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Effect of feed-forward audio-visual cues on gait performance under dual-task condition in people with Parkinson's disease

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CERTIFICATE OF ORIGINALITY

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it reproduces no material previously published or written, nor material that has been accepted for the award of any other degree or diploma, except where due acknowledgement has been made in the text.

_____(Signed)

Yu Liling (Name of student)

DEDICATION

I would like to thank Vivienne, Riv, Silvia and my family for their continual support and inspiration during the period of my MPhil study. This study would not be completed without the support of my close friends.

ABSTRACT

Background: Previous studies showed that gait deficits are exacerbated during addition of dual motor or cognitive tasks in patients with Parkinson‟s disease (PD). However, no study has reported the effect of naming an object that a patients saw while walking in PD patients. Visual cue was found to increase the stride length, but not gait velocity in PD patients under dual cognitive-walking task condition. A previous study reported that when combined auditory and visual cues were given before sit-to-stand, the performance in PD patients was enhanced. Whether preparatory audio-visual (AV) cues could facilitate walking under dual cognitive-walking task condition in PD patients is unknown.

Objectives: This study aimed to examine the effect of adding a cognitive task to walking on gait performance; and to determine whether preparatory AV cues could enhance walking under dual cognitive-walking task condition in PD patients.

Methods: This study composed of a pilot and two inter-related main studies. The pilot study established the reliability of the methodology. In *Study 1*, twenty-two PD patients and 15 healthy subjects were instructed to: (1) walk at their natural pace ($Walk_0$); (2) name the object on the computer screen while they walked ($Walk_{naming\ object}$) and (3) say out the serial subtractions of three from 100 while they walked ($Walk_{calculation}$). In *Study 2*, fifteen PD patients and 13 control subjects randomly walked under 4 conditions (AV-and non-cued). The AV cues were simulated road-crossing traffic light and sound, which were presented once to subjects before walking so they could estimate the walking time. Subjects had to walk while (1)

naming the object on the computer screen ($Walk_{naming\ object}$); (2) saying out the serial subtractions of three from 100 ($Walk_{calculation}$); (3) naming the object on the computer screen with the addition of AV cues ($AV_{naming\ object}$); (4) saying out the serial subtractions of three from 100 with the addition of AV cues ($AV_{calculation}$). Gait velocity, stride length, cadence and the number of correct answers for the cognitive tasks were recorded.

Results and discussion: Excellent ICCs (>0.90) were found in all gait parameters in both subject groups, indicating that the methodology was reliable. For *Study 1*, PD patients walked with significantly slower gait velocity (by 15.3%) and shorter stride length (by 10.1%) than control subjects under $Walk_0$. When either concurrent task of "naming object" or "calculation" was added to walking, a significant group*task interactions was found in gait velocity and stride length. PD subjects significantly decreased gait velocity (by 17.4%, 25.8%), stride length (by 13.5%, 15.0%) and cadence (by 4.5%, 12.1%) in $Walk_{naming\ object}$ and $Walk_{calculation}$ than $Walk_0$ ($p<0.05$). The difference between $Walk_{naming\ object}$ and $Walk_{calculation}$ was insignificant. In contrast, control subjects maintained their performance in $Walk_{naming\ object}$ as those of $Walk_0$, but significantly reduced gait velocity and cadence in $Walk_{calculation}$. These findings indicate that distraction of attention such as simple object naming or calculation could affect walking performance in PD patients. Therefore, walking appeared to demand more attention in these patients. In *Study 2*, PD subjects significantly increased gait velocity (by 12.8%, 17.4%), stride length (by 7.6%, 8.2%) and cadence (by 4.7%, 9.2%) in $AV_{naming\ object}$ and $AV_{calculation}$ than non-cued conditions ($p<0.01$). In control

group, the addition of AV cues also produced significant but less strong and widespread effects on the various gait parameters. The stronger and more widespread positive outcomes in PD patients suggest that AV cues could have facilitated the motor preparatory process and heightened the attention level of these subjects. Therefore they were better able to complete their walk within the pre-set time, leading to increased stride length, gait velocity and cadence.

Conclusion: When a concurrent cognitive task (naming object or calculation) was added to walking, PD patients showed deterioration in all gait parameters. Our findings imply that PD patients require more attention to walk than normal controls. Provision of preparatory AV cues enhanced all gait performance under the two dual cognitive-walking task conditions examined. The positive findings from this study provide scientific evidence for the use of AV cues in the facilitation of dual cognitive-walking in PD subjects.

PUBLICATION ARISING

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LIST OF ABBREVIATIONS

ANOVA	analysis of variance
AV	audio-visual cues
BG	basal ganglia
CSA	Clinical Stride Analyser
DBS	deep brain stimulation
EMG	Electromyographic
FOGQ	freezing of gait questionnaire
GABA	γ-amino-butyric acid
GPe	external globus pallidus
GPi	internal globus pallidus
H&Y	Hoehn and Yahr scale
ICC	intraclass correlation coefficient
MMSE	Mini Mental Status Examination
MPTP	methyl-4-phenyl-1,2,3, 6-tetrahydropyridine
PD	Parkinson‟s disease
PMC	premotor cortex
PPN	pedunculopontine uncleus
REM	rapid eye movement
SD	standard deviations
SMA	supplementary motor area
SN	substantia nigra

SNc	substantia nigra pars compacta
SNr	substantia nigra pars reticulate
STN	subthalamic nucleus
STS	sit-to-stand
UPDRS	Unified Parkinson Disease Rating Scale

CHAPTER 1 INTRODUCTION

The first chapter provides an overview of the study. The background of the Parkinson‟s disease and the knowledge gap existing in the previous studies are stated together with the purposes and hypotheses of the present study. The chapter ends with an introduction to the organization of the thesis.

1.1 Background and Justification

Parkinson‟s disease (PD) is a pathological condition, resulted from progressive degeneration of the basal ganglia that leads to movement disorders, and interferes with independent function of individuals (Leland et al. 2004). Clinical presentation of PD includes motor symptoms, such as bradykinesia, tremor, rigidity, postural and gait instability. Other non-motor symptoms include neuropsychiatric symptoms such as depression, attention deficit, dementia; sleep disorders such as restless legs and periodic limb movements, rapid eye movement (REM), sleep behaviour disorder and REM loss of atonia; autonomic symptoms such as bladder disturbances, urgency, sweating; gastrointestinal symptoms including dribbling of saliva, ageusia, reflux, vomiting; sensory symptoms such as pain, paraesthesia, olfactory disturbance, and other symptoms including fatigue, diplopia, blurred vision and weight loss (Chaudhuri et al. 2005). Reasonable estimate of prevalence is 250 to 300 per 100,000 individuals (Mayeux 2003). In China, the prevalence of PD is approximately 2% of the population over age of 65, and 1.7 million people with PD with age above 55 years

old (Rocca 2005, Zhang et al. 2003). Based on the 2% prevalence, it gives an estimated total of 20,765 people with PD in Hong Kong.

At present, there is no cure for PD, and no existing therapy has been shown clearly to slow or reverse progression of the disease (Singh et al. 2007). Therefore, the treatment goals are directed at providing symptomatic relief for both motor and non-motor symptoms, preserving functional independence and health-related quality of life (Pallone 2007; Rao et al. 2006; Rezak 2007). So far, the most effective pharmacological agent for treating motor symptoms is levodopa (Halkias et al. 2007; Jankovic 2006; Pallone 2007; Rao et al. 2006; Rezak 2007; Simuni 2007; Singh et al. 2007). Usually, patients are given levodopa combined with carbidopa. Carbidopa delays the conversion of levodopa into dopamine until it reaches the brain. Nerve cells can use levodopa to make dopamine and replenish the dwindling supply in the brain. Although levodopa helps at least three-quarters of parkinsonian cases, not all symptoms respond equally to the drug. Bradykinesia and rigidity respond best, while tremor may be only marginally reduced. Problems with balance and other symptoms may not be alleviated at all. Anti-cholinergics may help to control tremor and rigidity. Other drugs, such as bromocriptine, pramipexole, and ropinirole, mimic the role of dopamine in the brain, causing the neurons to react as they would to dopamine. An anti-viral drug, amantadine, also appears to reduce symptoms.

If PD does not respond to drugs, surgery, like deep brain stimulation (DBS) may be considered (Simuni 2007). In DBS, electrodes are implanted into the brain and connected to a small electrical device called a pulse generator that can be externally programmed. DBS can reduce the need for levodopa and hence, can reduce the adverse side effect of levodopa such as dyskinesias. It also helps to alleviate fluctuations of symptoms and to reduce tremors, slowness of movements, and gait problems. Non-pharmacologic therapy such as physiotherapy can improve functional independent level and well-being of patients (Pallone 2007, Rao et al. 2006). Physical training programs such as the use of appropriate external cues (Behrman et al. 1998, Farley et al. 2005, Howe et al. 2003, Lehman et al. 2005, Martin 1967, McIntosh et al. 1997, Morris et al. 1994, 1996, Suteerawattananon et al. 2004, Werner 2003), stretching, exercise and balance training may improve balance, gait speed and activities of daily living in patients with PD (Rao et al. 2006).

Walking difficulty is one of the most disabling features in people with PD. Previous studies have shown that PD patients walked with reduced stride length, gait velocity and cadence (Blin et al. 1991, Morris et al. 1994, 1996). With addition of one or more concurrent motor or cognitive tasks, there was greater gait deterioration than the solo motor task of walking in PD patients (Baker et al. 2007, Bloem et al. 2001, Bond and Morris 2000, Galletly and Brauer 2005, O'Shea et al. 2002, Rochester et al. 2004, Yogev et al. 2005). A review of the literature indicated that no study has reported the effect of visual distraction on walking in patients with PD. Therefore, it

would be interesting to explore the interference of naming an object that a subject saw on walking in PD patients, and to compare this task with another cognitive task (i.e. calculation) on walking performance in these patients.

A number of studies reported that external cues and attentional strategy could enhance gait performance in patient with PD. However, only one study examined the effect of visual cue on gait performance under dual cognitive-walking task condition (Galletly and Brauer 2005), and the improvement was only found in stride length. Mak and Hui Chan (2004) found that, with the addition of preparatory audio-visual (AV) signals, PD patients could enhance the performance of their sit-to-stand (STS) task. In the light of the positive effect of preparatory AV cues in improving STS task in PD patients, it would be interesting to examine whether preparatory AV cues could enhance walking under concurrent task condition in PD patients.

1.2 Statement of purpose

This study had two inter-related studies: a pilot study and the main study. The purpose of the pilot study was to establish the reliability of the methodology and the data measured by GAITRite system which was the instrument used in the main study. The main study was designed (1) to examine the effect of a concurrent cognitive task of naming an object seen and of calculation on gait performance in PD patients; and

(2) to determine whether preparatory audio-visual cues could enhance walking under dual cognitive-walking task conditions in PD patients.

1.3 Hypotheses of the study

We hypothesized that (1) a distraction of attention such as object naming or calculation would affect walking performance in PD patients; and that (2) the use of preparatory AV cues could improve gait performance under dual cognitive-walking task conditions in PD patients.

1.4 Organization of Chapters

This thesis composes of 5 chapters in addition to the Introduction. The first chapter provides an overview of the study. The background of the Parkinson‟s disease and the knowledge gap existing in the previous studies are stated together with the purposes and hypotheses of present study. Chapter 2 provides the literature review relevant to the present study. This includes the neurophysiology of basal ganglia, gait disorders in PD patients, the effect of dual task in gait performance in PD patients, and finally the effect of external cues on gait performance during dual-task walking in PD patients. Chapter 3 describes the experimental design and methodology. The results are presented in Chapter 4. Chapter 5 is the discussion of the findings, limitations and direction of future study. This is followed by Chapter 6 which states the conclusion of present study.

CHAPTER 2 LITERATURE REVIEW

This chapter provides the literature review of previous studies relevant to the present study. It includes the neurophysiology of basal ganglia, gait disorders in PD patients, the effect of dual task on gait performance in PD patients and finally the effect of external cues in gait performance during dual cognitive-walking task in PD patients.

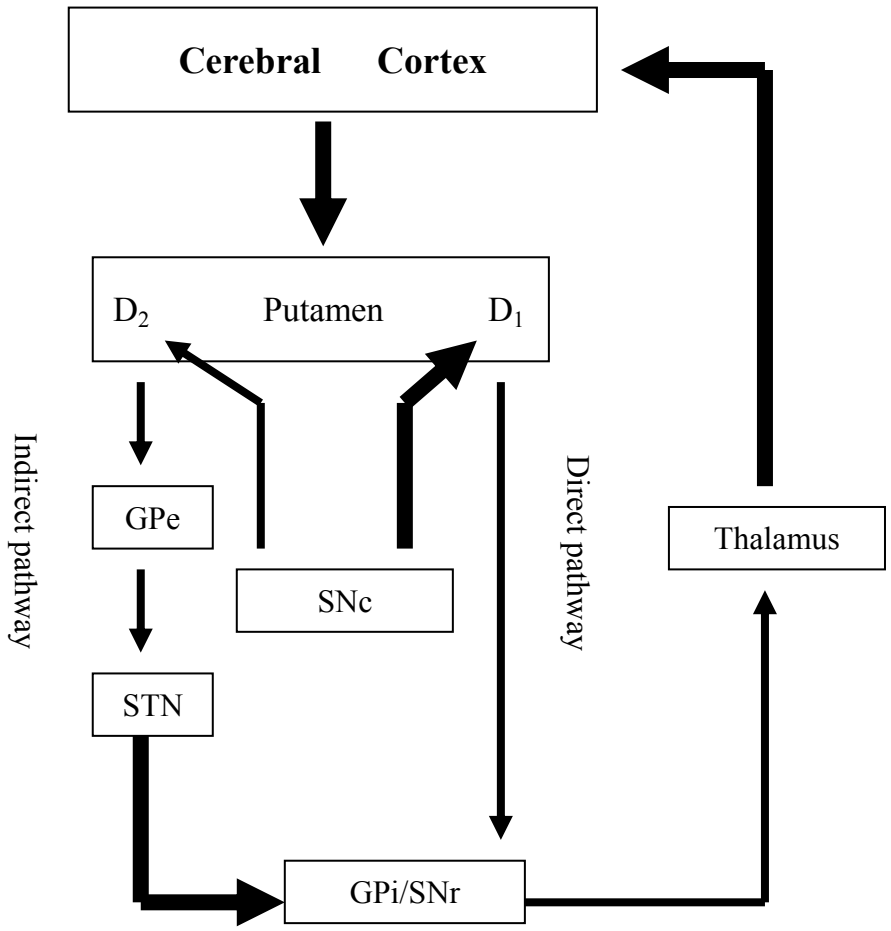
2.1 Neurophysiology and pathological models of basal ganglia

The basal ganglia (BG) are located in the basal telencephalon and consist of five interconnected nuclei: caudate nucleus, putamen, globus pallidus, substantia nigra and subthalamic nucleus (STN). In primates, caudate and putamen, the input nuclei of BG, are generally referred to as striatum, which is the largest structure in basal ganglia. The main neuronal population in striatum is spiny projection neurons, which accounts for almost 95% of total striatal cells (Kemp and Powell 1971) and uses γ-amino-butyric acid (GABA) as a neurotransmitter (Kita and Kitai 1998). The presence of dopaminergic neurons intrinsic to the striatum has also been suggested (Betarbet et al. 1997). Striatal neurons contain both D_1 and D_2 dopamine receptors which account for the dopamine release from nigrostriatal terminal. The pallidus comprises two segments, internal and external globus pallidus (GPi and GPe). Both of them lie medial to the putamen, and are populated by GABAergic neurons (Oertel and Mugnaini 1984). The substantia nigra (SN) lies in the ventral tegmentum of the

midbrain, which consists of two distinct structures: substantia nigra pars compacta (SNc) and substantia nigra pars reticulate (SNr). Globus pallidus and SN are the output nuclei of BG. The STN is a small lentiform nucleus located at the border between the midbrain and the diencephalon.

