in decreased attentional capacity and increased attentional requirement in postural control.[9,10,12] Therefore, adding a seconding task secondary task to postural task may increase the attention load and reach the limit of attentional capacity to allocate in older adults, which consistent with the opinion of cross-domain competition model.[12-14] In addition, when adding a secondary task, younger adults may shift part of attention to the secondary task and allow more automatic control of posture. However, older adults were unable to efficiently shift attention away from posture, which lead to interference of postural control.[50]

Second, for postural variability, the results showed a higher value of normalized postural ApEn in the SF condition than that in the PF condition (Figure 6), which represents more irregularity of postural control. [47,51] Postural regularity has been found to be positive correlated with amount of attention allocated in postural control, with higher regularity (or lower ApEn value), more attentional resource is devoted to the postural control. [47] Thus, combination of the results of postural error and normalized postural ApEn values, it could be interpret as less amount of attention required to keep postural balance when adopting SF strategy in postural-suprapostural task, and also reflects SF strategy could be have more efficient and automatic postural control.[47,51] In addition, the value of normalized postural ApEn was significantly greater in the younger group than that in the older group when performing postural-suprapostural task, indicating that younger adults could use more automatic control for keeping postural balance, and this phenomenon may partly explain the better postural performance in the younger group than that in the older group.

4.2 Facilitated P1 Wave in the Older Group in SF Condition

The present study appears to be the first to assess electrophysiological correlates (P1, N1, and P2) for postural-suprapostural tasks with different task prioritization between younger and older adults. One of our novel finding is different ERP waves facilitated during postural-suprapostural task between age groups, with P1, N1, and P2 waves in the older adults, whereas only N1 and P2 waves in the younger adults (Figure 9). Specially, the facilitated P1 waves were more dominant in the SF condition than that in the PF condition (Figure 13). According to previous literatures, although P1 and N1 were associated with sensory gain control, they reflected different aspect of attention.[52] P1 was thought to reflect the facilitation of sensory processing of task-related stimuli. [52-54] In addition, enhanced P1 positivity was found associated with increased sensory input to attended task and increased arousal,[38,39] related to high activation level of emotion, mental and physiological system.[55] Hence, facilitated P1 wave may imply that more sensory processing facilitation and arousal were involved at the initial preparation phase of postural-suprapostural task in older adults for compensating decreased information processing or reduced attentional capacity. In this study, the greater P1 positivity was observed across left primary motor cortex, sensorimotor cortex, and frontal-parietal and right frontal-temporal area in the SF condition indicated that older adults with SF strategy showed more arousal and sensory input facilitation than with PF strategy (Figure 11(c)). According to previous researches, frontal-parietal cortical region was reported related to recognition of postural instability and right frontal-temporal cortical region was related to modulation of finger force scaling.[56,57] The finding indicates that SF strategy facilitated higher sensory processing for both upcoming balance and force-matching task and results in better behavioral outcomes.

The other important finding in the present study was that N1 amplitude increased in the PF conditions for both younger and older groups. N1 was also reported associated with sensory processing for postural control.[37] Enhance N1 negativity was found related to high perceptual load, reflecting increased perceptual resource of sensory processing[36,58] and reduction of N1 amplitude was associated with automatic postural control.[37] According to our results, under PF conditions, N1 negativity was greater at left frontal-parietal area in the younger group and at left central-parietal regions in the older group respectively (Figures 11(a), (d)). Frontal-central cortical region has been found related to action monitoring and detection of error, and activation of parietal region has been found related to postural instability.[56] In addition, left hemisphere was reported a dominant role in the control of movement and motor skills that are carried out with those that require bimanual coordination.[59] Therefore, increased N1 amplitude in these areas may imply that more attention was required for executing postural task under the PF conditions. However, more attention devoted to the postural task was not necessary to result in better postural performance. According to the results of postural error, the PF conditions had more postural error indicating that PF strategy is an ineffective strategy for postural control in both younger and older adults.

On the other hand, it is interesting to find that there was an opposite task prioritization effect on P2 positivity between the younger and older groups. P2 was found related early attentional allocation for initial conscious awareness for the task[60] and suprapostural difficulty.[32] Reduction of P2 amplitude was found representing more attentional allocation to suprapostural task.[32] In younger adults, greater P2 positive around left temporal-parietal-occipital region (T_5, P_3, P_Z, and O_1), in the SF condition (Figure 11 (b)), indicating that less attention for multimodal sensory integration was allocated (or required) for the suprapostural task under SF condition than PF condition. Although, less attention was required to perform the suprapostural task, no suprapostural performance decline was found in behavioral results (Figure 7). Moreover, the topological plots also showed an earlier activation of P2 wave in the SF condition than that in the PF condition in younger adults (Figure 13). The early P2 activation may reflect more effectiveness of the attention shifted from postural task to the force-matching task. Oppositely, SF strategy would lead to less P2 positivity on right frontal-temporal cortex in the group of older adults (Figure 11 (e)), which represents more attention allocated to the suprapostural task in the SF condition. Right frontal-temporal cortex was reported acting an important role in finger force scaling and right hemisphere was related constant motor output.[57] The results may imply that more attention was devoted for better force-matching accuracy in older adults with SF strategy to compensate the decreased ability of force scaling.[61] Therefore, according to behavioral and ERP results, SF strategy may be the better strategy for both younger and older adults than PF strategy.

4.3 Age Effect on ERPs in Postural-suprapostural Tasks

Besides, N1 negativity was observed around frontal-parietal area in older adults than in younger adults for both PF condition and SF condition (Figures 12 (a), (c)). The fact indicates that more attentional resource was required for older adults to keep their balance because of less automatic postural control in older adults (smaller ApEn value, Figure 6). The topological plots also support this argument by longer activation duration and longer activation area of N1 wave in the older group (Figure 13). Age-related changes were reported in left premotor and sensorimotor cortices, which was related to postural control and internal representation of body in space,[52,53] especially for skilled movement.[54] On the other hand, enhanced P2 positivity on occipital area was found in the younger adults under SF condition (Figure 12(d)), indicating that less attentional resource was required for performing the suprapostural task in younger adults. An functional magnetic resonance imaging study showed that the occipital area was related to sensory processing.[38] Hence, the results may represent increased attentional requirement of suprapostural task in older adults for compensating the decline of sensory processing.

4.4 Methodological Issues and Limitation

First, in the current experimental paradigm, a force-matching task with 50% MVC force was used as the suprapostural task. In order to choose an adequate level of force target, we executed a pilot study to examine the variability of force output in different force-intensity and the effects of force-intensity on postural balance. With the same apparatus and postural-suprapostural task design as the current experiment, twelve healthy right-handed volunteers (4 males, 8 females; mean age: 24.5 ± 3.0 years) without past neurological or neuromuscular impairment were recruited to perform a force-matching task with 25%, 50% and 75% of MVC force while standing on a stabilometer with keeping their balance at 50% of the maximal anterior tilt angle. The twelve subjects of the pilot study were different to that of the main experiment. Subjects were instructed to performed both postural and force-matching tasks as precision as possible with providing online visual feedback of both targets and their performance. Coefficient of variance of peak precision grip force (CV_PPF) and postural error were measured in each condition. A one-way repeated-measures analysis of variance with Bonferroni adjustments were used to contrast force-matching variability (CV_PPF) and postural error differences among 25%, 50%, and 75% of MVC force conditions. The level of significance was set as $p < 0.05$. ANOVA statistics suggested that CV_PPF differed among the force-intensity conditions ($F_{2,22}= 24.18$, $p < 0.01$), and CV_PPF was greatest in the 25% MVC condition ($p < 0.01$)(Figure 14 (a)). ANOVA statistics also suggested that the postural error was not significantly different among three force-intensity conditions ($F_{2,22}= 0.03$, $p = .97$)(Figure 14 (b)). These facts indicated that postural error was not significantly affected by force-intensity of the force-matching task and force-matching with 50% or 75% of MVC force would have less within-subject variability of force output. Also, Slifkin and Newell (1999) reported that optimal signal to noise ratio is in about 50% of maximal force output that subjects can produce.[62] Besides, for avoiding possible fatigue effect result from higher force-intensity output (75% of MVC), we chose the 50% of MVC force as the target of the force-matching task in the main experiment.

Second, the experiments were conducted in two separate days with one-week apart in order to avoid the potential fatigue or learning effect. In this study, participants of both younger and older groups were assigned to either the PF or SF conditions on the first experimental day and executed the other condition on the second experimental day. On the first experimental day, half participants in both age groups were assigned to the PF condition and the others were assigned to the SF condition. Moreover, all behavioral parameters of postural-suprapostural task were normalized to their corresponding control task measured in the same experimental day, avoiding the results from the effect of different baseline conditions between two experimental days. In order to test the potential learning effect, all behavioral parameters, including normalized postural error, normalized postural ApEn, normalized force-matching error, and normalized force-matching RT, were compared between the participants who conduct the SF condition on the first experimental day and the participants who conduct the PF condition on the first experimental day via student t-test. The results showed no significant difference between these two groups in both conditions (Table 2), indicating there was no significant learning effect on behavioral performance.

Third, both younger and older adults performed the same postural task and suprapostural task in the present study. The task difficulty may be different between the younger and older adults since older adults might have less capability of balance control or force scaling than younger adults.[52,61] And the differences of relative task difficulty might vary central resource allocation and affect the optimal strategy selection and performance of postural and suprapostural tasks. However, we could not quantify the real perception of task difficulty in postural and suprapostural task for younger and older adults and it is beyond the scope of this study. Further investigation is needed by considering different task difficulty level of postural and suprapostural tasks.

Chapter 5

Conclusion

This study first presented three ERP components (P1, N1, and P2) in a postural-suprapostural task with a perceptual-motor goal to investigate the effects of task prioritization in younger and older adults. Significant task prioritization benefit was found with SF strategy, with better task accuracy and attentional resource allocation. In healthy older adults, P1 positivity was enhanced for achieving optimal postural and force-matching performance, especially under the SF condition. Our behavioral and neurophysiological data suggested that SF strategy may be the adequate strategy for both younger and older adults in a postural-suprapostural task, with more automatic postural control and optimal resource allocation between postural and suprapostural tasks (Figure 15). However, neurological disease is a critical factor to affect postural-suprapostural performance, especially for balance control. Some researchers argued that posture-first might be a safe strategy for patients with Parkinson’s disease. Therefore, the appropriateness of task priority strategy in patients with neurological disease, such as Parkinson’s disease, requires further investigation for providing optimal attentional strategy clinically.

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Figures

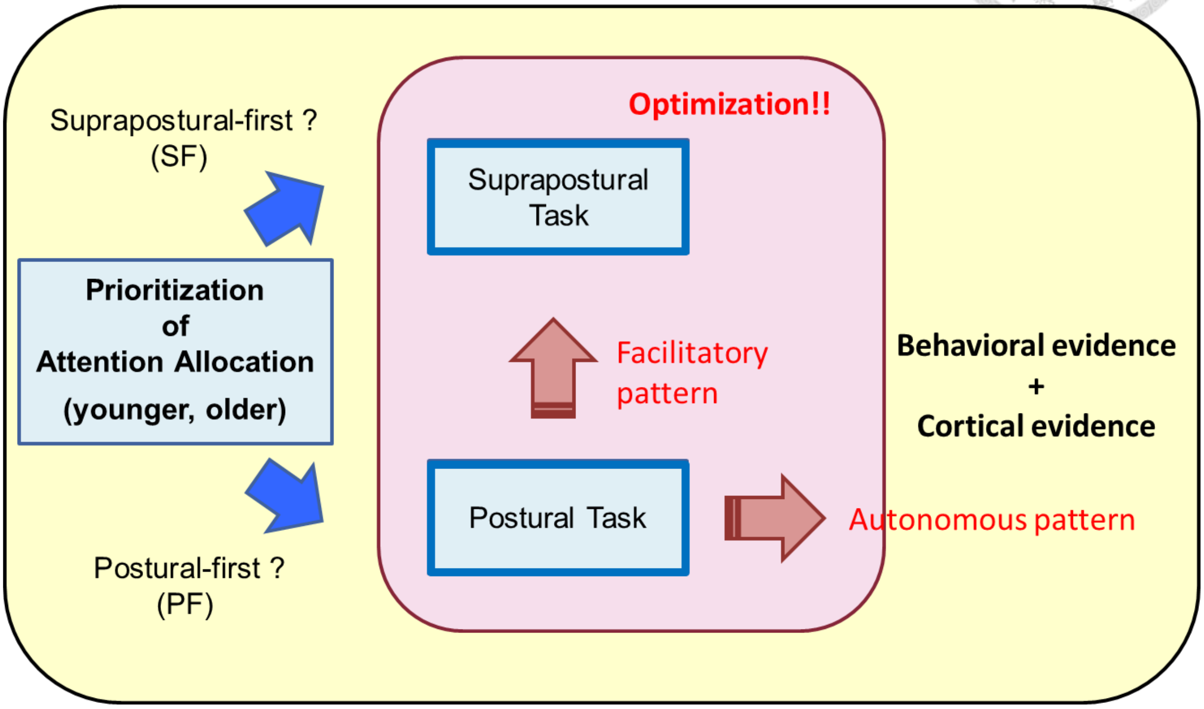


Figure 1. Thinking process of the study.

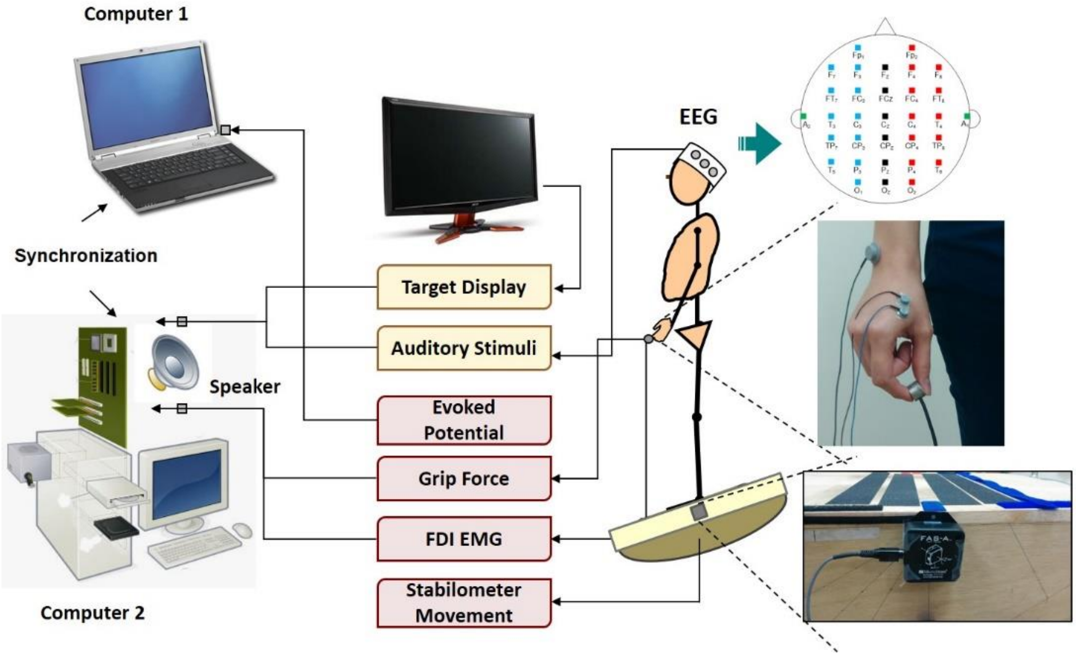


Figure 2. Experimental setup of the study.

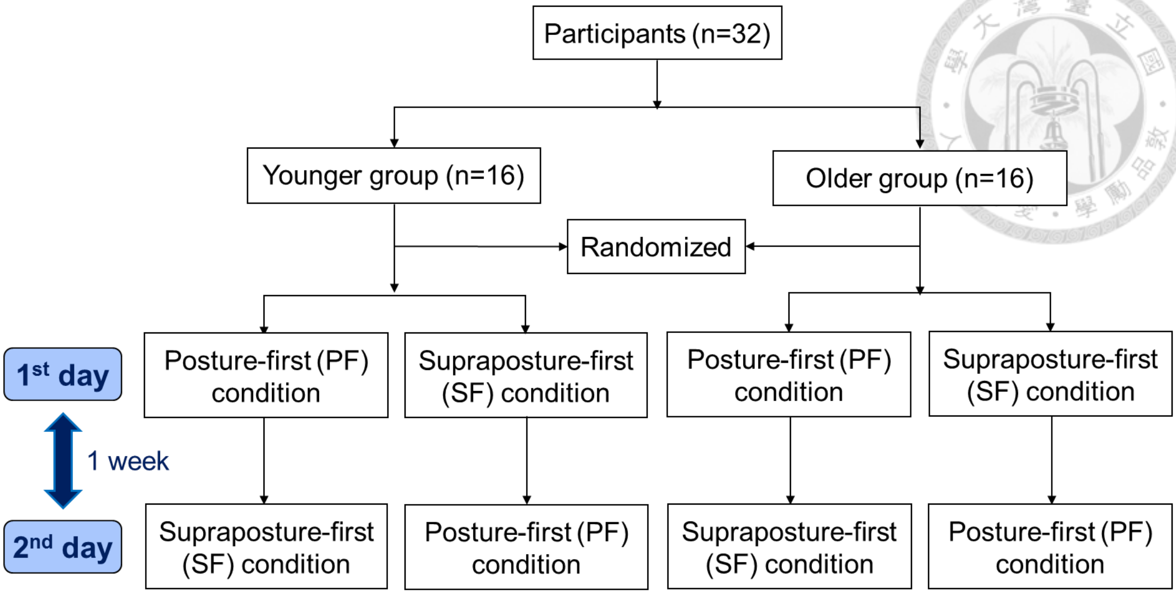


Figure 3. Flow diagram of the study.

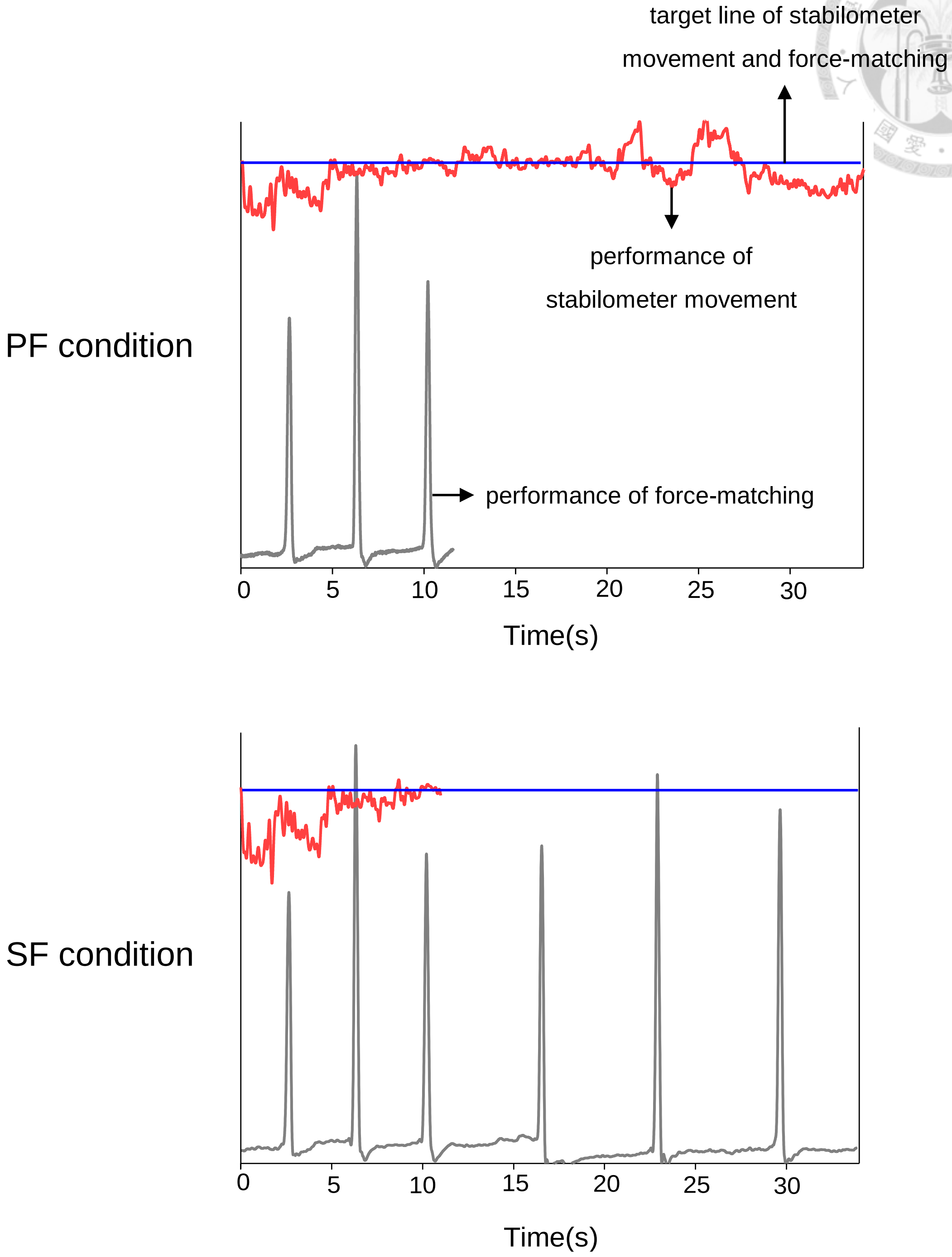


Figure 4. Visual information for the PF and SF conditions. (PF: posture-first; SF: supraposture-first)