Alexander and colleagues (1986) formulated a model of basal ganglia functioning in the mid-1980. According to this model, the striatum is the main input of the circuit, which transmits the flow of information received from the cortex to the basal ganglia output nuclei, SNr and GPi, via a direct and an indirect pathway (Fig. 2.1). In the direct pathway, the information flows from putamen to the GPi/SNr. In the indirect pathway, information flows from the putamen to the GPe, the STN, and ultimately to the GPi/SNr. The neurontransmitters in the direct pathway contain GABA and substance P, and those in the indirect pathway contain GABA, enkephalin and dynophin. In a general sense, the activation of the GABAergic neurons in the direct pathway causes inhibition of the GPi/SNr. This leads to disinhibition of the thalamic nuclei, and hence facilitation of the motor cortex. Conversely, activation of GABA neurons that project to the GPe in the indirect pathway causes inhibition of GPe and disinhibition of the STN. The activation of STN increases the activity of the GPi/SNr, eventually increasing the inhibition on the thalamus and the motor cortex (Fig. 2.1). The neurotransmitter dopamine which is released from the SNc predominated act on the putamen (Freeman et al. 2001). Dopamine can have either an inhibitory or excitatory effect on striatal neurons depending on the receptor subtype.

Fig. 2.1 Direct and indirect pathways of basal ganglia (adopted from Alexander and Delong 1990)



GPe: external globus pallidus

GPi: internal globus pallidus

SNc: substantia nigra pars compacta

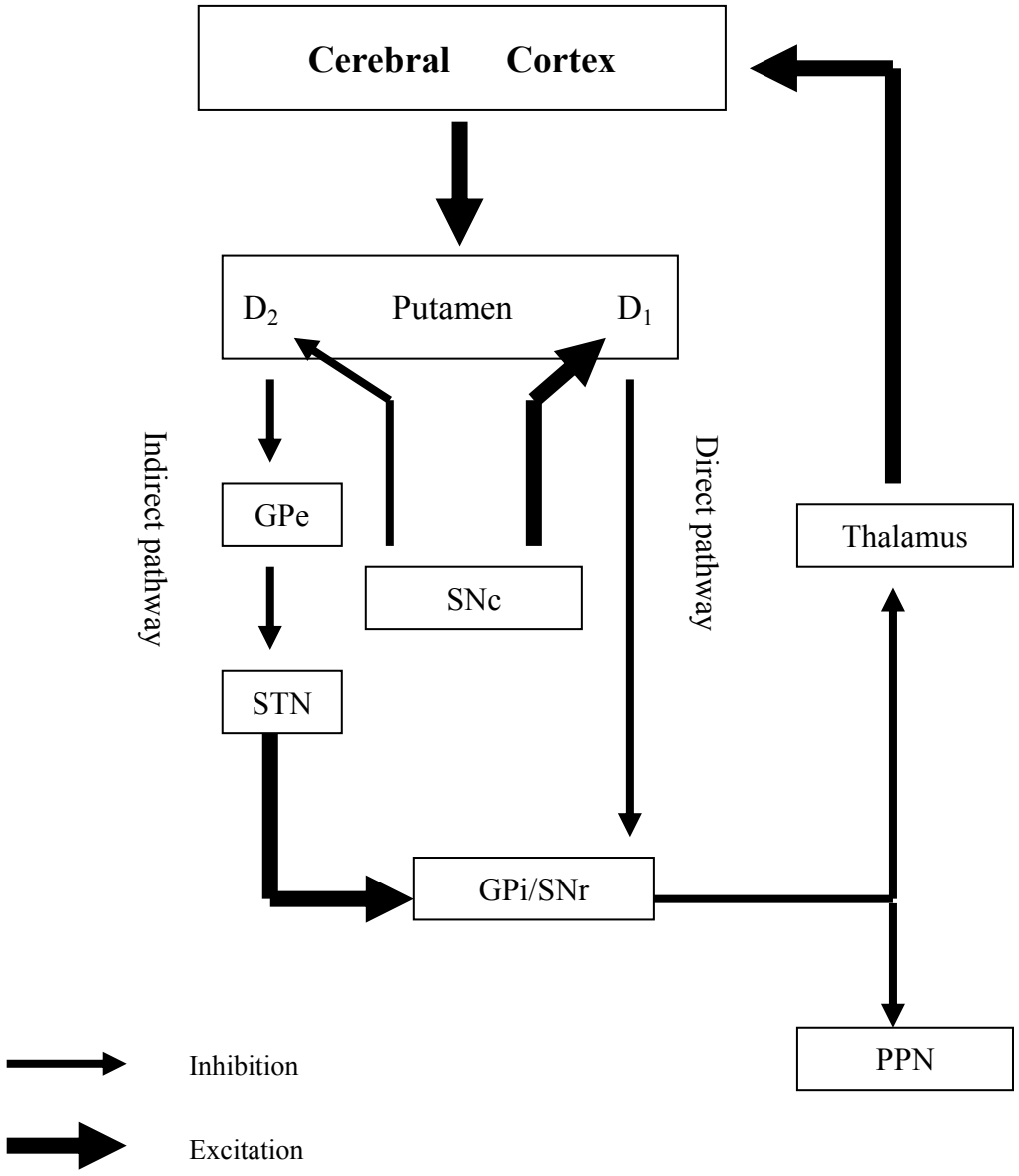
SNr: substantia nigra pars reticulate

STN: subthalamic nucleus

D_1 receptors result in an excitatory effect that send GABA and substance P projections to the GPi/SNr via the direct way, while D_2 receptors result in an inhibitory effect that send GABA/enkephalin projections to GPe via the indirect pathway (Kopell et al. 2006). Therefore, the function of the direct pathway is facilitation of the motor cortex, which initiates the intended movement. On the other hand, the function of the indirect pathway is inhibition of the motor cortex. In normal individuals, dopamine activates the direct pathway and inhibits the indirect pathway to promote facilitation of cortically initiated movement.

Recently, Kopell et al. (2006) added other networks to the original model for the function of BG (Fig. 2.2). These networks serve to integrate cortical, thalamic, BG, and spinal activities, and their damages are suggested to play important roles in the genesis of PD symptom such as gait deficits. The GPi/SNr gives direct ascending thalamocortical projections and sends a prominent GABAergic projection to the descending pathways to the brainstem and spinal cord. The receiving area is pedunculopontine uncleus (PPN). This nigral output inhibits the activity of the PPN (Saitoh et al. 2003). The PPN is part of the brainstem reticular formation and reciprocally connected to the BG, as a fundamental part of the mesencephalic locomotor center. It has attracted much attention in movement control and in gait particular (Obeso et al. 2008). Neuropathological studies on humans reported that around 50% of the large cholinergic neurones of PPN could undergo degeneration in

Fig. 2.2 New model of indirect and direct pathways (Adopted from Kopell et al. 2006)



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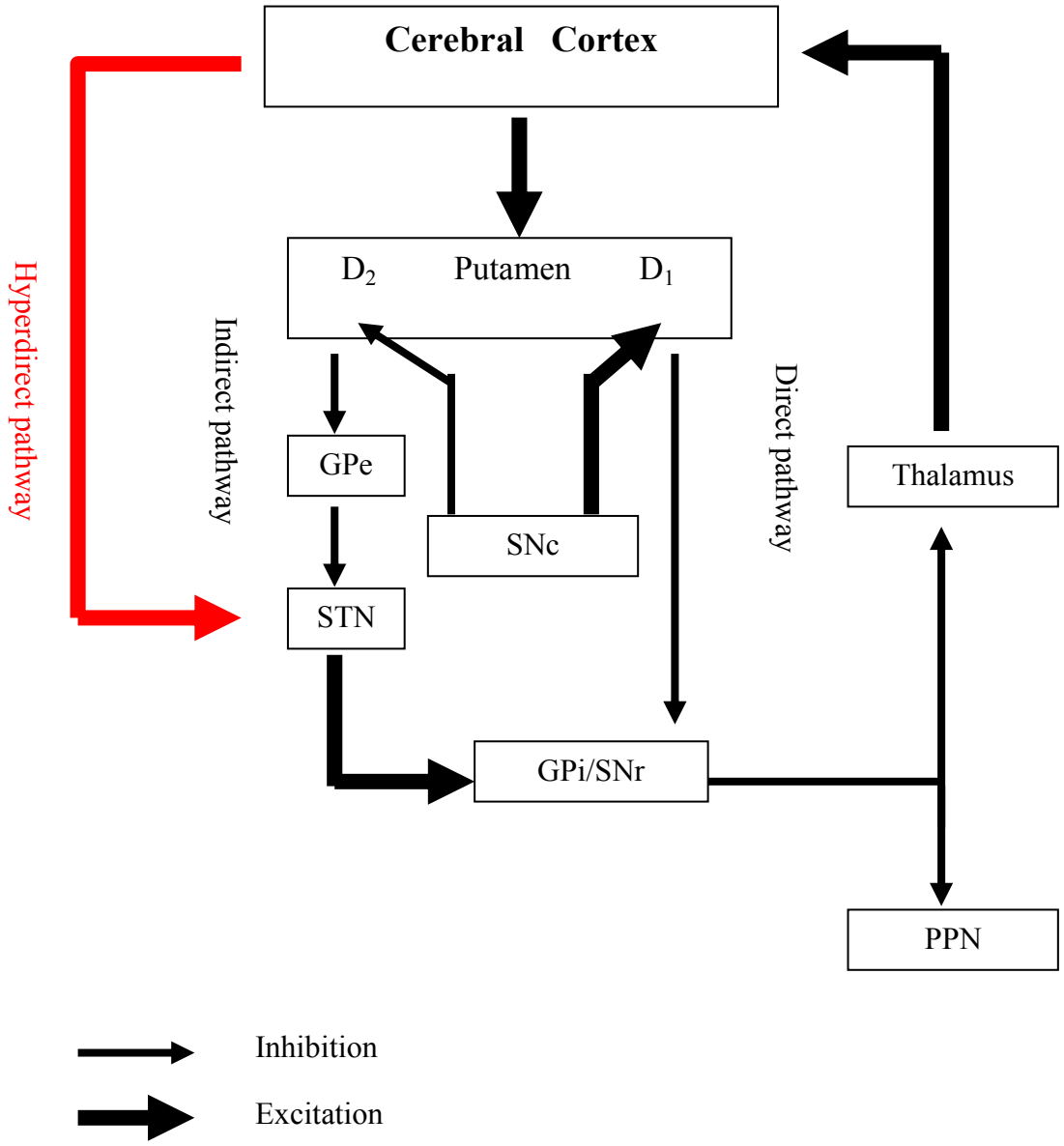
Parkinson's disease (Gai et al. 1991, Hirsch et al. 1987, Jellinger 1988, Zweig et al. 1989), and lesions in the PPN could lead to gait and postural disturbances in Parkinsonism (Aziz et al. 1998, Kojima et al. 1997). The pathophysiological changes in motor circuit activity in PD was further elucidated by the availability of 1-methyl-4-phenyl-1,2,3,6- tetrahydropyridine (MPTP), which is a neurotoxin that induces extensive dopaminergic degeneration resulting in parkinsonian syndrome. Studies in MPTP animal model demonstrated that the depletion of dopamine led to increased activity of striatal indirect pathway neurons (resulting in increased inhibition of GPe, disinhibition of STN, and excitation of the GPi/SNr), and reduced the activity of striatal direct pathway neurons. As a result, there was increased inhibition of thalamal projection to the motor cortex. These changes are thought to represent the neural substrate for PD motor symptoms, namely depletion of dopamine in the BG, the PPN and the frontal lobe, resulting in various patterns of abnormal gait patterns (Nobuo et al. 2006).

In addition, Nambu et al. (2000) formed another pathway so-called hyperdirect pathway that the STN receives input station directly from cortex, eventually facilities the motor cortex. This pathway exerts powerful excitatory effects on output nuclei, and is more rapid in signal conduction than the direct and indirect pathway (Nambu et al. 2000).

Fig. 2.3 Direct & Indirect pathway of BG (Nambu et al. 2000)



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Basal ganglia were thought to have an important role in the control of well learned, repetitive sequences of movement and sequential motor task (Brotchie et al. 1991). For instance, well learnt sequential movements such as walking were believed to be controlled by BG (Iansek et al. 1995). It was suggested that during the execution of walking, BG provide internally generated cues to guide the motor preparation, movement onset, initiation of subsequent step, and termination of walking (Cunnington et al. 1999). Hence, healthy individuals can initiate walking, maintain or change their stride length, and stop walking in a smooth manner. However, the defective function of BG might force people with PD to overly rely on cortically mediated mechanisms of motor control when carrying out movements such as walking (Cunnington et al. 1999). When a concurrent task was added to walking, the increase demand to concentrate on 2 tasks simultaneously could place further pressure on limited attentional resources in people with PD, and might account for their difficulties in performing one or both tasks (Bond et al. 2000).