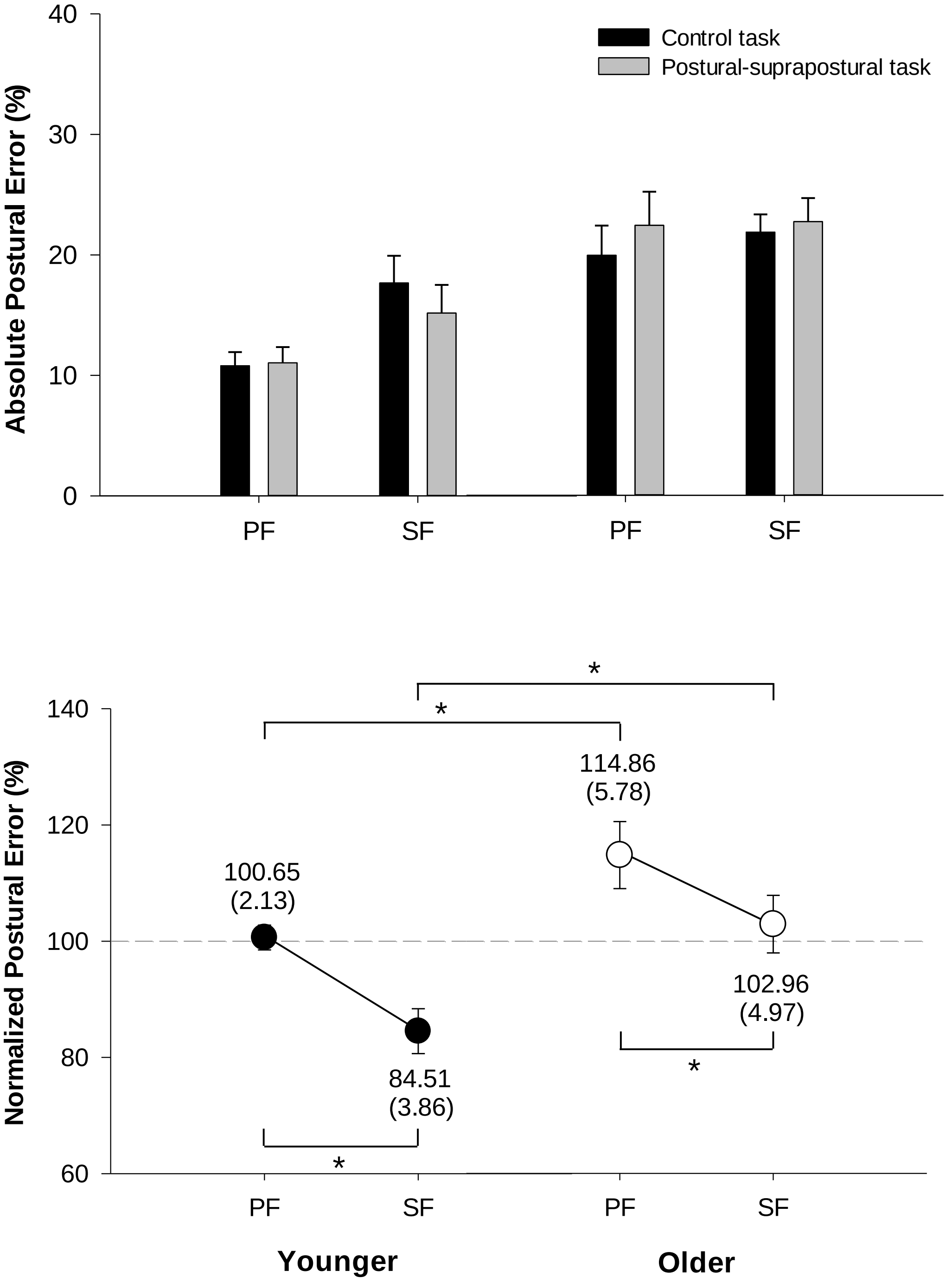


Figure 5. Means and standard errors of absolute (upper) and normalized (lower) postural error of younger and older groups in the SF and PF conditions. (PF: posture-first; SF: supraposture-first)(*p < 0.05)

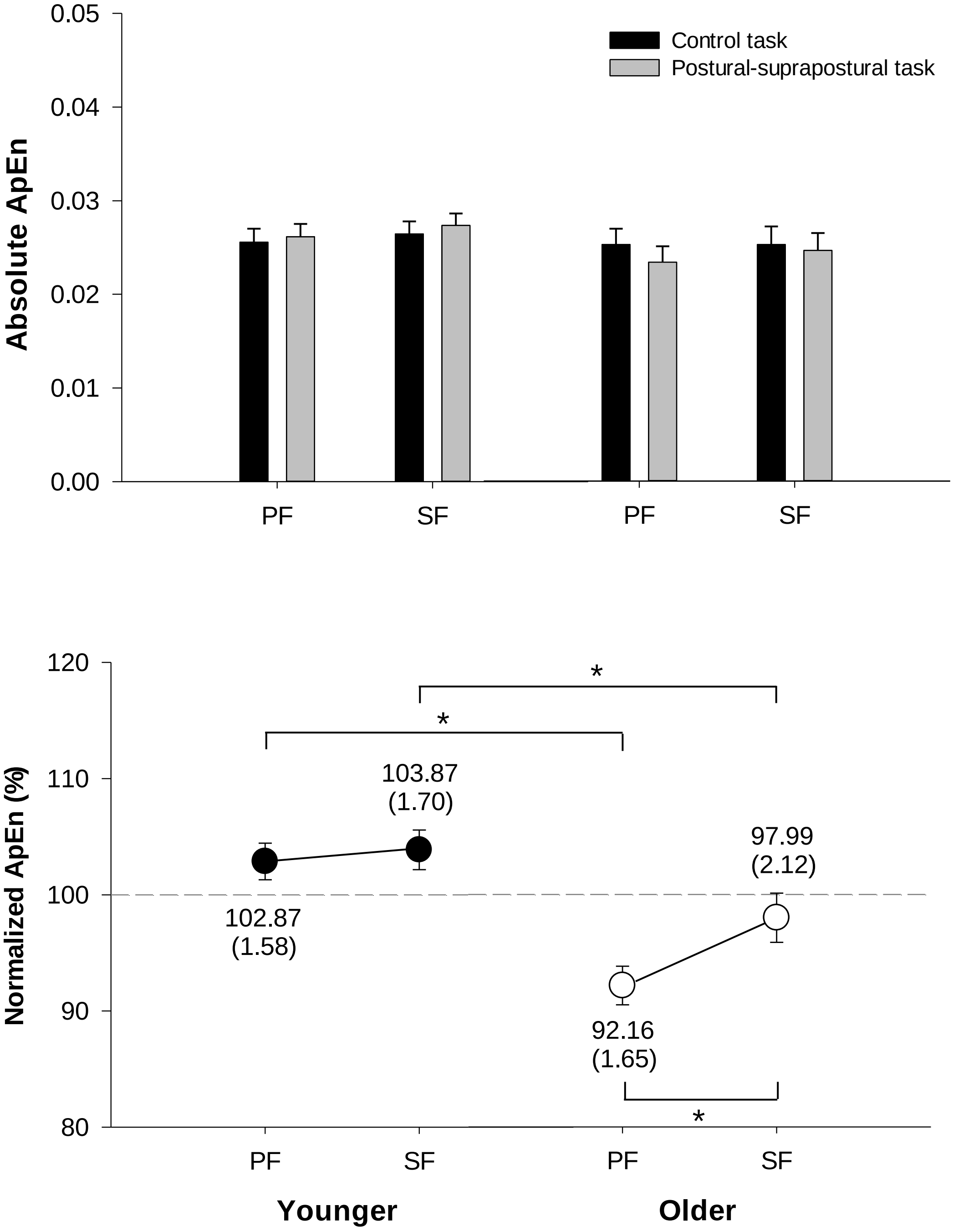


Figure 6. Means and standard errors of absolute (upper) and normalized (lower) ApEn of younger and older groups in the SF and PF conditions. (PF: posture-first; SF: supraposture-first)(*$p < 0.05$)

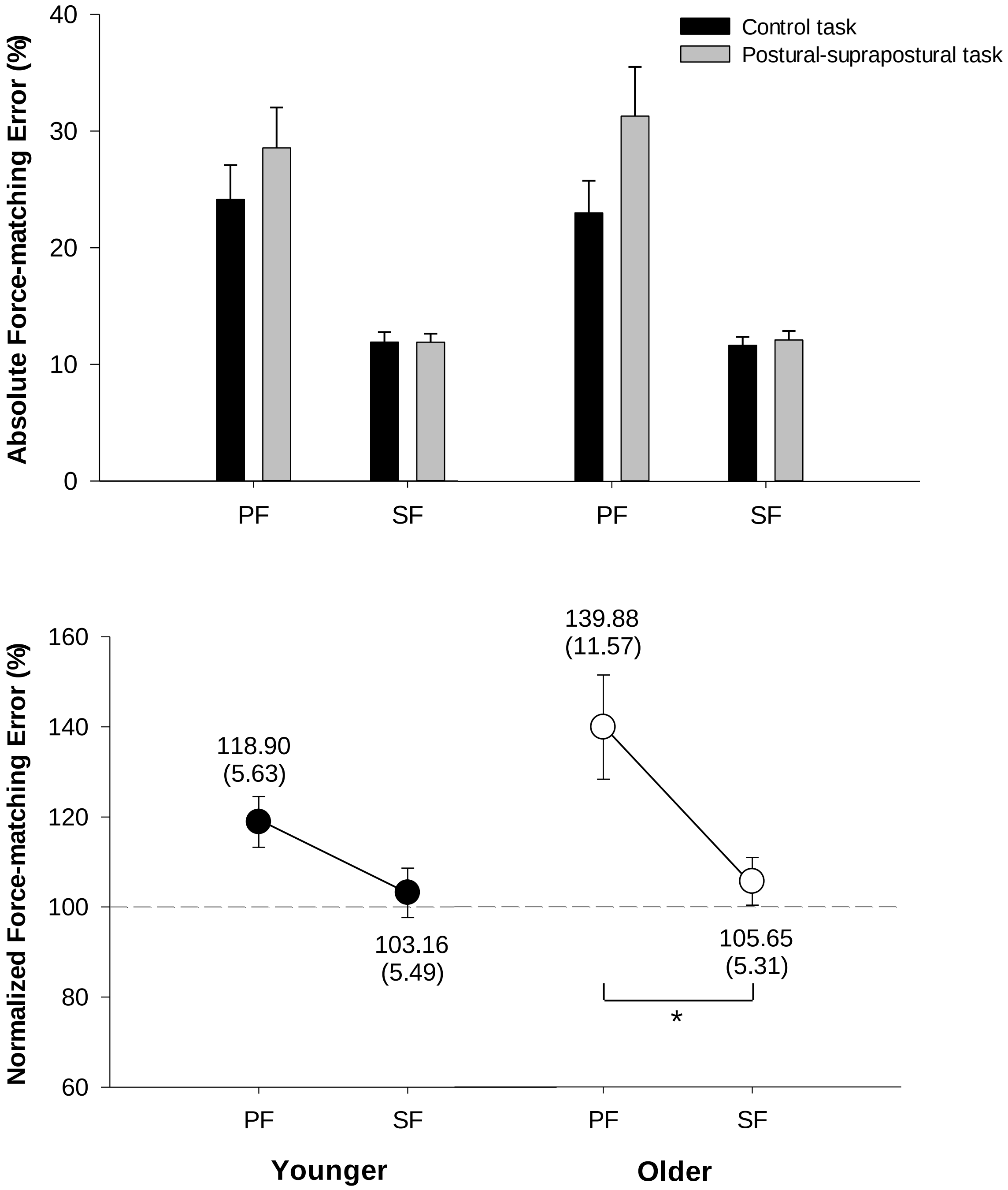


Figure 7. Means and standard errors of absolute (upper) and normalized (lower) force-matching error of younger and older groups in the SF and PF conditions. (PF: posture-first; SF: supraposture-first)(**p*** **< 0.05)**

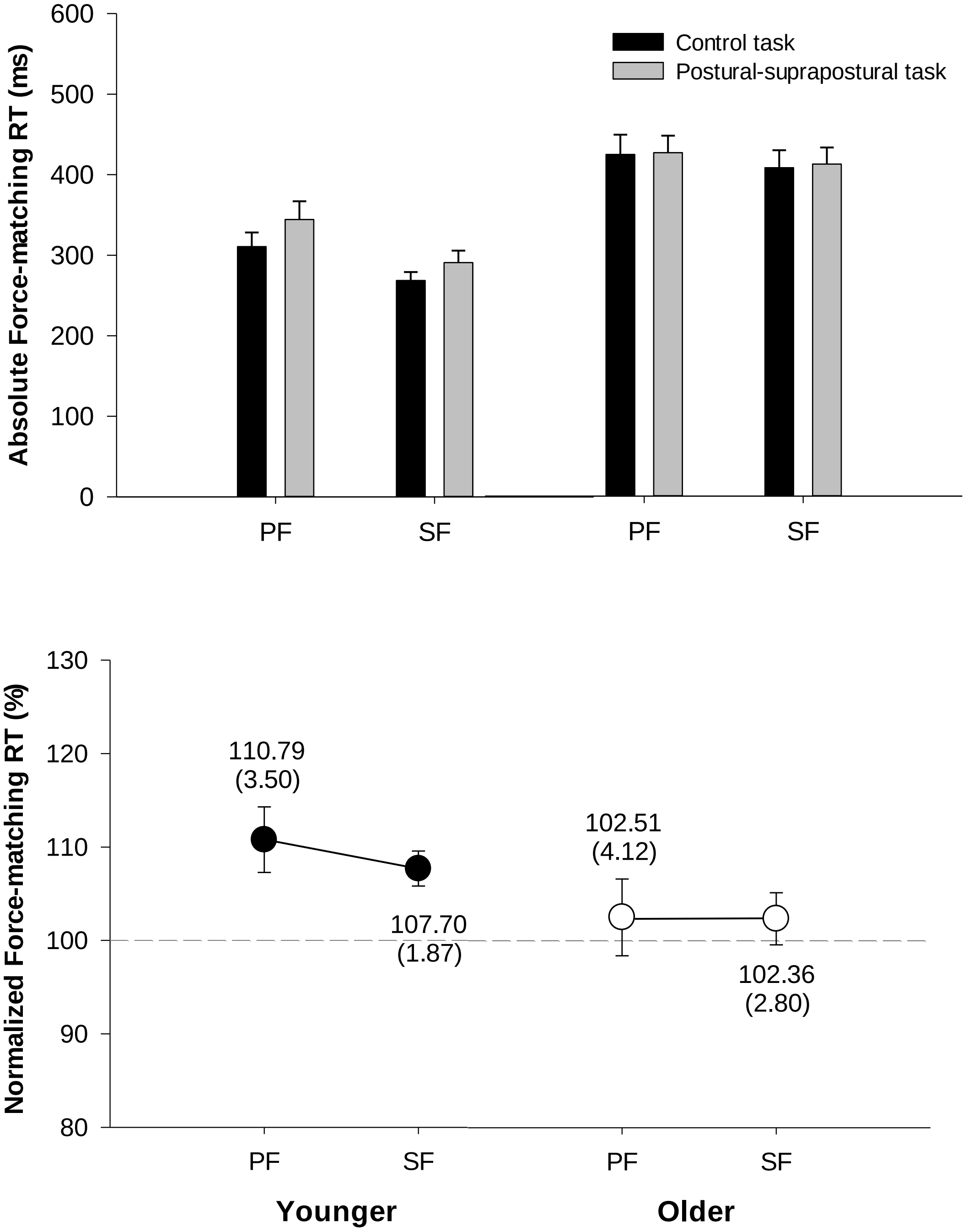
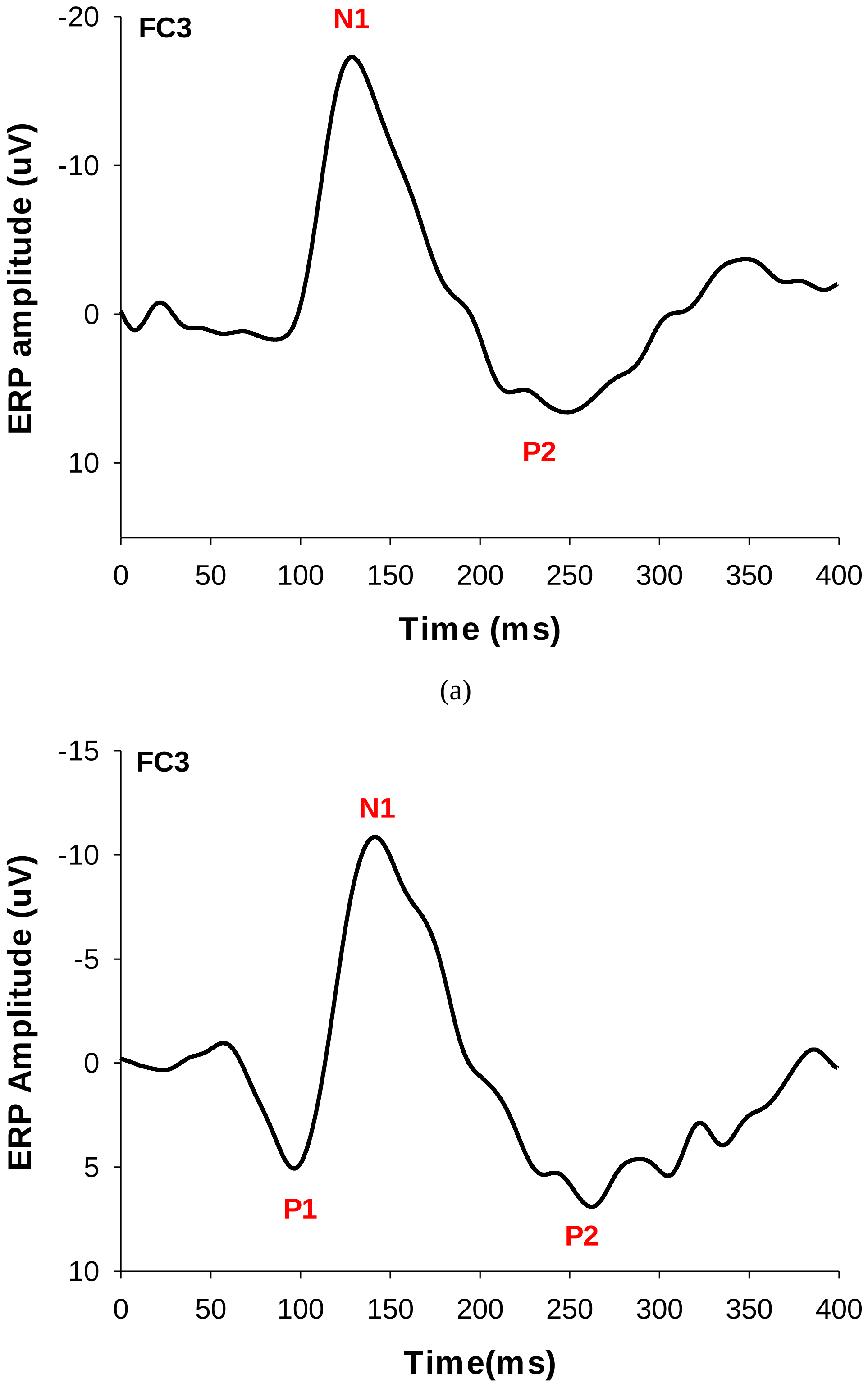