2.2 Gait disturbances

Gait disturbances are cardinal signs of PD (Hoehn and Yahr 1967). The reduction of stride length is considered the most prominent feature of PD gait, which is often accompanied by reduced gait velocity and a tendency toward a longer duration in the double-support phase (Blin et al. 1991, Morris et al. 1994, 1996). Some studies (O¨Shea et al. 2002, Rochester et al. 2004) also found a decrease in

cadence in people with PD. However, Morris et al. (1996) indicated that some patients might increase the cadence to compensate for reduced stride length.

Morris et al. (1994) compared the gait performance of 34 PD subjects with 34 age- and height-matched controls under three walking conditions (slow, normal and fast speed). In all conditions, PD patients walked with a significant lower gait velocity and shorter stride length than control subjects. During self-selected walking speed, the gait velocity of PD patients was significantly slower than that of control subjects, by 28.9% ($p=0.0001$). The reduced gait velocity was associated with mean stride length being significantly shorter than control, by 28.2%. There was no significant difference between the two groups for the cadence during walking at subjects‟ preferred speed. These results suggested that reduced gait velocity for the preferred gait in PD patients was attributable to the reduced stride length. O‟Shea et al. (2002) compared 15 people with PD with 15 control subjects similar in age, sex and height when they all walked at a natural speed. These investigators reported significant reductions in gait velocity and stride length values by 18% and 14.6% ($p<0.0001$) respectively, and a small reduction in cadence by 4.3%. Sofuwa et al. (2005) compared gait parameters recorded on an 8-m walkway in 20 people with PD and 10 healthy elderly control subjects. Subjects were instructed to walk at their self-selected natural speed. Results showed a significantly lower walking velocity in PD than control subjects by 21% ($p=0.004$) and a significance shorter stride length by 16.9% ($p=0.002$). There was no significant difference in cadence between the two groups.

All studies mentioned above examined elder people with PD, who had a mean age ranging from 63.1 to 75.9 years (Morris et al. 1994, Sofuwa et al. 2005), and moderate disease severity as indicated by mean Hoehn and Yahr scale (H&Y) stage from 2.6 to 3.0 (Morris et al. 1994, Sofuwa et al. 2005) or Webster rating scores from 12.6 to 16.8 (Morris et al. 1994, O'Shea et al. 2002). When these patients walked at their natural speed, they were found to have significant decreases in gait velocity (Morris et al. 1994, O'Shea et al. 2002, Sofuwa et al. 2005) and stride length (Morris et al. 1994, O'Shea et al. 2002, Sofuwa et al. 2005) and a small reduction in cadence (O'Shea et al. 2002). However, other studies reported no change in cadence (Morris et al. 1994, Sofuwa et al. 2005) when compared with that of the control subjects.

2.3 Effect of dual task on gait performance in patients with PD

Dual task performance is also known as "concurrent performance". It involves the execution of a primary task, which is the major focus of attention, and a secondary task performed at the same time. In general, dual tasking relies upon executive function and the ability to divide attention between the 2 tasks (Della et al. 1995). Attention has been defined as a person's information-processing capacity (Woollacott et al. 2002), which involves the concentration and focusing of mental activity either intentionally or habitually (Bond et al. 2000). According to the capacity-or resource-sharing model, the attentional capacity is limited for any individual. Therefore, if a task requirement exceeds the available capacity, its performance may be expected to deteriorate (Shumway et al. 2000a, b).

In people with PD, dual task interference is a noticeable problem because of the disruption of motor functions of the basal ganglia (Iansek et al. 1995). Theoretically, the control by basal ganglia of more automatic (rhythmic) movement such as walking would leaves some attentional resources available for performance of other concurrent task(s) in healthy subjects. The defective function of the basal ganglia in people with PD might force them to overly rely on cortically mediated mechanisms of motor control when carrying out rhythmic movements such as walking (Cunnington et al. 1999). In dual-task situations, the need to concentrate on 2 tasks simultaneously could place pressure on the limited attentional resources in these patients. The latter could account for the difficulties patients with PD show when they perform 2 tasks at the same time (Bond et al. 2000), resulting in deterioration of their performance in one or both tasks.

Earlier studies on dual task interference in people with PD are mainly concerned with upper limb movements or verbal-cognitive tasks. Talland and Schwab (1964) compared people with and without PD when they manipulated small beads with tweezers by one hand, whilst using a marker in the other hand. PD patients were slower than the control subjects when performing an individual task, and their speed further diminished when they had to use both hands simultaneously. Soliveri et al. (1992) found that when patients with PD attempted to perform a bimanual finger sequence at the same time as foot tapping, the speed of finger movement decreased. These results confirmed that in bi-manual performance of two different tasks, the

general performance of parkinsonians is more affected than that of normal subjects. Dalrymple et al. (1994) investigated the effects of adding a cognitive task (digit recall) when subjects performed an upper-limb random pursuit tracking task. PD patients showed a significant decline in performing the tracking task while recalling digit span in forward sequences than performing the tracking task alone. In contrast, the eight control subjects showed no change when performing dual versus single task.

Morris et al. (1996) conducted the first study that reported the effects of dual cognitive-walking task on walking performance in people with PD. Sixteen patients were trained to walk at the same stride length as that of healthy subjects similar in age, sex and height. After 20 minutes of gait training, gait velocity, stride length and cadence in PD subjects improved by 31.2%, 26.2% and 3.8% respectively ($p<0.05$). Gait parameters were then assessed while reciting sentences of increasing complexity. There was a significant decrease in stride length by 47.6% and gait velocity by 22.3% in PD subjects which was found at the most difficult sentence recited. Control subjects also showed a small reduction in stride length and cadence in the most difficult secondary task conditions. However these changes were not statistically significant. Camicioli et al. (1998) examined the effect of talking while walking in PD patients. Altogether, three groups of subjects participated in the study: a comparison healthy group, people with and without motor freezing. Ten PD patients with freezing exhibited a significantly greater increase in the number of steps (n=4.2) to complete

the walk while talking when compared to that of 9 PD patients without freezing (n=0.1), and nineteen control subjects (n=1.5).

Furthermore, Hausdorff et al. (2003) examined gait variability of 10 PD patients when performing a cognitive task (serially subtracting 7's from a 3-digit number) during walking. When these patients performed such a dual task, their gait became hesitant and stride-to-stride fluctuations became large. In addition, their average stride time was longer (p=0.006). These results indicate that walking while performing a cognitive task impairs the ability of PD patients to maintain a stable gait pattern. A similar study was conducted by Yogev et al. (2005). Thirty PD patients and 28 control subjects were instructed to walk while performing serial subtractions of 7 starting from 500. Gait velocity was used as the only outcome measure. Although PD subjects decreased their gait velocity by 19% which was more than the 9.2% in control subjects, this difference was insignificant. Control subjects had similar deteriorations in gait performance as that of PD patients during such a dual task. This finding was somewhat contradictory to that of Morris et al. (1996). Since the age of the control subjects in these 2 studies was similar, the different results might be due to the complexity of the cognitive task. In the study by Morris et al. (1996), the complexity of the cognitive task was progressively increasing. Significant differences in gait velocity between the two groups were found only as the tasks reached the last 2 most complex levels. Therefore, when the complexity of a cognitive task reached a critical level, PD patients would show significantly larger deterioration in gait

performance than control subjects. The above-mentioned studies found that when a concurrent cognitive task was added during walking, PD patients had deterioration in gait velocity and stride length, and showed more stride-to-stride fluctuations.

Apart from dual cognitive-walking task, some previous studies examined the effect of dual motor task in gait performance in PD patients. Bond and Morris (2000) used a tray-carrying-and-walking task to examine dual task interference. Twelve PD patients and 12 control subjects performed 10-meter gait trials under 3 conditions: 1) walking freely, 2) carrying a tray, or 3) carrying a tray with four plastic glasses. In the control subjects, no deterioration was found in gait performance under any of the 3 conditions. PD subjects also showed an insignificant reduction in stride length (by 2.4%) and gait velocity (by 1.8%) in condition 2. However, they had a significant reduction of gait velocity and stride length by 10.2% and 10.9% respectively, in condition 3 when compared with that of condition 1. There was no change in cadence in both groups across 3 conditions. Bond and Morris (2000) concluded that a critical level of task complexity (such as condition 3) had to be reached before gait deterioration could be found in PD subjects. Baker et al. (2007) used a similar motor task (carrying a tray with 2 cups of water) to examine the dual task effect on gait in 15 PD patients. The results showed that PD patients significantly decreased their gait velocity (by 8.2%) and step length (by 9.2%) when compared with walking alone. There was no significant change in cadence. Therefore, both studies showed that a concurrent motor task reduced gait velocity and stride length in PD patients.

O'Shea et al. (2002) further examined the effect of a concurrent cognitive or motor task on gait performance. Fifteen PD patients and 15 controls were compared when they walked 1) at a self-selected speed, 2) simultaneously performing coin transference, 3) simultaneously digit subtraction by 3. Both groups significantly reduced their stride length and gait speed when they had to walk while performing a concurrent task but the deterioration was significantly greater in PD patients. In these patients, gait velocity and stride length decreased by 18% and 14% respectively during coin transference and by 18.8% and 12.4% respectively during the cognitive task. In addition, cadence also significantly decreased by 5.4% and 7.4% respectively when patients walked while doing a concurrent motor or cognitive task. For control subjects, gait velocity and stride length decreased by 7.5% and 6.6% respectively during coin transference, and by 6.9% and 4% during a concurrent cognitive task. Since the deterioration of each gait parameter was similar whether patients did a concurrent motor or cognitive task, O'Shea et al. (2002) concluded that the type of secondary task was not a major determinant of the severity of dual task interference on walking. However, other studies reported opposite findings (Galletly and Brauer 2005, Rochester et al. 2004).

Rochester et al. (2004) instructed 20 PD patients and 10 controls to walk 1) alone, 2) while doing a concurrent motor task of carrying a loaded tray, or 3) while doing a concurrent cognitive task of answering simple questions, or 4) while doing a combination of task 2 and 3. PD patients showed a significant reduction in gait

velocity by 21.4% and 22.9% ($p<0.05$) respectively, in condition 3 and 4 when compared with that of condition 1. In contrast, no significant change in gait velocity was found in condition 2 (dual-motor task). Furthermore, PD patients had a similarly significant decrease in step length by 16.3% and 20.9% respectively ($p<0.005$), during condition 3 and 4, when compared with that condition 1; and no significant reduction in condition 2. Control subjects did not show significant difference in gait velocity among all the conditions, and only showed significant reduction of step length (by 14.3%) in condition 4. Both PD and control subjects did not show significant changes on cadence in all conditions. These results indicated that the cognitive task had a greater interference on gait than the motor task in PD patients, suggesting that a cognitive task may be more difficult than a motor task.

Galletly and Brauer (2005) compared the different effects on walking between dual-motor task (press the button) and dual-cognitive task (subtraction by 3 or list specific letter with "F" and "S") in PD patients. With the added task of either calculation or language, there was significant decrease in gait velocity and stride length, by 21% and 16% ($p<0.05$), but no change in cadence when compared with that of walking alone. However, when a motor task was added, PD patients only significantly decreased their gait velocity by 6.6%, with no change in stride length and cadence when compared with that of walking alone. In addition, the reduction in gait velocity for the dual cognitive-walking task was significantly larger than that of dual motor-walking task. For control subjects, the addition of a calculation task

significantly decreased their gait velocity, stride length and cadence by 14%, 7% and 7% respectively. The addition of a language task significantly decreased gait velocity by 16.1%, stride length by 9.6% and cadence by 7.4%. With the addition of a motor task to walking, there was significant but less reduction in gait velocity (by 3%) and stride length (by 4.1%) with no change in cadence. Galletly and Brauer (2005) also found that a concurrent cognitive task had a greater interference on gait than did the motor task in PD patients. The different results between the 2 latter studies and that of O'Shea et al. (2002) might not be due to the level of difficulty of the dual cognitive task. Since all these studies had used similar cognitive task: calculation or language. However, the level of difficulty of the motor task was not the same. In the study by O'Shea et al. (2002), PD patients had to use both hands to complete the coin transfer in a sequential manner. For the other studies, PD patients held a tray by both hands (Rochester et al. 2004) or pressed a button by one hand (Galletly and Brauer 2005). These patients were found to manifest more deficits when they moved both hands at same time than if they moved only one hand (Talland and Schwab 1964). Therefore, the motor task used in study by O'Shea might be more difficult than that used by Rochester et al. (2004) and by Galletly and Brauer (2005). This might explain why no difference in gait performance was found between dual motor-walking and cognitive-walking task in the study by O'Shea et al. (2002).

Galletly and Brauer (2005) further examined the accuracy required of task performance. PD patients committed less accuracy in all cognitive tasks. However, the

differences were not significant, which contradicted the finding by Yogev et al. (2005). In the latter study, PD patients committed significantly lower accuracy (by 74%) than controls (by 89%) in subtraction. The different results between the 2 studies might be due to the difficulty level of subtraction. Yogev et al. (2005) asked subjects to say out serial subtractions of 7 starting from 500. It might be more difficult than subtraction of 3 used in the study by Galletly and Brauer (2005). Bloem et al. (2001) compared PD and control subjects in making motor and cognitive errors during performance of complex postural tasks. Twenty elderly controls and 20 people with PD performed 8 separate motor tasks with increasing complexity while doing a concurrent cognitive task. The motor task composed of several motor components: standing up, walking, avoiding obstacles, touching the floor, turning around and sitting down and the cognitive task was answering serial questions. Their results showed that patients made more motor errors (such as hesitation and motor block) than control subjects. Only 8% of patients completed all the tasks without motor error. However, control subjects made more cognitive errors during complex motor tasks (i.e. avoiding obstacles, touching the floor while walking) than PD patients. Therefore, Bloem et al. (2001) suggested that PD patients paid more attention to the concurrent cognitive task rather than the motor task such as walking. These investigators further proposed that control subjects used “posture first strategy”, whilst PD patients were less able to lend priority to motor performance than controls. Contrary to the study by Bloem et al. (2001), the studies mentioned above found that PD patients committed more cognitive errors than control subjects. An alternative explanation could be that, in the study by Bloem et al.

(2001), the motor tasks performed by the subjects were more complex than straight-line walking (Galletly and Brauer 2005, Yogev et al. 2005), such as walking while avoiding obstacles, turning around during walking. Therefore, PD patients may not be able to switch their attention between the different motor task components, and hence committed more motor errors than control subjects.