Figure 8. Means and standard errors of absolute (upper) and normalized (lower) force-matching RT of younger and older groups in the SF and PF conditions. (PF: posture-first; SF: supraposture-first)



(a)

(b)

Figure 9. Typical ERP waveforms of (a) younger group and (b) older group in postural-suprapostural tasks

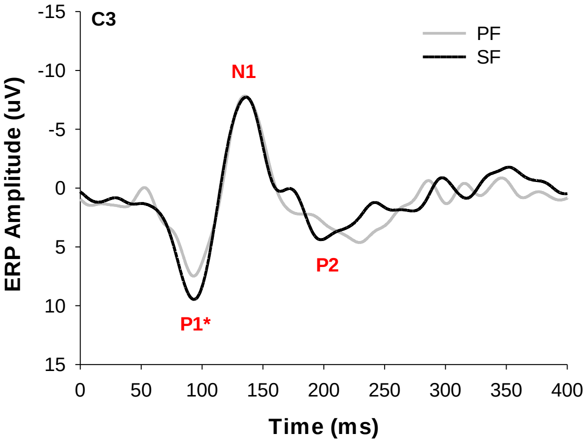
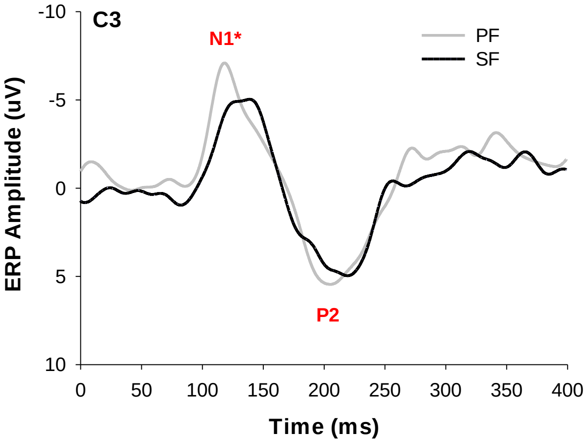
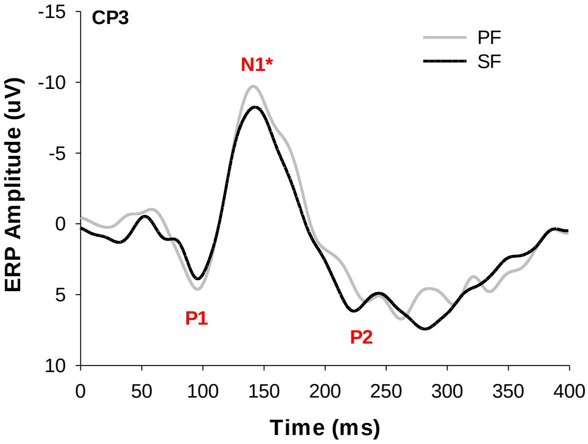
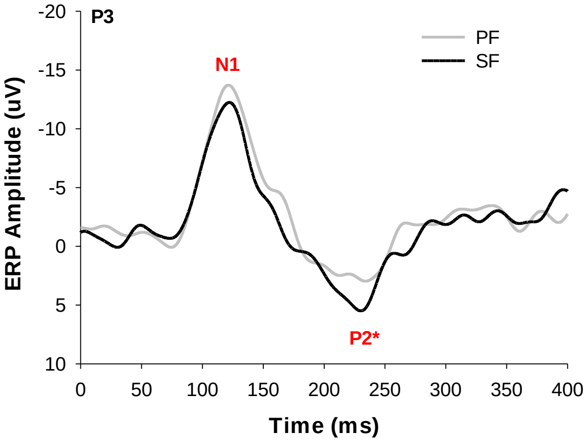
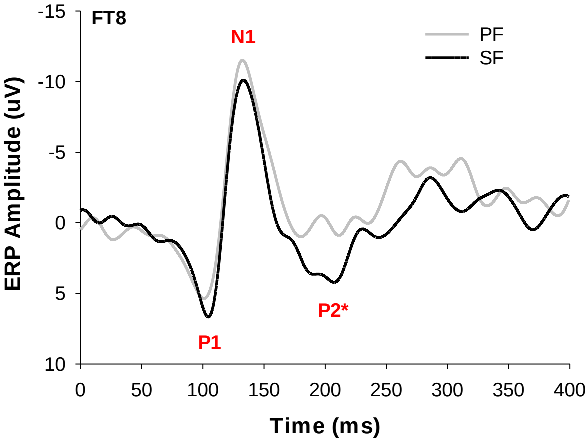
	Younger Group	**Older Group**
P1	—	 (c)
N1	 (a)	 (d)
P2	 (b)	 (e)

Figure 10. Task prioritization effect on ERP waveforms of (a) N1 amplitude of younger group, (b) P2 amplitude of younger group, (c) P1 amplitude of older group, (d) N1 amplitude of older group, and (e) P2 amplitude of older group in postural-suprapostural tasks.

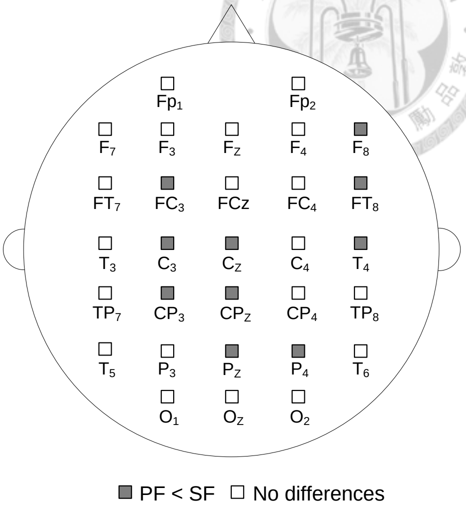
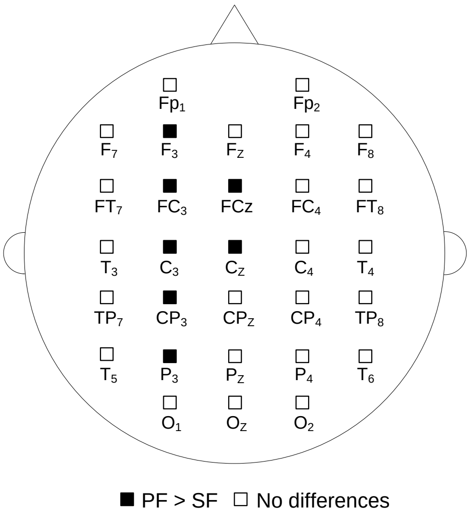
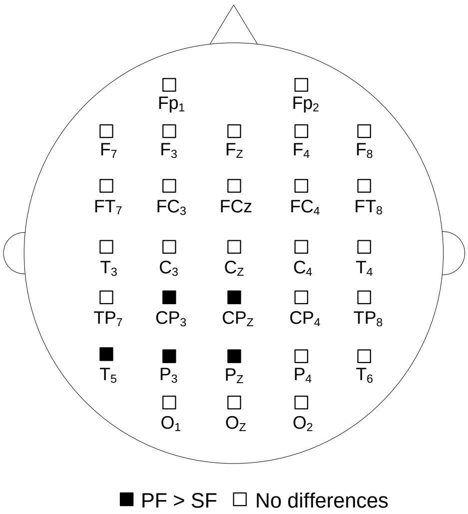
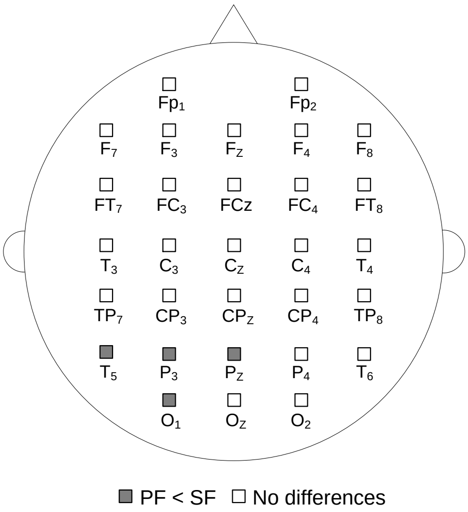
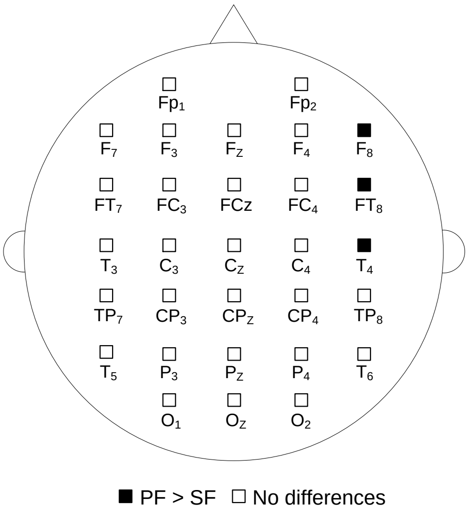
	Younger Group	**Older Group**
P1	—	 (c)
N1	 (a)	 (d)
P2	 (b)	 (e)

Figure 11. Task prioritization effect on grand-averaged ERP topological plots of (a) N1 amplitude of younger group, (b) P2 amplitude of younger group, (c) P1 amplitude of older group, (d) N1 amplitude of older group, and (e) P2 amplitude of older group in postural-suprapostural tasks. Filled squares represent the electrode had a significant difference in ERP amplitudes between the SF and PF conditions in ERP amplitudes ($p < 0.05$).

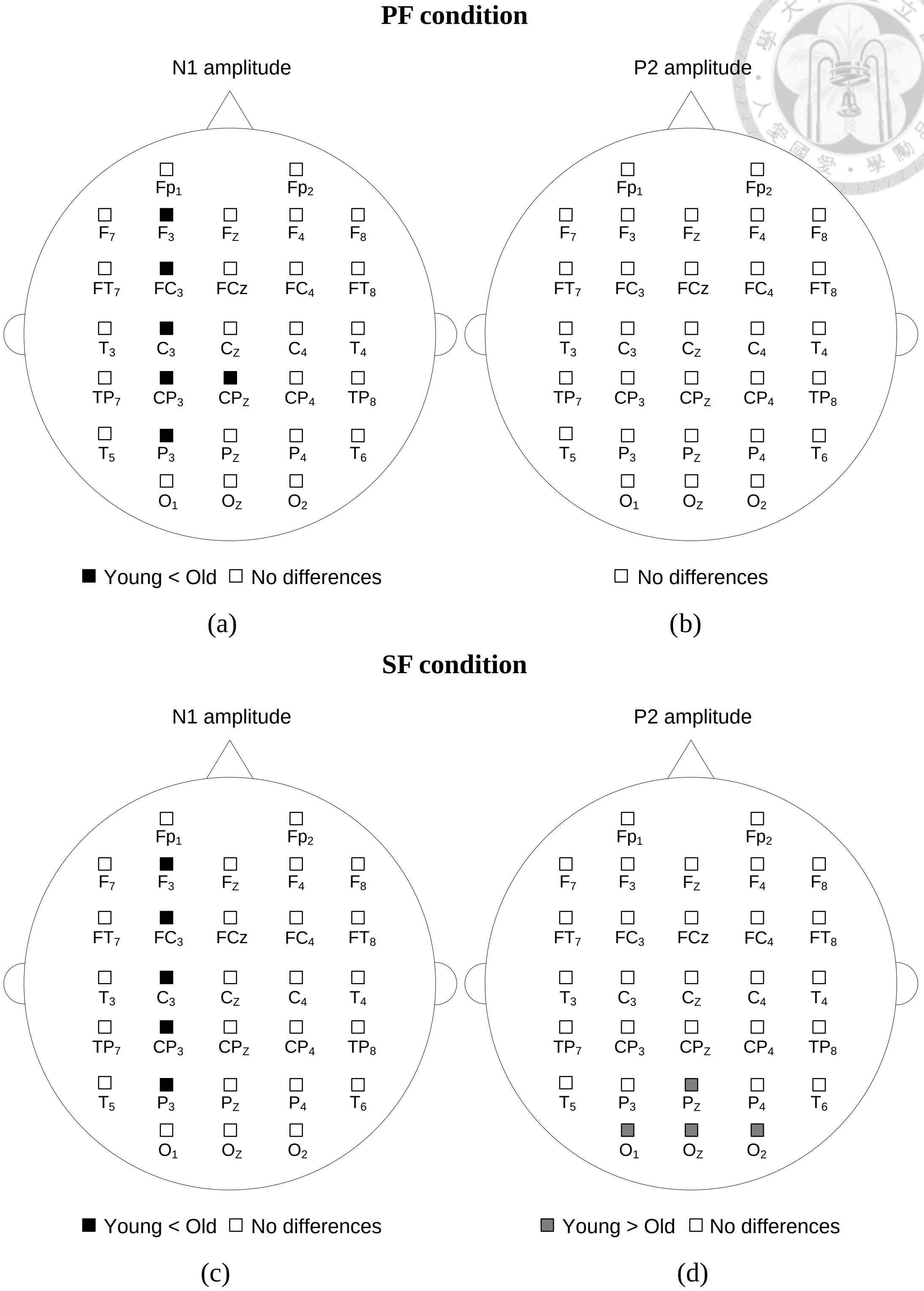


Figure 12. Age effect on grand-averaged ERP topological plots of (a) N1 amplitude in the PF condition, (b) P2 amplitude in the PF condition, (c) N1 amplitude in the SF condition, and (d) P2 amplitude in the SF condition in postural-suprapostural tasks. Filled squares represent the electrode had a significant difference in ERP amplitudes between the SF and PF conditions in ERP amplitudes ($p < 0.05$).

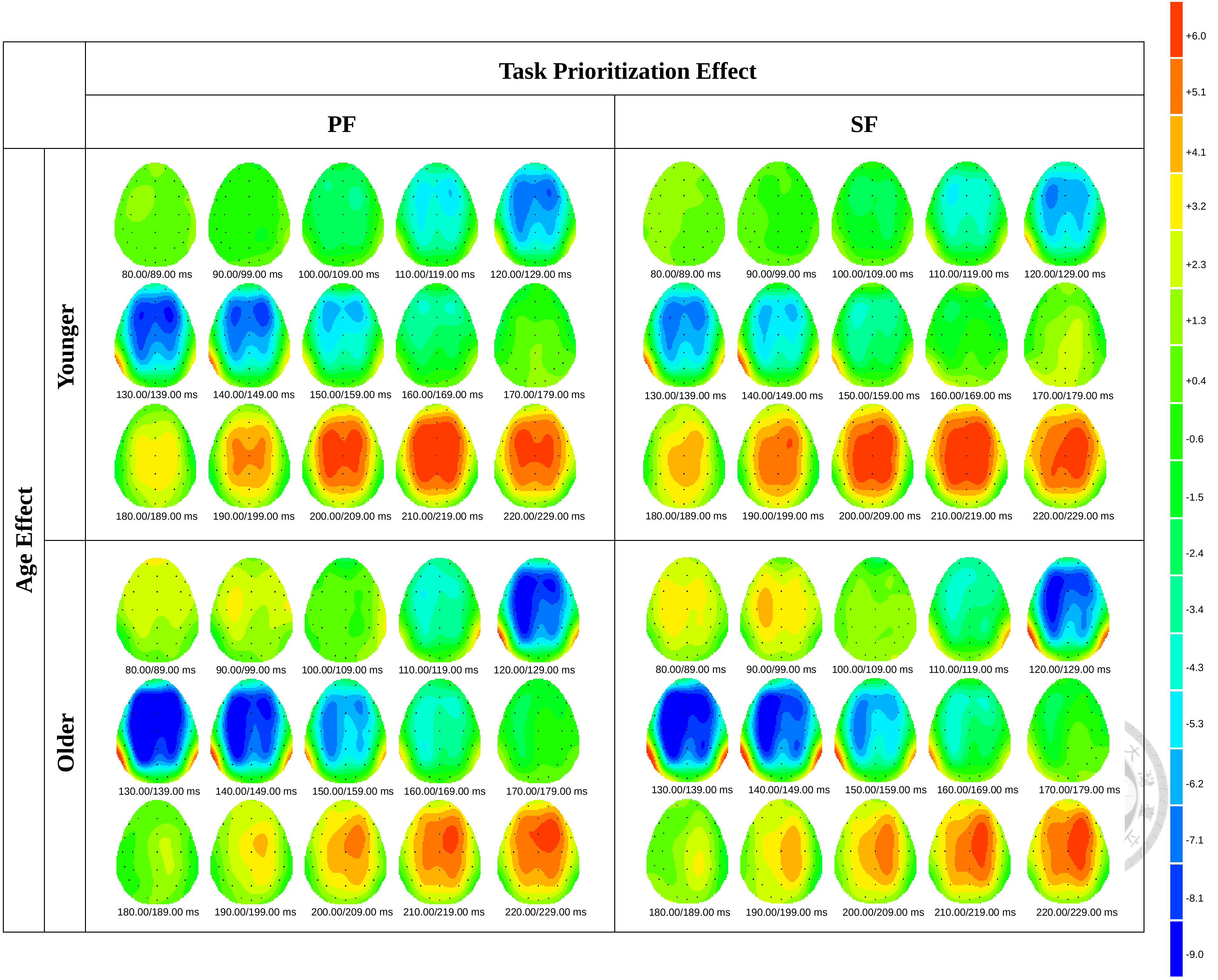
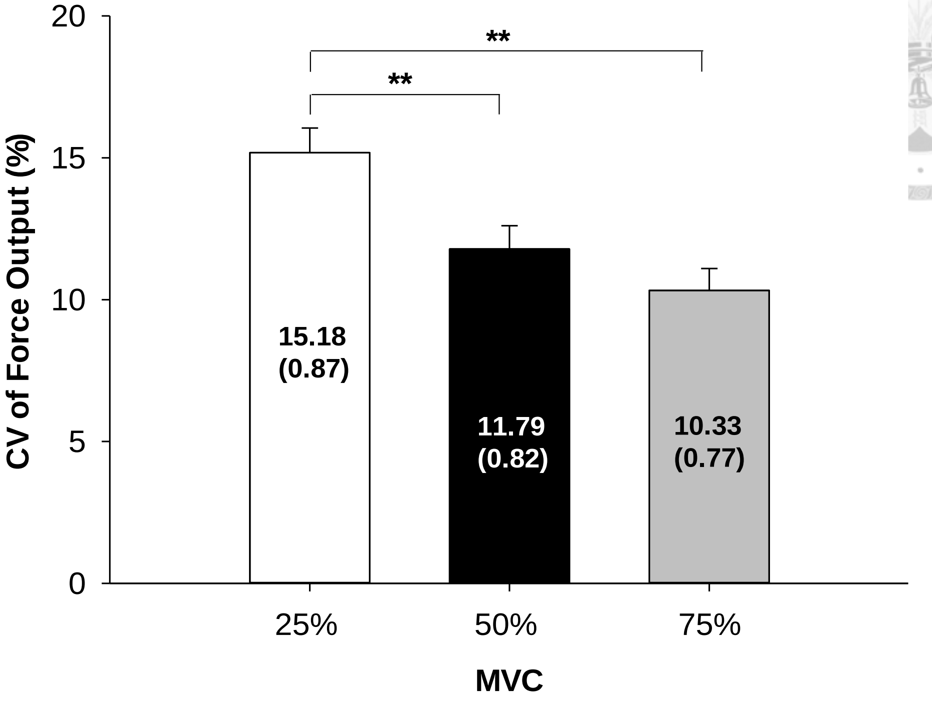
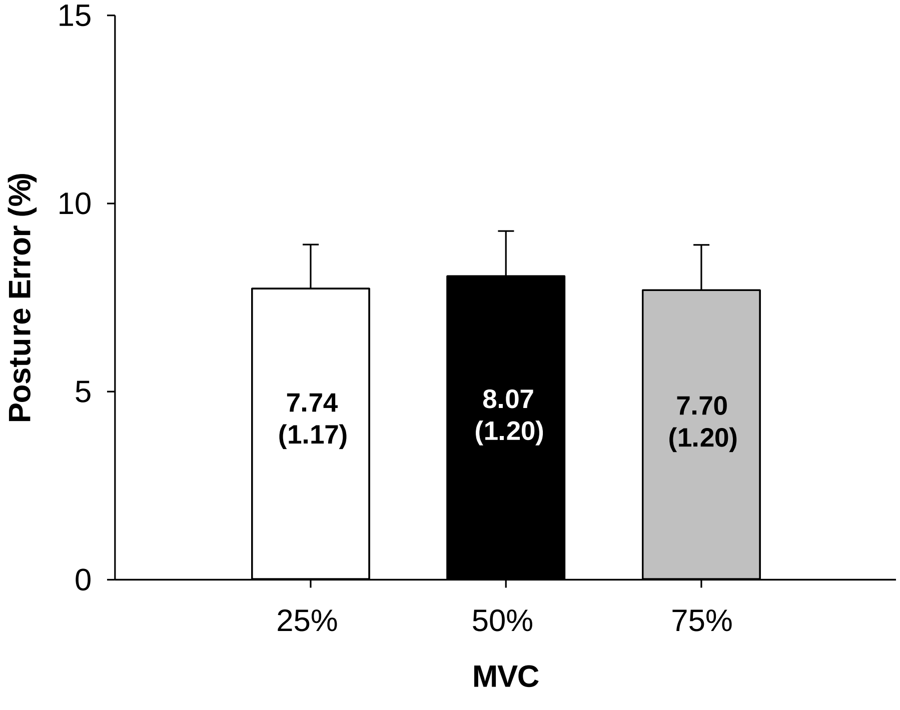