To sum, all the studies mentioned above (dual cognitive-motor task, dual motor task) examined elder people with PD with mean age ranging from 60 to 73.4 years (O'Shea et al. 2002, Yogev et al. 2005). They had PD with moderate severity as indicated by mean H&Y stage from 2.2 to 2.7, Webster rating scores from 12.6 to 14.1, or Unified Parkinson Disease Rating Scale (UPDRS) motor part scored from 14.4 to 30.1. When PD patients walked under dual motor task, there was significant decrease in gait velocity (Baker et al. 2007, Bond and Morris 2000, Galletly and Brauer 2005, O'Shea et al. 2002), stride length (Baker et al. 2007, Bond and Morris 2000, O'Shea et al. 2002) and cadence (O'Shea et al. 2002) than that of walking alone. Other studies reported no change in cadence (Baker et al. 2007, Bond and Morris 2000, Galletly and Brauer 2005, Rochester et al. 2004). When PD patients walked under dual cognitive-motor task, there was significant reduction in gait velocity (Galletly and Brauer 2005, Morris et al. 1996, O' Shea et al. 2002, Rochester et al. 2004, Yogev et al. 2005), stride length (Gallely and Brauer 2005, Morris et al. 1996, O' Shea et al. 2002, Rochester et al. 2004), and cadence (O' Shea et al. 2002) than that of walking alone. A number of studies reported no change in cadence (Rochester et al. 2004,

Galletly and Brauer 2005). Only one study examined the effect of 2 different cognitive tasks on gait performance in PD patients (Galletly and Brauer 2005). However, the cognitive tasks (language and calculation) used were more likely skill dependent, and could be influenced by the education level of subjects (Yogev et al. 2008). It is also difficult to distinguish the complexity of these 2 cognitive tasks. Aside form the cognitive task used in the laboratory, Bloem et al. (2004) reported that in PD patients experienced worsening of gait performance in daily life, at home or on the street. It might be because visual objects in the surrounding distract the attention of PD patients while they walk. However, no study has reported the effect of visual distraction on walking in patients with PD. Therefore, it would be interesting to examine the interference of visual distraction (i.e. to name an object that a subject saw) on walking in PD patients, and to compare this task with another concurrent cognitive task (i.e. calculation) on walking performance in these patients. The present study was designed to examine the effect of naming object and calculation on gait performance in PD patients.

2.4 Effect of external cues on gait performance with dual task in patients with PD

Several studies have shown that use of external cues (i.e. visual and auditory) could enhance the gait performance in people with PD (Lewis et al. 2000, Morris et al. 1996, Thaut et al. 1996). The commonly used visual cues are transverse lines or rods

placed on the floor, as first described by Martin (1967). When PD patients were instructed to walk on a runway with visual cues placed upon it, there was an improvement in stride length. The most effective cues were the lines that were placed perpendicular to the runway, apart each step (Martin 1967). The auditory cues are commonly rhythmical signals generated by a metronome or equivalent, sometimes embedded in music (McIntosh et al. 1997), and with a frequency set at or slightly above subjects‟ cadence (Freedland et al. 2002, Rochester et al. 2005). It was found that the use of auditory cues increased gait velocity and stride length in PD patients (Rochester et al. 2005). Recently, a number of studies examined the effect of external cues on gait performance while doing a concurrent motor task in PD patients (Baker et al. 2007, Galletly and Brauer 2005, Rochester et al. 2005, 2007). Only one study investigated the effect of external cues on walking while PD patients walked and performed a concurrent cognitive task (Galletly and Brauer 2005). These investigators demonstrated that the use of visual cue could normalize stride length in people with PD during walking under concurrent cognitive task. In this study, 16 PD patients and 16 control subjects were instructed to walk with and without visual cue while performing a concurrent cognitive task (subtraction by 3 or list specific letter with “F” and “S”). The visual cues were white lines which were placed on floor, with the distance between each line set at the step length of matched control subjects. The results showed that with the addition of visual cues, PD subjects significantly increased their stride length by 13.1% and 15.0% respectively for calculation and language task ($p<0.007$), and to a level comparable to that of the control subjects. In

contrast, their cadence was significantly decreased respectively by 11.8% and 16% for the calculation and language task ($p<0.005$). Gait velocity did not change in cued when compared with non-cued walking conditions, possibly due to the opposite effect of visual cue on the stride length and cadence.

Rochester et al. (2005) assessed the effect of visual cue on walking during concurrent motor task in PD patients at their home environment. Twenty people with PD and 10 age-, sex-, education level-matched healthy controls performed a functional task with and without external cues. Subjects started with standing up from the chair, walked to the kitchen, picked up a tray and carried it back to the lounge, placed the tray on a table next to the chair, and sat down. The visual cue was a flash light generated by a light-emitting diode which was attached to subject's glasses. The results showed that when using visual cue, step length increased by 7.7%, cadence decreased by 5.4%, and no change in gait velocity when compared with non-cued condition. However, all these changes did not reach a significantly level, possibly due to a small sample size. Rochester et al. (2007) subsequently performed the same experiment in a larger group of 153 PD patients. When visual cue was added, there was a significant increase in step length (by 4%), but significant decreases in cadence (by 4.4%) and gait velocity (by 3.6%). Therefore, the use of visual cue increased the stride length under dual motor-walking task condition in PD patients. With the provision of visual cue, PD subjects could have focused their attention on the step size, leading to an increase in the stride length.

In addition to visual cue, Rochester et al. (2005) also investigated the effect of auditory cue on gait performance while performing a concurrent motor task (carry a tray) in PD patients. The auditory cue was an auditory tone which was delivered by an earphone; and with the frequency matched to healthy subjects‟ cadence. The result showed that in PD subjects, gait velocity and stride length increased by 11.1% and 16.3% respectively, but cadence decreased by 1.2% when compared cued to non-cued condition. However, these changes did not reach a significant level. The follow-up large scale study conducted by Rochester et al. (2007) demonstrated that, with the addition of auditory cue, PD patients significantly increased gait velocity by 3.6% and step length by 5.9%, but a significant decrease in cadence by 2.9% ($p<0.005$) when compared with non-cued condition. Baker et al. (2007) performed a similar study to assess the effect of auditory cue (metronome beat, frequency unknown) in gait performance under dual motor-walking task in PD patients. Fifteen PD patients and 12 control subjects were instructed to walk while carrying a tray with 2 cups of water, with or without auditory cue. With the addition of auditory cue, PD patients showed small and insignificant increases in their gait velocity by 2% and step length by 2.4%, and decreased in cadence by 4.5%. Results from afore-mentioned studies revealed that the use of auditory cue resulted in significant but small increases in gait velocity and stride length, but a decrease in cadence in PD patients.

It is also known that attentional strategy could improve gait performance of PD patients by focusing their attention on the walking task (Behrman et al. 1998,

Morris et al. 1996). For instance, Morris et al. (1996) instructed PD patients to stand next to the lines and to "measure" their step length prior to each walking trial until they had developed a "mental picture of the correct step size". When these patients paid attention to this criterion stride length, they achieved the same improvement in gait performance as that of the use of visual cue. Canning (2005) demonstrated that with specific attentional instructions, PD patients showed improvement in gait when performing a concurrent motor task simultaneously. Twelve PD patients were instructed to attend to maintaining big step or to attend to balancing the tray while carrying a tray with 4 empty glasses. The results showed that when PD patients attended to maintain big step, they walked with significantly faster gait velocity by 9.1% ($p=0.003$), longer stride length by 14.3% ($p=0.003$), but similar cadence ($p=0.98$) when compared with dual motor-walking task without instruction. These improvements reached a level comparable to the walking alone condition. However, when PD patients were asked to attend to balancing the tray; there was no significant difference between with- and without-instruction dual-walking conditions for all gait parameters.

Similar study was conducted by Baker et al. (2007). PD patients were instructed to walk with big step while carrying a tray with 2 cups of water. The results showed that with the addition of attentional strategy, PD patients walked with significantly faster gait velocity by 8.2%, longer step length by 16.7%, but smaller cadence by 9.0% than no-instruction dual-motor walking. Furthermore, there was no

interaction effect of group * attention, suggesting that PD patients responded to attentional strategy in a way similar to that of control subjects. Baker et al. (2007) further examined the effect of combination cues (auditory cue and attentional strategy) in gait performance while performing a concurrent motor task (carry a tray with 2 cups of water). They found that the use of combined cues produced similar results as using attentional strategy alone. PD patients had significant increases in gait velocity and stride length respectively by 9.6%, 14.8%, but decrease in cadence by 4.5%. The similar findings of these 2 studies (Baker et al. 2007, Canning 2005) showed that when PD patients focused their attention on the walking task, there were significant improvements in gait velocity and step length during the performance of dual motor-walking tasks. It appeared that the use of attentional strategy leads to greater improvements in gait performance (Baker et al. 2007) than those achieved by using either auditory or visual cue alone (Rochester et al. 2005, 2007).

While most studies evaluated the effect of cues given during walking, Mak and Hui Chan (2004) investigated whether the preparatory signals could enhance the performance of STS in people with PD. In this study, preparatory signals were defined as AV cues given before the initiation of STS. Fifteen patients and fifteen control subjects similar in age, gender, weight, and height were examined. All subjects were asked to perform the STS task under self-initiated and cue-initiated conditions. In the cue-initiated condition, subjects had to look at the light placed in front of them (visual cue), and listen to the verbal command “get ready, stand up” (the

auditory cue) to initiate and execute STS in a forward and upward direction. The result showed that in people with PD, the addition of AV cues significantly increased the hip flexion (p=0.000) and knee extension torques (p=0.013). PD patients also showed significantly increased peak horizontal (p=0.001) and vertical velocities (p=0.000) of the body center of mass as well as decreased the time taken to complete the STS task (p=0.000). Mak and Hui Chan (2004) suggested that preparatory AV cues were able to enhance the motor preparatory phase of STS and to heighten patients' attention, leading to the motor improvement. It is interesting to examine whether preparatory AV cues could enhance walking under dual cognitive-walking task in PD patients.

All fore-mentioned studies examined people with PD with mean age ranging from 64 to 68.8 years (Baker et al. 2007, Rochester et al. 2005). They had moderate severity of disease indicating by mean H&Y stage from 2.1 to 2.7. UPDRS motor part scored from 14.4 to 23.4. In summary, most studies reported that the use of visual cue (Rochester et al. 2005, 2007), auditory cue (Baker et al. 2007, Rochester et al. 2005, 2007) or attentional strategy (Baker et al. 2007, Canning 2004) improved gait performance under dual motor-walking task condition. There was increases in gait velocity (Baker et al. 2007, Canning 2004, Rochester et al. 2005, 2007) and stride length (Baker et al. 2007, Canning 2004, Rochester et al. 2005, 2007), but no change in cadence (Canning 2004) or a decrease in cadence (Baker et al. 2007, Rochester et al. 2005, 2007). The improvements brought by the use of attentional strategy appeared to

be greater than those by either auditory or visual cue. Only one study examined the effect of visual cue on gait performance under dual cognitive-walking task (Galletly and Brauer 2005). However, the improvement was only found in the stride length, but not gait velocity. Therefore, more studies are required to explore interventions to improve walking under dual cognitive-walking condition. In the light of the positive effect of preparatory AV cues in enhancing the STS task in PD patients, it is possible that the AV signals were given prior walking in a feed-forward manner, PD patients would have more gait improvement under dual cognitive-walking condition. In present study, we designed the AV cues which simulated the road-crossing traffic light and sound familiar to the subjects, when they walk across a road in their daily life. In addition, subjects were allowed to watch and to listen to the AV signals prior to the walking trial, and the AV signals started prior to gait initiation. We hypotheses that the preparatory signals combined with ongoing AV cues could improve gait performance under a concurrent cognitive task in patients with PD.

2.5 Summary

Previous studies showed that gait deficits are exacerbated during the addition of one or more concurrent motor or cognitive tasks in PD patients. However, no study has reported the effect of naming an object that a patient saw while walking, and to compare this task with another cognitive task (i.e. calculation) on walking performance in these patients. Only one study reported that visual cue increased stride

length but not gait velocity in PD patients when they walked while performing a concurrent cognitive task. Another study found that when combined auditory and visual cues were given before STS, performance of STS was enhanced the in PD patients. No study has examined whether preparatory audio-visual cues could enhance walking under concurrent cognitive task in PD patients.

This study aimed (1) to examine the effect adding a cognitive task (naming object or calculation) on gait performance in PD patients; (2) to determine whether preparatory AV signals could enhance walking under dual cognitive-walking task condition in PD patients. We hypothesized that (1) a distraction of attention such as object naming or calculation would affect walking performance in PD patients; and (2) the preparatory signals combined with AV cues could improve gait performance under concurrent cognitive task in PD patients.

CHAPTER 3 METHODS

This chapter describes the methods used to conduct the study. The method of investigation includes experimental design, subjects, instrumentation, experimental procedure and data analysis are presented.