Task Prioritization Effect
PF
SF
Age Effect
Younger
Older
80.00/89.00 ms
90.00/99.00 ms
100.00/109.00 ms
110.00/119.00 ms
120.00/129.00 ms
130.00/139.00 ms
140.00/149.00 ms
150.00/159.00 ms
160.00/169.00 ms
170.00/179.00 ms
180.00/189.00 ms
190.00/199.00 ms
200.00/209.00 ms
210.00/219.00 ms
220.00/229.00 ms
+6.0
+5.1
+4.1
+3.2
+2.3
+1.3
+0.4
-0.6
-1.5
-2.4
-3.4
-4.3
-5.3
-6.2
-7.1
-8.1
-9.0

Figure 13. Population means of topological plots of all task priority condition (PF and SF conditions) and age groups (younger and older groups) in postural-suprapostural tasks.



(a)



(b)

Figure 14. Force CV and postural error of pilot study.

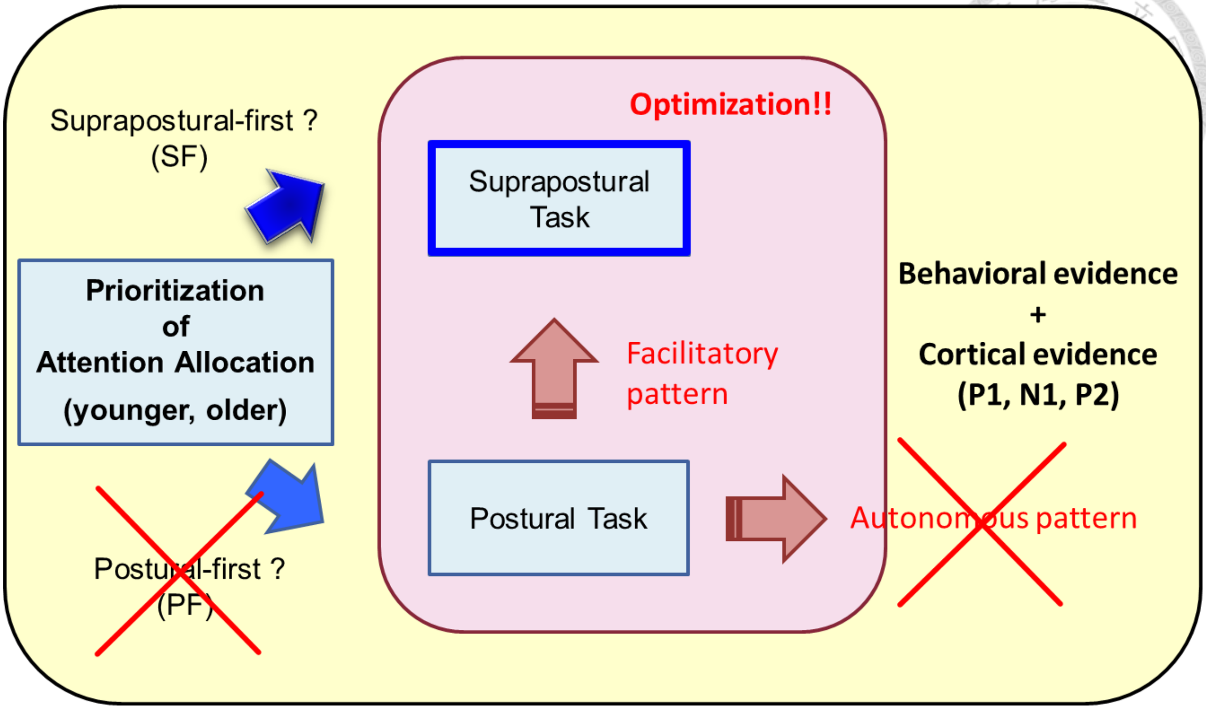


Figure 15. Graphic summary of the study.

Tables

Table 1. Baseline characteristics of the participants.

	Younger Group (n=16)	Older Group (n=16)
Age (yrs)	24.4 ± 4.6	69.1 ± 2.7
Gender, M/F	8/8	6/10
Height (cm)	168.7 ± 9.3	155.9 ± 7.6
Weight (kg)	64.4 ± 14.0	60.1 ± 9.2
MMSE score	-	29.3 ± 1.5

Table 2. Comparison of collected normalized postural error, postural ApEn, force-matching error, and force-matching RT between the first and second experimental days.

	NPE(%)	**NPApEn(%)**	**NFE(%)**	**NFRT(%)**
Collected Day				
(a) PF condition				
1st day	105.37 ± 2.15	97.89 ± 2.49	135.32 ± 9.95	109.65 ± 4.70
2nd day	110.14 ± 6.27	97.15 ± 1.68	123.45 ± 8.75	103.66 ± 2.86
	($p = 0.48$)	($p = 0.81$)	($p = 0.37$)	($p = 0.29$)
(b) SF condition				
1st day	92.19 ± 5.25	101.05 ± 1.83	97.75 ± 4.35	105.48 ± 2.65
2nd day	95.28 ± 4.80	100.82 ± 2.28	111.06 ± 5.80	104.58 ± 2.29
	($p = 0.67$)	($p = 0.94$)	($p = 0.08$)	($p = 0.80$)

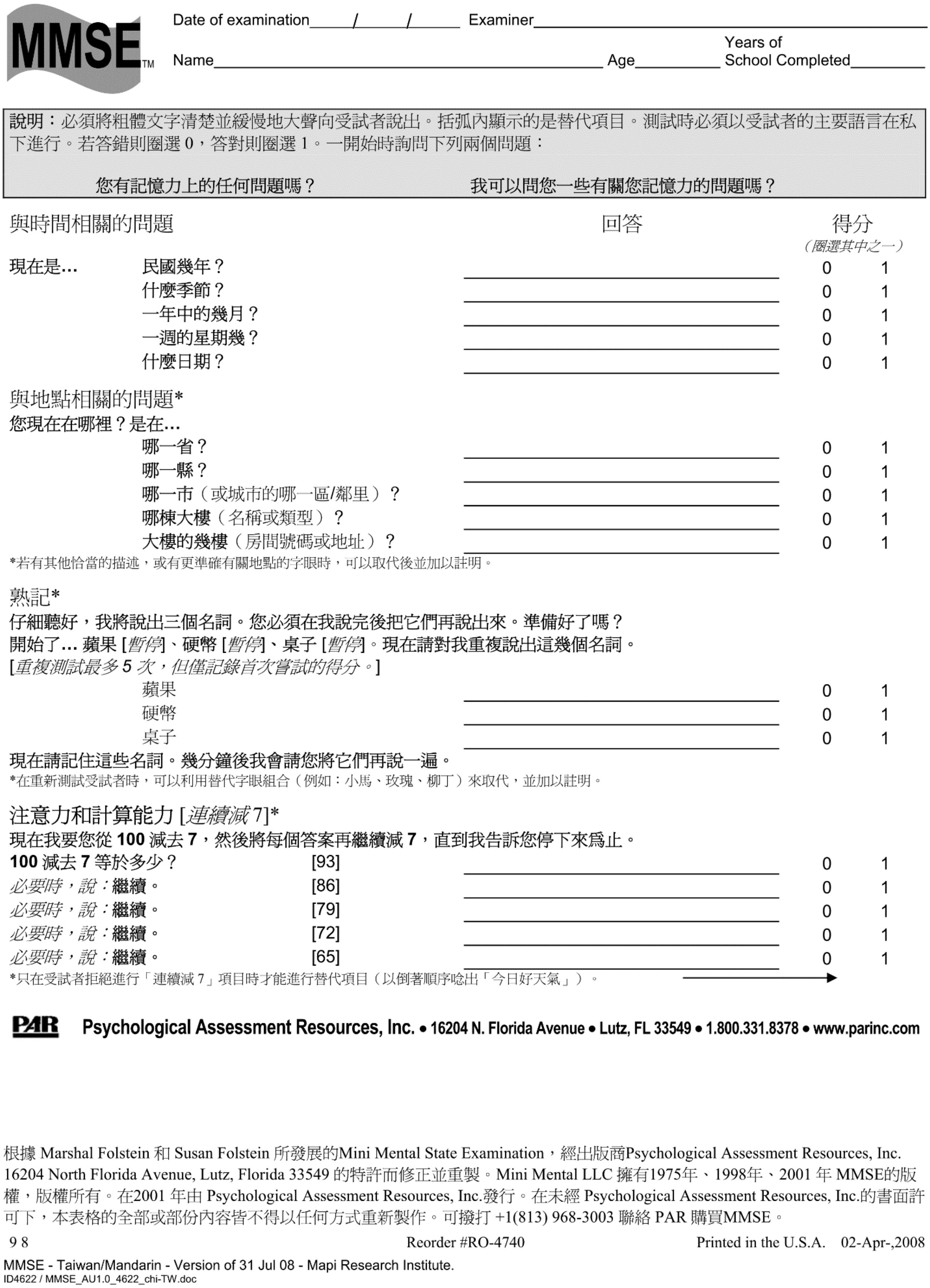
NPE: normalized postural error

NPApEn: normalized postural ApEn

NFE: normalized force-matching error

NFRT: normalized force-matching reaction time

Appendices



MMSE™

Date of examination____/____/____ Examiner__________

Name__________ Age______ Years of School Completed______

說明：必須將粗體文字清楚並緩慢地大聲向受試者說出。括弧內顯示的是替代項目。測試時必須以受試者的主要語言在私下進行。若答錯則圈選 0，答對則圈選 1。一開始時詢問下列兩個問題：

您有記憶力上的任何問題嗎？　　**我可以問您一些有關您記憶力的問題嗎？**

與時間相關的問題		回答	得分 （*圈選其中之一*）	
現在是…	**民國幾年？**	______	0	1
	什麼季節？	______	0	1
	一年中的幾月？	______	0	1
	一週的星期幾？	______	0	1
	什麼日期？	______	0	1

與地點相關的問題*

您現在在哪裡？是在…

哪一省？	______	0	1
哪一縣？	______	0	1
哪一市（或城市的哪一區/鄰里）**？**	______	0	1
哪棟大樓（名稱或類型）**？**	______	0	1
大樓的幾樓（房間號碼或地址）**？**	______	0	1

*若有其他恰當的描述，或有更準確有關地點的字眼時，可以取代後並加以註明。

熟記*

仔細聽好，我將說出三個名詞。您必須在我說完後把它們再說出來。準備好了嗎？

開始了… 蘋果 [*暫停*]、硬幣 [*暫停*]、桌子 [*暫停*]。現在請對我重複說出這幾個名詞。

[*重複測試最多 5 次，但僅記錄首次嘗試的得分。*]

蘋果	______	0	1
硬幣	______	0	1
桌子	______	0	1

現在請記住這些名詞。幾分鐘後我會請您將它們再說一遍。

*在重新測試受試者時，可以利用替代字眼組合（例如：小馬、玫瑰、柳丁）來取代，並加以註明。

注意力和計算能力 [*連續減* 7]*

現在我要您從 100 減去 7，然後將每個答案再繼續減 7，直到我告訴您停下來爲止。

100 減去 7 等於多少？	[93]	______	0	1
必要時，說： **繼續。**	[86]	______	0	1
必要時，說： **繼續。**	[79]	______	0	1
必要時，說： **繼續。**	[72]	______	0	1
必要時，說： **繼續。**	[65]	______	0	1

*只在受試者拒絕進行「連續減 7」項目時才能進行替代項目（以倒著順序唸出「今日好天氣」）。 →

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Appendix 1. Mini Mental State Examination (MMSE).

只有在受試者拒絕進行「連續減 7」項目時才能以此項目取代並計分。

先順著唸出「今日好天氣」，然後將這句話倒著唸回來。

若順著念錯時，可以更正。但只在倒著念時才評分。

____	____	____	____	____	______
(氣 = 1)	(天 = 1)	(好 = 1)	(日 = 1)	(今 = 1)	(0 至 5)

記憶力

	回答	得分 （圈選其中之一）	
我剛剛請您記住的三個名詞是什麼？[*不得給任何提示。*]			
蘋果	______________	0	1
硬幣	______________	0	1
桌子	______________	0	1

名稱*

這是什麼？[*指著一支鉛筆或原子筆。*]	______________	0	1
這是什麼？[*指著一支手錶。*]	______________	0	1

*可以用其他常用物品（例如：眼鏡、椅子、鑰匙）來取代，並加以註明。

複述

現在我要您重複我所說的話。準備好了嗎？「沒有如果、而且、或但是。」現在由您來說這句話。

[*最多重複 5 次，但僅記錄首次嘗試的得分。*]

「沒有如果、而且、或但是。」	______________	0	1

> 將下一頁沿著垂直線撕下，然後沿著水平齒孔線將它撕成兩半。使用上半頁（空白頁）進行接下來的理解、書寫和畫圖項目。使用下半頁作爲閱讀（「閉上眼睛」）和畫圖（相交錯的五邊形）項目的提示紙。

理解

仔細聽好，因爲我要請您做些動作。

右手拿著這張紙 [*暫停*]，將它對半折起 [*暫停*]，然後把它放在地上（*或*桌上）。

右手拿著	______________	0	1
對半折起	______________	0	1
放在地上（*或*桌上）	______________	0	1

閱讀

請閱讀這個，並照著它所說的做。[*向受試者展示提示紙上的文字。*]

閉上眼睛	______________	0	1

書寫

請寫出一個句子。[*若受試者沒有反應，則說：***寫出今天天氣。**] 0 1

將空白紙張（未經折疊的）放在受試者面前，並提供原子筆或鉛筆。若句子可以理解，且含有主詞和動詞，就得 1 分。忽略文法錯誤或錯別字。

畫圖

請將此圖形畫出來。[*向受試者顯示提示紙上相交錯的五角形。*] 0 1

若所畫的圖含有兩個互相交錯的五邊形，且交錯部分形成了一個四邊形，就得 1 分。

意識程度的評估。

____

清醒/有反應	呆滯	恍惚	昏睡狀態/ 無反應

總分 = ______

（*加總所有項目得分*）（最高 30 分）

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閉上眼睛

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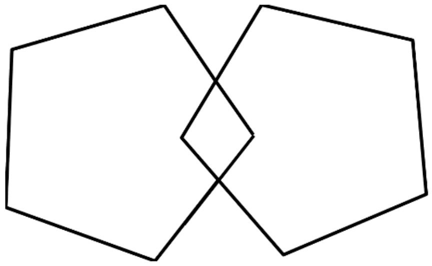

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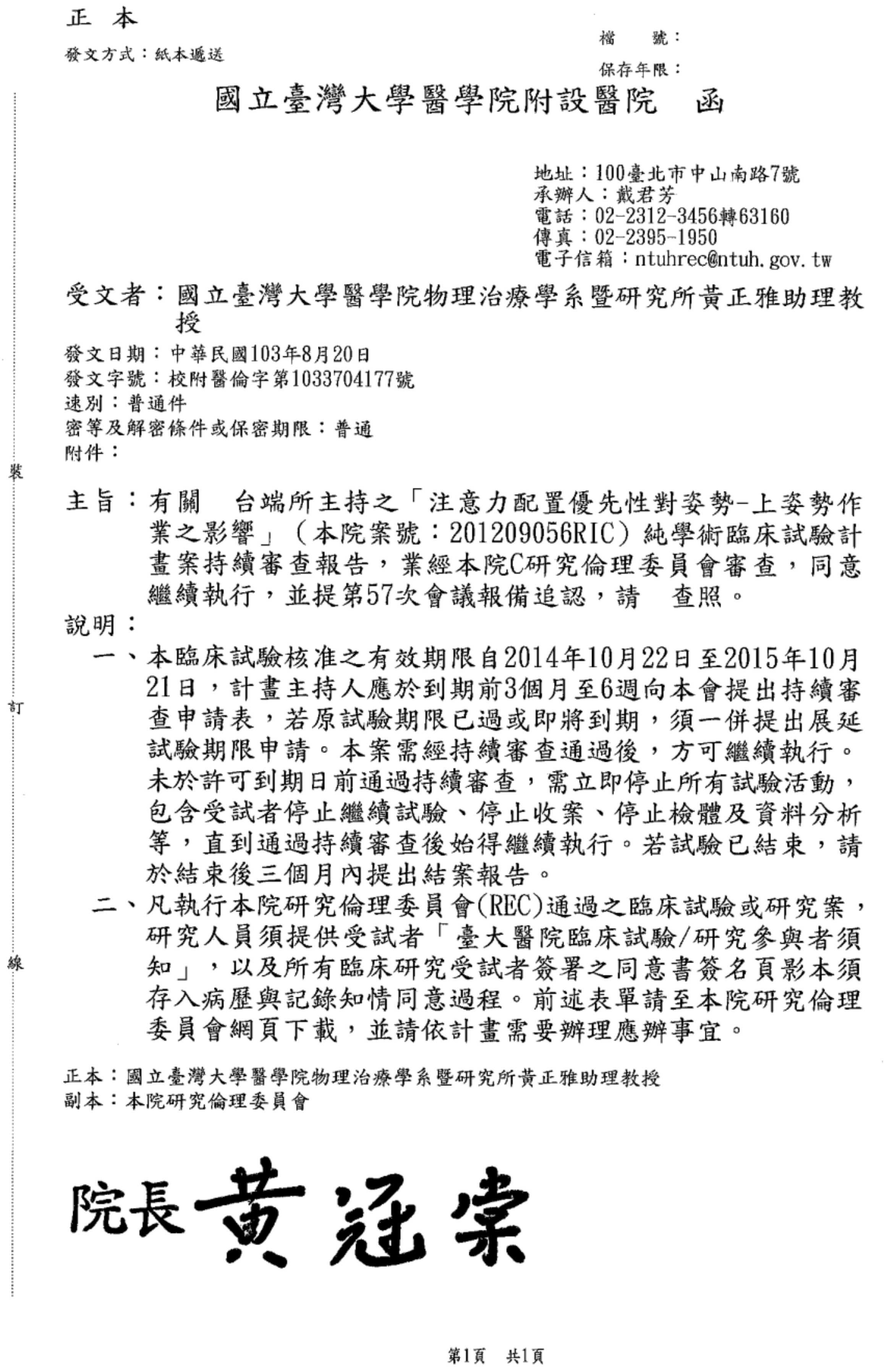

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附件：

主旨：有關　台端所主持之「注意力配置優先性對姿勢-上姿勢作業之影響」（本院案號：201209056RIC）純學術臨床試驗計畫案持續審查報告，業經本院C研究倫理委員會審查，同意繼續執行，並提第57次會議報備追認，請　查照。

說明：

一、本臨床試驗核准之有效期限自2014年10月22日至2015年10月21日，計畫主持人應於到期前3個月至6週向本會提出持續審查申請表，若原試驗期限已過或即將到期，須一併提出展延試驗期限申請。本案需經持續審查通過後，方可繼續執行。未於許可到期日前通過持續審查，需立即停止所有試驗活動，包含受試者停止繼續試驗、停止收案、停止檢體及資料分析等，直到通過持續審查後始得繼續執行。若試驗已結束，請於結束後三個月內提出結案報告。

二、凡執行本院研究倫理委員會(REC)通過之臨床試驗或研究案，研究人員須提供受試者「臺大醫院臨床試驗/研究參與者須知」，以及所有臨床研究受試者簽署之同意書簽名頁影本須存入病歷與記錄知情同意過程。前述表單請至本院研究倫理委員會網頁下載，並請依計畫需要辦理應辦事宜。

正本：國立臺灣大學醫學院物理治療學系暨研究所黃正雅助理教授
副本：本院研究倫理委員會

院長 黃冠宗

第1頁　共1頁

Appendix 2. Approved document form the research ethics board at the National Taiwan University Clinical Trail Center.