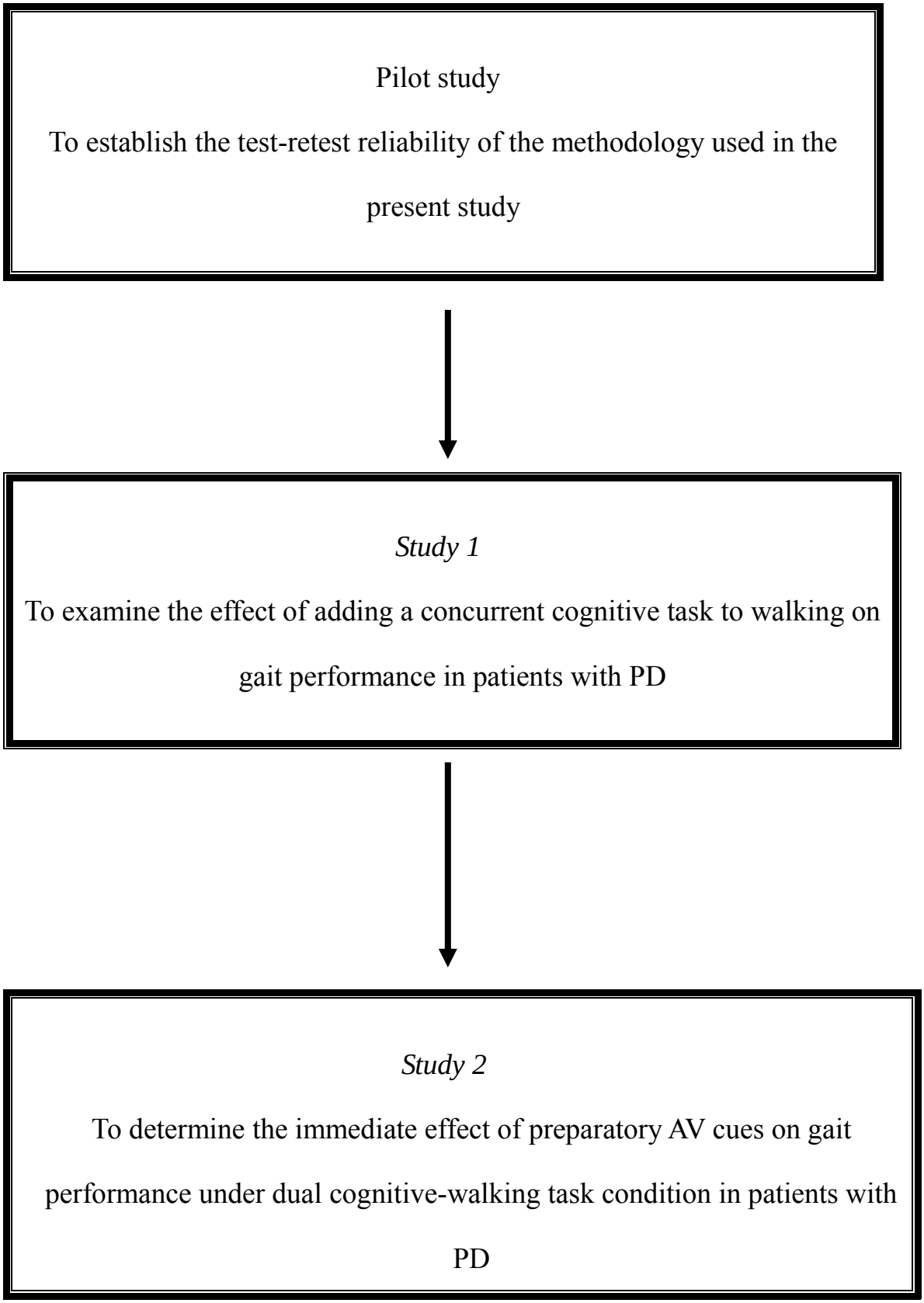
3.1 Experimental design

To fulfil the objective mentioned in Section 2.5 of Chapter 2, two inter-related studies were conducted. *Study 1* examined the effect of adding a concurrent cognitive task to walking on gait performance in patients with PD. *Study 2* investigated the immediate effect of preparatory AV cues on gait performance under dual cognitive-walking task condition in patients with PD. Cross-sectional comparative method was employed for both studies. Prior to the main study, a pilot study was performed to establish the test-retest reliability of the methodology and the data obtained with the GAITRite system, the main instrument used in the present study. The experimental design is illustrated in Fig. 3.1.

3.2 Subjects

Subjects with idiopathic PD, as defined by the UK Brain Bank criteria (Gelb et al. 1999) were recruited from the Hong Kong PD Association, a self-help patient group. To be included, PD subjects were aged between 50 and 70 years, on levodopa treatment; having disease duration of more than 1 year; H&Y scale between stage

Fig. 3.1 Experimental design



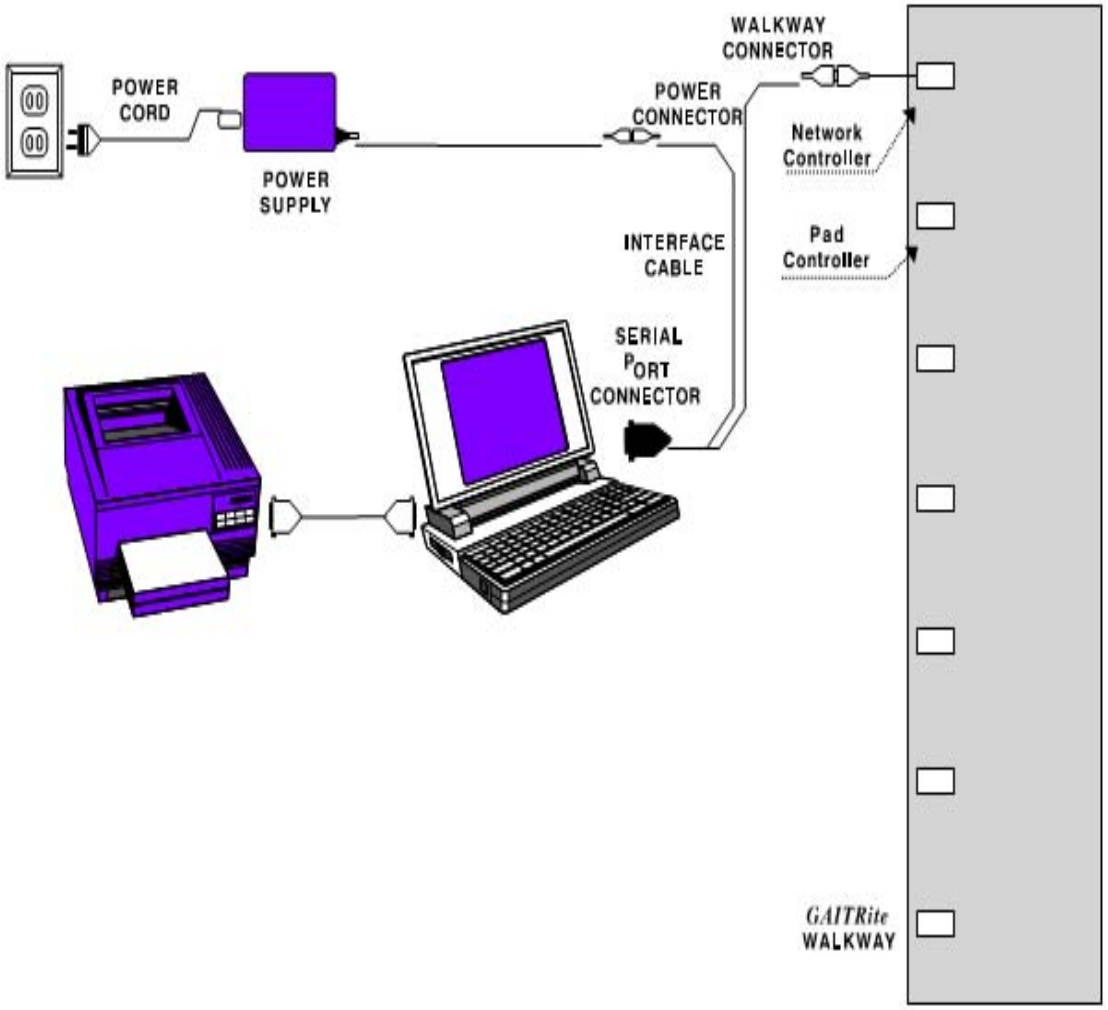
1-3 (Hoehn and Yahr 1967); able to stand independently and walk with or without an assistive device for a minimal distance of 6 metres; and having Mini Mental Status Examination (MMSE) score of 23 or above (Folstein et al. 1975). Subjects were excluded if they had history of neurologic conditions other than PD; cardiovascular or orthopedic impairments that would limit their ability to walk; visual, hearing, or cutaneous sensory impairments to such a degree that would affect their ability to recognize the computer screen; and the presence of severe on/off L-dopa motor fluctuations or dyskinesias. Healthy participants were recruited from several sources in the community, i.e. patient's spouse, and local senior centres, to form a control group. Recruitment of subjects was based on a "convenient" sample. Control subjects fulfilled the same inclusion and exclusion criteria as those of the PD subjects, except that they did not have PD.

3.3 Instrumentation

3.3.1 GAITRite

Temporal and spatial parameters of gait were recorded by the GAITRite walkway system (SMS Technologies Ltd, Harlow Essex UK), which contains six sensor pads encapsulated in a roll up carpet to produce an active area of 61cm wide and 366cm long (Fig. 3.2). As a subject ambulates across the walkway, the system captures the geometry and the relative arrangement of each footfall as a function of time. The application software controls the functionality of the walkway, processes

Fig. 3.2 GAITRite walkway system (SMS Technologies Ltd, Harlow Essex UK)



the raw data into footfall patterns, and computes the temporal (timing) and spatial (distance) parameters. The Gaitway software database stores the record of each individual test of subjects, and supports a variety of reports and analyses (2005 CIR System, Inc). Reliability and validity of GAITRite walkway system was established by previous studies (Bilney et al. 2003, McDonough et al. 1998). McDonough et al. (1998) performed the first study to compare the gait parameters captured by the GAITRite system with measures of the footfall imprints by paper and chalk. They concluded that the ability of measuring the spatial parameters such as step length and stride length by the GAITRite system was excellent. Bilney et al. (2003) evaluated the concurrent validity of the GAITRite in a large adult sample using the Clinical Stride Analyser (CSA) as the criterion measure. The level of absolute agreement between the GAITRite and the CSA was analyzed with intraclass correlation coefficient (ICC). Gait velocity, cadence and stride length demonstrated excellent agreement (ICC=0.99). Bilney et al. (2003) also investigated the inter-trial repeatability of GAITRite measures using ICC (3,1). The ICCs for gait speed, cadence and stride length indicated good reliability at subjects‟ preferred and fast speeds (ICC ranged from 0.92 to 0.97). In the present study, gait velocity, cadence and the stride length were used as dependent variables.

3.3.2 Mini Mental Status Examination (MMSE)

MMSE is a tool used to systematically assess the mental status of subjects (Folstein et al. 1975). It is an 11-question measure that tests 5 areas of cognitive function: orientation, registration, attention and calculation, recall, and language with a total score of 30 points. A score of less than 23 indicated dementia (Folstein et al. 1975).

3.3.3 Unified Parkinson Disease Rating Scale (UPDRS) scores

The UPDRS was used to document the impairment and disability level of patients with PD (Fahn et al. 1987). The motor examination (III) of UPDRS was used in this study. There are a total of 14 items, including speech; facial expression; tremor at rest; action or postural tremor; rigidity; finger taps; hands movements; rapid alternating movements; leg agility; arising from chair; posture; gait; postural stability and body bradykinesia/hypokinesia. Each item scores from 0 to 4, with 0 indicating no disability and 4 maximum disability. The total UPDRS motor examination (III) score ranges from 0 to 108. Previous studies have shown that the UPDRS has high internal consistency (Martinez-Martin et al. 1994; Stebbins and Goetz 1998). The test-retest reliability of the UPDRS motor section was excellent with a ICC value of 0.90.

3.3.4 The freezing of gait questionnaire (FOGQ)

FOGQ was used to quantify the self-reported history of mobility, gait disturbances, and freezing episode of PD patients (Giladi et al. 2000). FOGQ consists of six items: walking performance at the worst state, daily activities, making a turn, longest freezing episode, start hesitation episode, and turning hesitation episode. Patients were asked to quantify their performance based on a 4-point scale, with 0 indicating no freezing and 4 maximum freezing. The total score is 0 to 24 points, with 24 represents the worst performance. Reliability analysis revealed that FOGQ was highly reliable (ICC=0.94), and the total score of the FOGQ was found to be correlated with UPDRS total score ($r=0.48$, $p<0.01$) (Giladi et al. 2000).

3.4 Experimental procedure

3.4.1 Pilot study

Prior to the main study, four PD patients and 4 healthy subjects were recruited for the test-retest reliability tests. The testing procedure was the same as that of the main study and details will be presented in Section 3.4.2 (*Study 1)*. Subjects had to come twice, with the two testing sessions separated by 3 days, and tests were performed at the same time of the day. In the each testing session, subjects were instructed to perform walking at their natural speed.

3.4.2 *Study 1*

Two groups of subjects, healthy controls and PD patients participated in this study. All subjects were tested at the Balance and motion analysis laboratory of The Hong Kong Polytechnic University. The experimental procedure was approved by The Hong Kong Polytechnic University Ethics Committee. Prior to participation in the study, the experimental procedure was explained to each participant and informed consent was obtained (Appendix I and II). Demographic data including gender, age, body height, body weight, UPDRS score, H&Y stage, MMSE score, FOGQ, duration of disease and medication was collected by the investigator. Data collection sheet is presented in Appendix III. All subjects with PD were tested during their "on" mediation phase (i.e. peak medication period). All tests were completed in 1 hour.

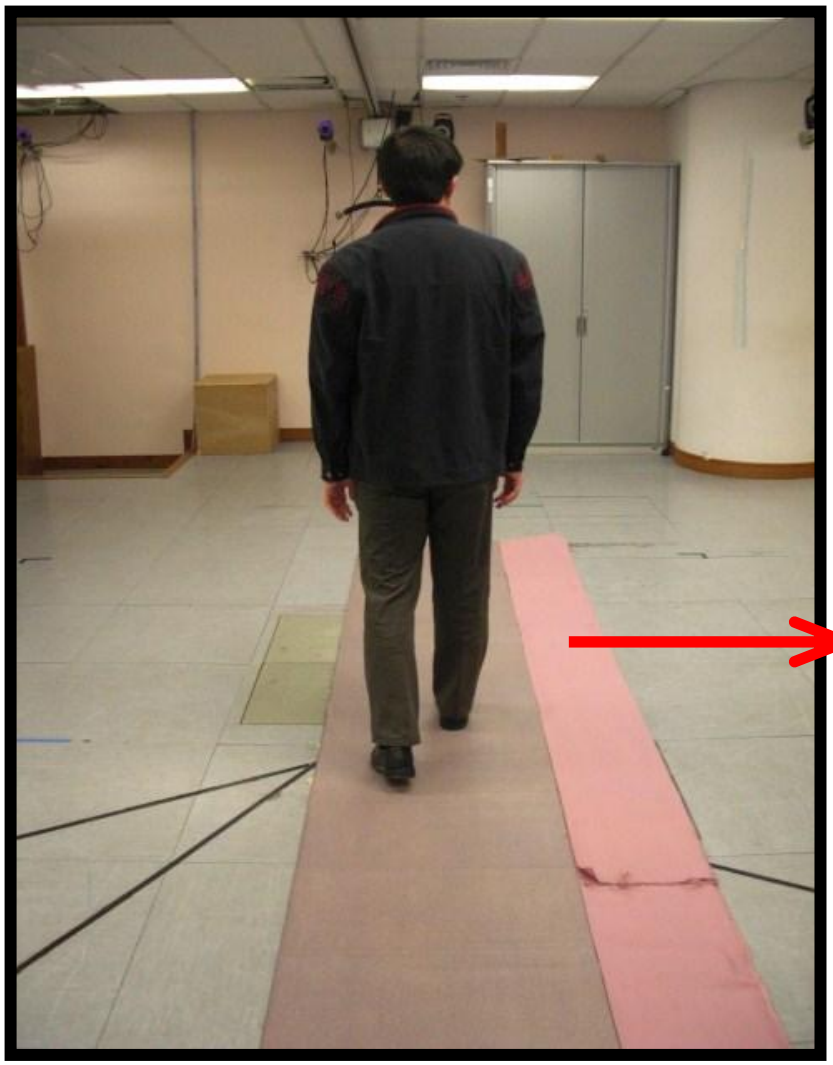
After collecting the demographic data, all participants were instructed to walk over the GAITRite walkway mat under 3 conditions arranged in a randomized manner:

1) to walk at their natural pace ($Walk_0$); Fig. 3.3a

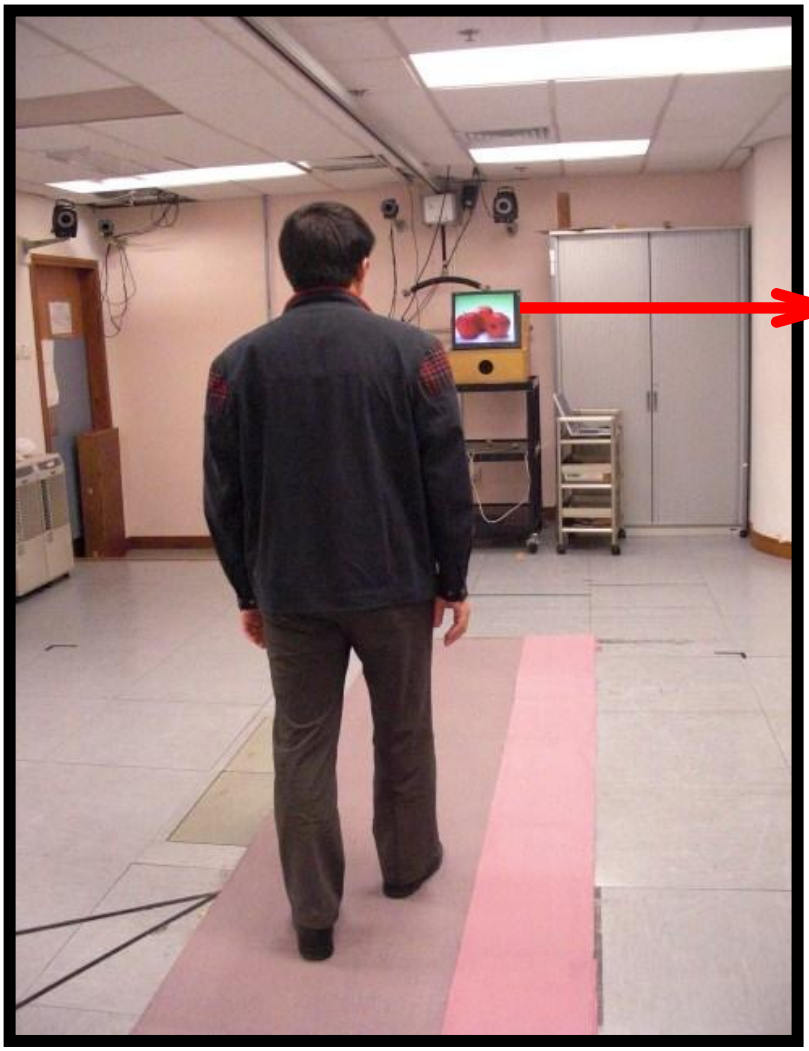
2) to name the object which appeared on a computer screen in front of them while they walked ($Walk_{naming\ object}$); Fig. 3.3b

3) to say out loudly the serial subtractions of three, starting from 100 while they walked ($Walk_{calculation}$). Fig. 3.3c

Fig. 3.3 Subjects were instructed to walk on the GAITRite mat (a) at their natural pace ($Walk_0$), (b) while naming an object they saw on the computer screen ($Walk_{naming\ object}$), (c) while performing serial subtractions of three, starting from 100 ($Walk_{calculation}$)



(a)



(b)

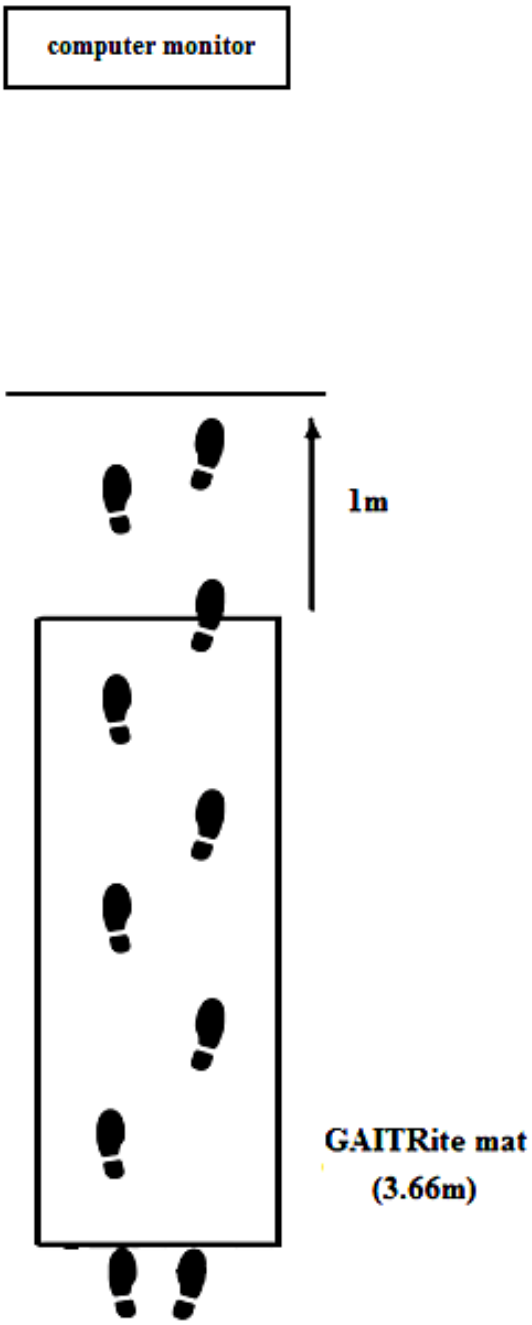
Serial subtraction of three, 100; 97; 94….

(c)

The naming object task required subjects to name the object that they saw on a computer screen in front of them. The objects chosen to be named were concrete objects which participants usually see while they are walking in the community (i.e. cars, pets and people). For the calculation task subjects were instructed to count backwards in threes from 100.

Under each condition, participants started walking from one end of the GAITRite walkway mat and stopped at a point 1 m beyond the walkway mat (Fig. 3.4). Four trials of each condition were performed, the first of which was a practice trial. The investigator walked beside the participants during all walking trials for safety precautions. A rest period of 2 minutes was allotted after each walking condition. Gait velocity (cm/s), stride length (cm) and cadence (step/ min) were recorded by GAITRite. The mean values of the 3 test trials were used for analysis. In addition, the number of correct answer for the object recognition and calculation were also recorded. Since subjects used different duration to complete the walking trial, we further divided the correct answer by time taken to complete each walk to obtain the normalized accuracy score of each concurrent cognitive task.

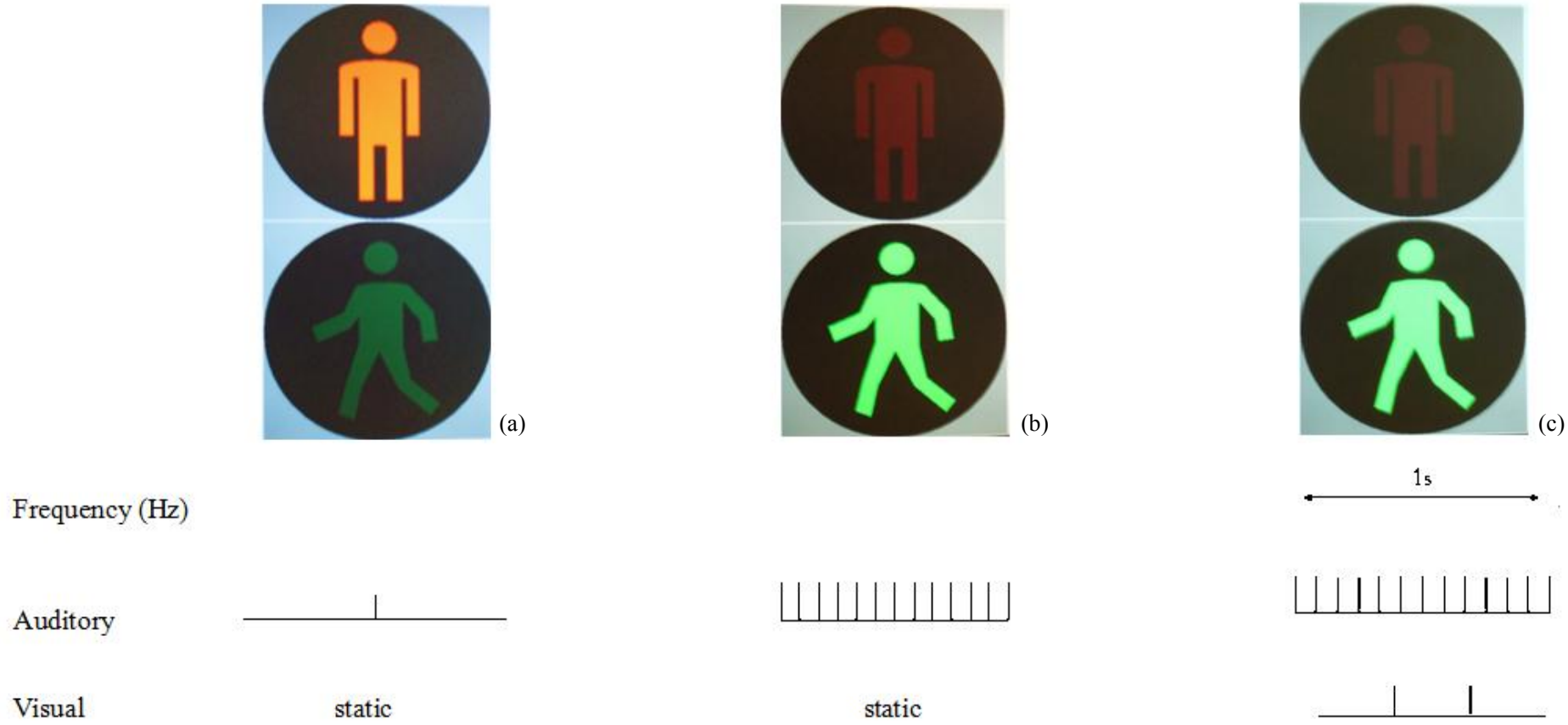
Fig. 3.4 Experimental protocol for *Study 1*



3.4.3 *Study 2*

The audio-visual cues were designed to simulate road-crossing traffic light and sound which was familiar to subjects. The auditory cue had 2 frequencies: a slow beat (frequency: 1 Hz) indicating „wait and prepare", a fast beat (frequency: 13 Hz) meaning "go" or "go faster". The visual cue consisted of 3 light signals: a static red light indicating „wait and prepare", a static green light indicating 'go' and a blinking green light denoting "go faster". The auditory and visual cues were synchronized to form the AV cues. The AV cues started with the static red light with a slow auditory beat (frequency=1 Hz, Fig. 3.5a). This was followed by the static green light with a fast 13 Hz auditory beat (Fig. 3.5b), and the "blinking" green light at a frequency of 2 Hz and with a fast 13 Hz auditory beat (Fig. 3.5c). The static red light and the blinking green light lasted for 5 and 3 seconds respectively. The duration of the static green light was the time taken for each subject to complete the walk by his/her self-selected speed i.e. condition $Walk_0$ from *Study 1*, with addition of one second to account for the reaction time. Subjects were allowed to watch and to listen to the AV cues once before walking to estimate the time allowed to complete the walk. In addition, the AV cues were given 5 seconds prior to gait initiation. Therefore, we suggested that the AV cues were preparatory signals.

Fig. 3.5 Illustration of AV cues (a) static red light (auditory beating frequency: 1 Hz), (b) static green light (auditory beating frequency: 13Hz), (c) blinking green light (auditory beating frequency: 13Hz)



The procedure was same as *Study 1* except that PD and control subjects had to walk under 4 conditions, with and without cue.

Under no cue situation, subjects were instructed:

1) to name the object they saw on a computer screen in front of them while they walked ($Walk_{naming\ object}$);

2) to say out loudly the serial subtractions of three, starting from 100 while they walked ($Walk_{calculation}$).

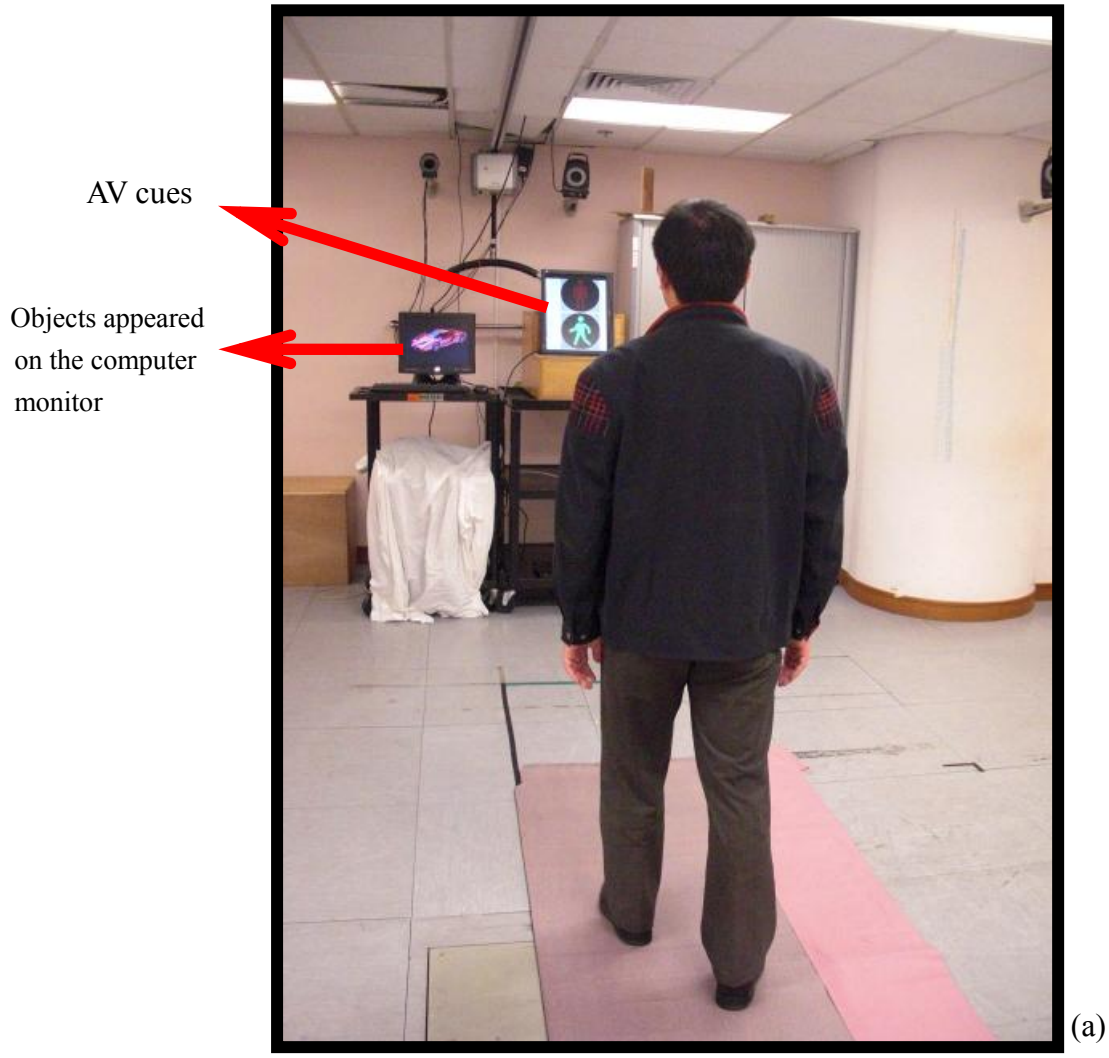
Under AV cues condition, subjects were instructed to walk under the audio-visual (AV) cues, and

3) to name the object which appeared on the computer screen in front of them ($AV_{walk\text{-}naming\ object}$ Fig. 3.6a)

4) to say out loudly the serial subtractions of three from 100 ($AV_{walk\text{-}calculation}$ Fig. 3.6b)

Under each condition, participants started walking from one end of the GAITRite walkway mat and stopped at a point 1 m beyond the walkway mat (Fig. 3.7). Subjects were instructed to perform condition 1 to 4, which were arranged in a randomized manner. Four trials of each condition were performed, the first of which was a practice trial. The investigator walked beside the participants during all walking trials for safety precautions. A rest period of 2 minutes was allotted after each walking

Fig. 3.6 Walking trails with addition of preparatory AV cues (a) $AV_{walk\text{-}naming\ object}$, (b) $AV_{walk\text{-}calculation}$



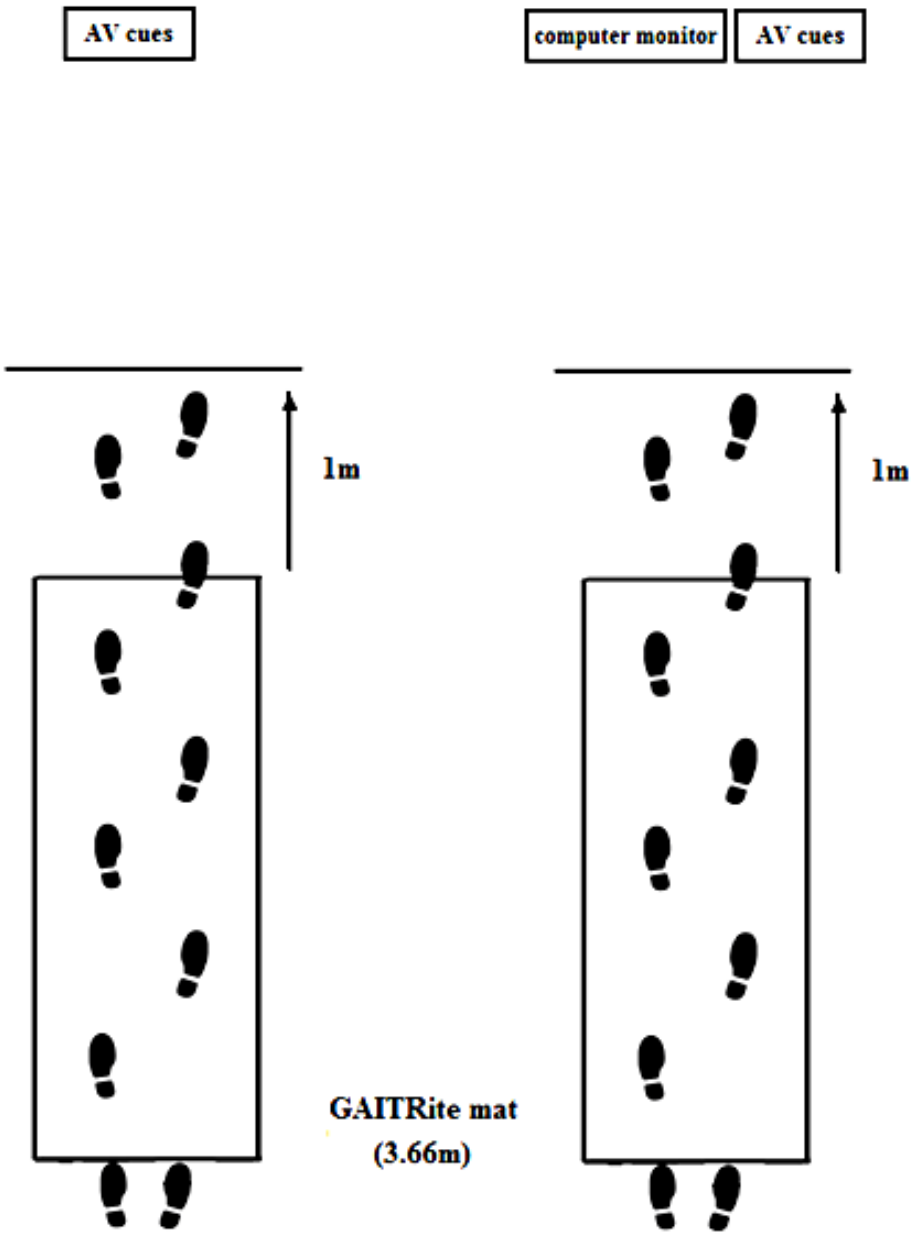
(a)

AV cues

Serial subtraction of three, 100; 97; 94….

(b)

Fig. 3.7 Experimental protocol for *Study 2* (a) $AV_{walk\text{-}calculation}$, (b) $AV_{walk\text{-}naming\ object}$



(a) (b)

condition. Gait velocity (cm/s), stride length (cm) and cadence (step/ min) were recorded by GAITRite. The mean values of the 3 test trials were used for analysis. In addition, normalized accuracy score of each concurrent cognitive task was also recorded.

3.5 Statistical analysis

3.5.1 Pilot study

For the pilot study, test-retest reliability for the walking test was assessed using the ICC (1,1).

3.5.2 *Study 1*

The demographic characteristics of subjects including gender, age, height, weight, UPDRS score, H&Y stage, MMSE score, FOGQ, duration of disease and medication were analyzed by descriptive analysis. Independent-samples *t*-tests were used to compare between PD subjects and control subjects for age, body height, body weight, score of MMSE and the number of correct object recognition and calculated answer. To study the effect of concurrent task on gait performance in people with PD, two-way repeated measures analysis of variance (ANOVA) was used to analyze the spatial-temporal gait parameters between two subject groups among 3 walking conditions. The within factor was task (walking alone, naming object and calculation)

and the between factor was group (PD patients and control subjects). In the case of an interaction being found, one-way repeated measure ANOVA and *t*-tests with Bonferroni adjustment were used to determine the real difference. A significance level of 0.05 was employed for analysis.

3.5.3 *Study 2*

The demographic characteristics of subjects including gender, age, body height, body weight, UPDRS score, H&Y stage, MMSE score, FOGQ, duration of disease and medication were analyzed by descriptive analysis. To study the effect of AV cues on gait performance under each concurrent cognitive task condition, two-way repeated measures ANOVA was used to analyze the spatial-temporal gait parameters for each walking condition between two groups. Under each dual cognitive-walking condition, the within factor was cues (non-cued and AV cued) and the between factor was group (PD patients and control subjects). In the case of an interaction being found, independent and paired *t*-tests were used to determine the real difference. Paired *t*-tests were used to compare between AV cued and non-cued for the number of correct object recognition and calculated answer in each subject group. A significance level of 0.05 was employed for analysis.

3.6 Summary

The present study consisted of a pilot study and a main study. The pilot study was used to establish the test-retest reliability of the methodology and the data recorded by the GAITRite system. The main study comprised 2 inter-related studies. *Study 1* examined the effect of adding a concurrent cognitive task to walking on gait performance in PD patients; *Study 2* investigated the effect of preparatory AV cues on walking under dual cognitive-walking task condition in PD patients. The demographic characteristics of subjects including gender, age, body height, body weight, UPDRS score, H&Y stage, MMSE score, FOGQ, duration of disease and medication as well as dependent variables including gait velocity (cm/s), stride length (cm), cadence (step/min), and number of correct answer for cognitive task are presented in the next Chapter.

CHAPTER 4 RESULTS

This chapter presents the results of the current study. Pilot study reports the test-retest reliability of the methodology and walking data measured by GAITRite system. *Study 1* presents the effect of adding a concurrent cognitive task to walking on gait performance in PD patients. *Study 2* illustrates the effect of preparatory AV cues on gait performance under dual cognitive-walking task condition in PD patients.

4.1 Pilot study

Four PD patients (mean age= 65.0±2.9 years old) and 4 healthy subjects (mean age= 67.0±11.3 years old) completed the reliability test. Results of the test–retest reliability for each of the gait parameters under $Walk_0$ condition are shown in Table 4.1. When control subjects walked at their self-selected speed, the ICCs (1,1) for the three gait parameters were 0.92 and higher. For PD patients, the ICCs were excellent for gait velocity, stride length and cadence (ICC=0.98, 0.99 and 0.90 respectively).

4.2 *Study 1*

4.2.1 Characteristic of participants

Twenty-two PD subjects (mean age 61.3±6.2) and 15 healthy subjects (mean age 59.1±7.1) participated the study. Characteristics of PD subjects are shown in

Table 4.1 Test-retest reliability of gait parameters under baseline walking condition

	PD subjects (n=4)			Control subjects (n=4)		
	1st session	2nd session	ICC	1st session	2nd session	ICC
Gait velocity (cm/s)	130.7±22.7	135.4±27.4	0.98	128.6±18.1	129.6±15.7	0.98
Cadence(step/m)	119.7±2.9	116.8±5.1	0.90	119.4±9.1	120.6±4.9	0.92
Stride length (cm)	129.3±18.4	129.1±16.3	0.99	133.6±17.1	136.2±18.1	0.99

Data shown are means ± standard deviations (SD)

(Table 4.2) PD patients had a mean disease severity of 2.1±0.4 reflected by the H&Y scale, and the mean score of UPDRS motor part was 15.7±4.4. These scores indicating that PD patients had mild impairment. The mean score of FOGQ was 12.5±6.3, indicating moderate gait freezing impairment. PD patients were taking anti-Parkinsonism medication including Sinemet, Madopar, Artane, etc. Mean values of demographic and clinical data between PD patients and control subjects are shown in Table 4.3. Independent 2-tailed *t*-tests showed that there were no significant differences in age, height and weight between PD patients and control subjects. All subjects had MMSE score above 23, and there was no significant difference between the two subject groups.

4.2.2 Baseline walking performance in patients with PD and controls

Table 4.4 shows that in $Walk_0$ condition, people with PD walked with a mean gait velocity of 113.8cm/s and stride length of 119.8cm, which was significantly slower (by 15.3%, p=0.000) and (by 10.1%, p=0.014) shorter than control subjects. For the cadence, people with PD walked with a smaller cadence than control subjects (by 5.4%), however this difference did not reach a significant level.

Table 4.2 Characteristics of subjects with Parkinson‟s disease

Subject No.	Age (Y)	Sex	Body height (cm)	Body weight (kg)	Duration of disease	UPDRS motor	H&Y	FOGQ	Medication	Daily Dose (mg)
1	59	F	164	53.1	13	16	2	14	Sinemet, Artane	400/100, 6
2	65	F	151	58.1	11	19	3	22	Sinemet, Sinemet CR	4000/400,600/150
3	69	F	148	50.4	16	17	2	20	Madopar	500
4	68	M	159	57.2	8	10	1.5	15	Sinemet, Parlodel	200/50,7.5
5	61	F	155	60.8	4	17	2	3	Sinemet, Sinemet CR	1500/150,600/150
6	54	F	152	49.1	7	9	1.5	17	Sinemet, Madopar, Parlodel	700/150,250,7.5
7	59	M	166	77.0	4	16	2	15	Madopar, Artane	500,4
8	69	F	154	54.5	11	8	2	1	Madopar	750
9	68	M	162	53.6	4	20	2.5	17	Sinemet, Parlodel	1000/100,7.5
10	60	F	149	45.5	3	14	2	3	Sinemet	300/75
11	59	M	172	81.0	8	16	2	10	Madopar	1000,500
12	63	M	159	71.6	16	18	2	12	Sinemet, Artane, Parlodel	300/75,2,7.5
13	68	M	160	40.5	2	16	2.5	7	Madopar, Artane, Parlodel	750,5,5
14	66	M	160	63.0	16	10	2.5	7	Madopar, Entacapone	1000, 800
15	57	M	162	63.5	5	14	2.5	3	Sinemet	300/75
16	67	F	152	43.7	9	23	2	21	Sinemet	1000/100
17	66	M	155	65.7	20	18	2	14	Sinemet, Sinemet CR	750/75,200/50
18	52	M	163	65.7	7	14	2	15	Amantadine, Artane	100,4
19	51	F	151	47.7	14	17	2.5	17	Sinemet, Parlodel	75,7.5
20	52	F	154	48.2	8	10	1.5	21	Sinemet	600/150
21	63	M	163	63.9	1.5	18	2.5	7	Madopar, Parlodel	500,2.5
22	51	M	163	62.6	9	26	2.5	14	Sinemet, Madopar, Pramipexole	600/150,750,4.5
mean	61.3		157.9	58.5	8.6	15.7	2.1	12.5		

Table 4.3 Demographic for PD and control subjects

	PD patients (n=22)	Control subjects (n=15)	p
Age (y)	61.3±6.2	59.1±7.1	0.330
Male/female	10/12	4/11	0.097
Height (cm)	157.9±6.2	156.7±6.0	0.534
Body mass (kg)	58.5±23.6	58.0±15.3	0.863
MMSE	27.2±2.6	28.3±1.2	0.072
Duration of PD (year)	8.6±5.3		
H & Y	2.1±0.4		
UPDRS (motor examination III)	15.7±4.4		
FOGQ	12.5±6.3		

Data shown are mean ± standard deviation (SD)
FOGQ: freezing of gait questionnaire
H&Y: Hoehn and Yahr staging scale
MMSE: Mini Mental Status Examination
UPDRS: Unified Parkinson Disease Rating Scale

4.2.3 Effect of adding a concurrent cognitive task to walking on gait performance in patients with PD patients

Result of 2-way repeated measure ANOVA showed a significant group*task interactions for gait velocity (p=0.002) and stride length (p=0.001) (Table 4.4). This finding implies that when a concurrent task (naming object or calculation) was added to walking, the influence on gait velocity and stride length differed between the 2 groups, with more reduction found in PD patients than control subjects. We therefore performed post-hoc analysis to reveal the real between-and within-group differences for each cognitive task. No group*task interaction was shown in cadence, suggesting that both groups had similar changes when each concurrent task was added to walking.

4.2.3.1 $Walk_{naming\ object}$ versus $Walk_0$

Post-hoc analysis showed that PD subjects had significantly slower gait velocity (by 17.4% p=0.008) and shorter stride length (by 13.5%, p=0.016) in $Walk_{naming\ object}$ than $Walk_0$ (Table 4.4). On the contrary, control subjects walked with similar gait velocity and stride length (p=1.000) in $Walk_{naming\ object}$ condition and $Walk_0$. For the cadence, PD patients significantly decreased their cadence by 4.5% whilst control subjects had a slight increase in cadence by 1.5% when compared $Walk_{naming\ object}$ with $Walk_0$ (p=0.000). For between-group differences, PD patients had significantly slower gait velocity (p=0.000), shorter stride length (p=0.000) and smaller cadence (p=0.016) than control subjects under $Walk_{naming\ object}$ condition.

Table 4.4 Comparison between PD patients and control subjects for gait performance under each walking condition

	$Walk_0$	$Walk_{naming\ object}$	$Walk_{calculation}$	P value: $Walk_{naming\ object}$ VS $Walk_0$	P value: $Walk_{calculation}$ VS $Walk_0$	P value: $Walk_{naming\ object}$ VS $Walk_{calculation}$
Gait velocity(cm/s)						
PD	113.8±19.1	94.0±21.7	84.4±21.7	0.008**	0.000***	0.396
Controls	134.3±14.7	133.1±15.6	116.4±15.3	1.000	0.007**	0.014*
p value†	0.001**	0.000***	0.000***			
Stride length (cm)						
PD	119.8±17.4	103.6±18.9	101.7±19.2	0.016*	0.006**	1.0000
Controls	133.3±12.3	130.1±12.2	124.2±13.3	1.000	0.166	0.618
p value†	0.014*	0.000***	0.000***			
Cadence (step/min)						
PD	115.0±12.0	109.9±16.3	101.1±22.0	0.000***	0.000***	0.000***
Controls	121.7±7.5	123.5±7.6	113.1±6.9			
p value†		0.016*				

*p<0.05, **p<0.01, ***p<0.001
p value†: control vs PD
p value: task
Interaction (task*group)

Gait velocity	p= 0.002**
Stride length	p= 0.001**
Cadence	p=0.152

4.2.3.2 $Walk_{calculation}$ versus $Walk_0$

Post-hoc analysis indicated that PD subjects walked significantly slower (by 25.8%, p=0.000) and had significant shorter stride length (by 15.0%, p=0.006) in $Walk_{calculation}$ than $Walk_0$ (Table 4.4). Control subjects had smaller reduction in those two parameters, and only gait velocity (by 13.4%, p=0.007) reached the significant level. For the cadence, PD subjects significantly decreased by 12.1% and control subjects decreased by 6.6% when compared $Walk_{calculation}$ with $Walk_0$ (p=0.000). Furthermore, between-group difference revealed that PD subjects had significantly slower gait velocity, shorter stride length and smaller cadence ($p<0.05$) than control subjects under $Walk_{calculation}$ condition.

4.2.3.3 $Walk_{naming\ object}$ versus $Walk_{calculation}$

Post hoc tests showed that in PD patients, there were no significant differences between $Walk_{naming\ object}$ and $Walk_{calculation}$ for gait velocity and stride length. On the contrary, control group walked with significantly slower gait velocity by 12.5% (p=0.014) but similar stride length when compared $Walk_{calculation}$ with $Walk_{naming\ object}$.

4.2.4 Accuracy of dual cognitive task

Under both $Walk_{naming\ object}$ and $Walk_{calculation}$, PD subjects identified 5.5 objects and had 3.1 correct calculation answers which were similar to those achieved

by the control subjects (identified objects=4.8, correct subtractions=3.2, Table 4.5). Since PD patients took longer time to complete the walking trials, we normalized the correct number by dividing the total number of correct answer achieved in each walking trial by the time taken to complete that walking trial (number of correct answer/time taken to complete each walking trial). After normalization, PD subjects obtained significantly less correct object identifications ($p=0.002$) and subtractions than control subjects ($p=0.001$) as shown in Table 4.5.

Table 4.5 The number of correct answer between PD patients and control subjects

	Total number			Normalized correct number		
	PD	Controls	p value†	PD	Controls	p value
$Walk_{naming\ object}$	5.5±1.2	4.8±1.0	0.113	1.4±0.3	1.7±0.3	0.001**
$Walk_{calculation}$	3.1±1.6	3.2±0.9	0.709	0.7±0.3	0.9±0.3	0.002**

**p<0.01

p value†: total number of correct answer control vs PD subjects

p value: total number of correct answer divided by the trial time control vs PD subjects

Number/s: total number of correct answer divide by time taken to complete each walking trial

4.3 *Study 2*

4.3.1 Characteristic of participants

All subjects who participated in *Study 1* were invited to participate in *Study 2*. Fifteen PD patients (patients‟ number 1 to 15 as shown in Table 4.2) and 13 control subjects returned to complete *Study 2*. Independent 2-tailed t-tests showed that there were no significant differences in age, body height and body weight between PD and control subjects. All subjects had MMSE score above 23, and there was no significant difference between two groups (Table 4.6).

4.3.2 Effect of preparatory AV cues task on gait performance under dual cognitive-walking task in patients with PD

4.3.2.1 $Walk_{naming\ object}$ versus $AV_{walk\text{-}naming\ object}$

Results of 2-way repeated measure ANOVA showed significant group*task interactions for gait velocity (p=0.015) and stride length (p=0.006). This finding implies that the influence of AV cues on gait velocity and stride length differed between the 2 groups, with more improvements found in PD than control subjects. Post-hoc analysis showed that PD subjects had significantly faster gait velocity (by 12.8% p=0.000) and longer stride length (by 7.6%, p=0.001) in $AV_{walk\text{-}naming\ object}$ than $Walk_{naming\ object}$ (Fig. 4.1a and b). Control subjects walked significantly faster (by 3.3%, p=0.038), but with similar stride length (p=0.072) in $AV_{walk\text{-}naming\ object}$.

Table 4.6 Demographic for PD and control subjects in *Study 2*

	PD patients (n=15)	Control subjects (n=13)	p
Age (y)	63.0±4.9	60.0±7.1	0.199
Male/female	8/7	4/9	0.237
Height (cm)	158.2±6.7	156.6±6.8	0.540
Weight (kg)	58.5±11.3	56.8±8.0	0.644
MMSE	27.5±1.7	28.4±1.2	0.054
Duration of PD (year)	7.7±4.3		
H & Y	2.1±0.4		
UPDRS (motor examination III)	14.7±3.8		
FOGQ	11.1±6.8		

Data shown are mean ± standard deviation (SD)
FOGQ: freezing of gait questionnaire
H&Y: Hoehn and Yahr scale
MMSE: Mini Mental Status Examination
UPDRS: Unified Parkinson Disease Rating Scale

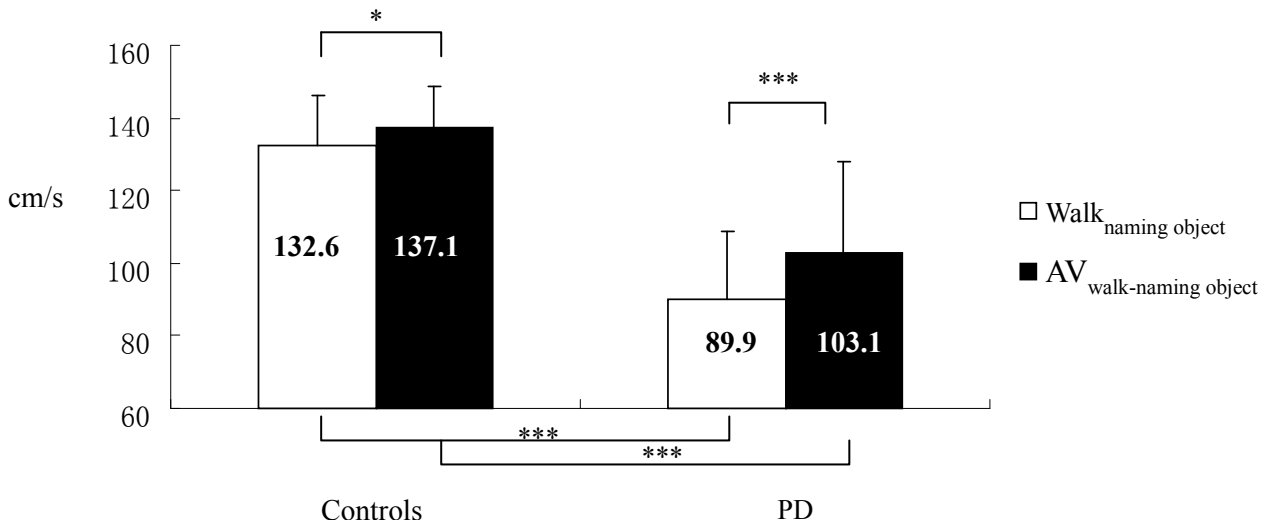
than $Walk_{naming\ object}$. Since no interaction was found in cadence, both PD and control subjects significantly increased their cadence respectively by 4.7% and 2% (p=0.001) in cued compared with non-cued condition (Fig. 4.1c). Although PD patients made greater improvement than control subjects, between-group difference remained. PD subjects had significant decreases in gait velocity (p=0.000), stride length (p=0.000) and cadence (p=0.006) than control group under $AV_{walk\text{-}naming\ object}$ condition. (Fig. 4.1a-c)

4.3.2.2 $Walk_{calculation}$ versus $AV_{walk\text{-}calculation}$

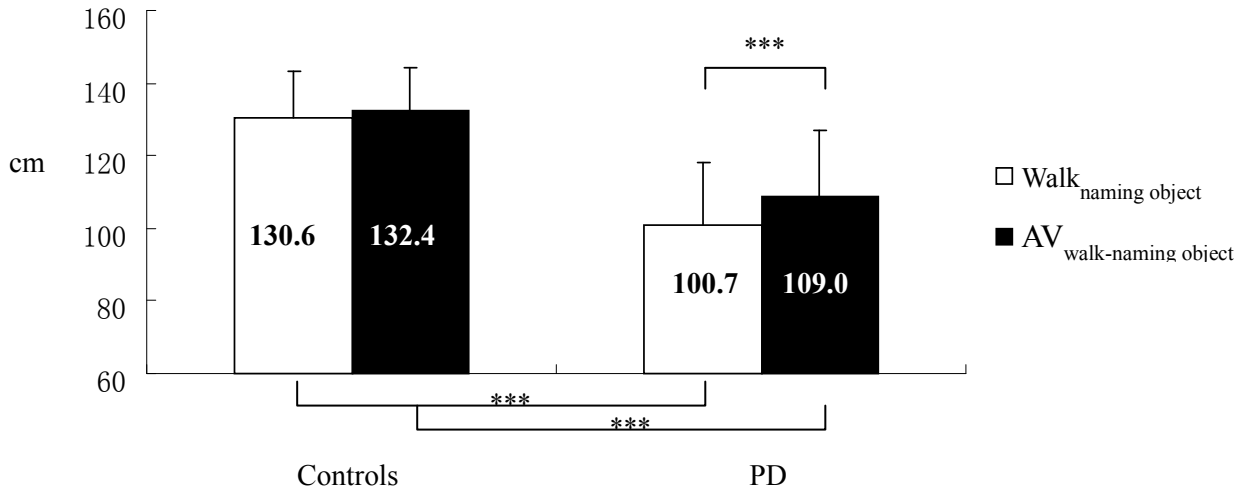
Similar to that of $AV_{walk\text{-}naming\ object}$, significant group*task interactions were found in gait velocity (p=0.041) and stride length (p=0.009). Post-hoc analysis indicated that PD patients had a significantly faster gait velocity (by 17.4%) and longer stride length (by 8.2%) in $AV_{walk\text{-}calculation}$ than $Walk_{calculation}$ (p=0.000) (Fig. 4.2a and b). Control subjects had smaller but insignificantly improvement in those two parameters. Since no interaction was found in cadence, both two groups significantly increased their cadence respectively by 9.2% and 3.4% (p=0.004) in cued when compared with non-cued condition (Fig. 4.2c). Although PD patients made greater improvement than control subjects, between-group difference remained. PD patients had significantly slower gait velocity (p=0.000), shorter stride length (p=0.004) and smaller cadence (p=0.042) than control subjects under $AV_{walk\text{-}calculation}$.

Fig. 4.1 Effect of AV cues on (a) gait velocity, (b) stride length and (c) cadence under dual object naming-walking task

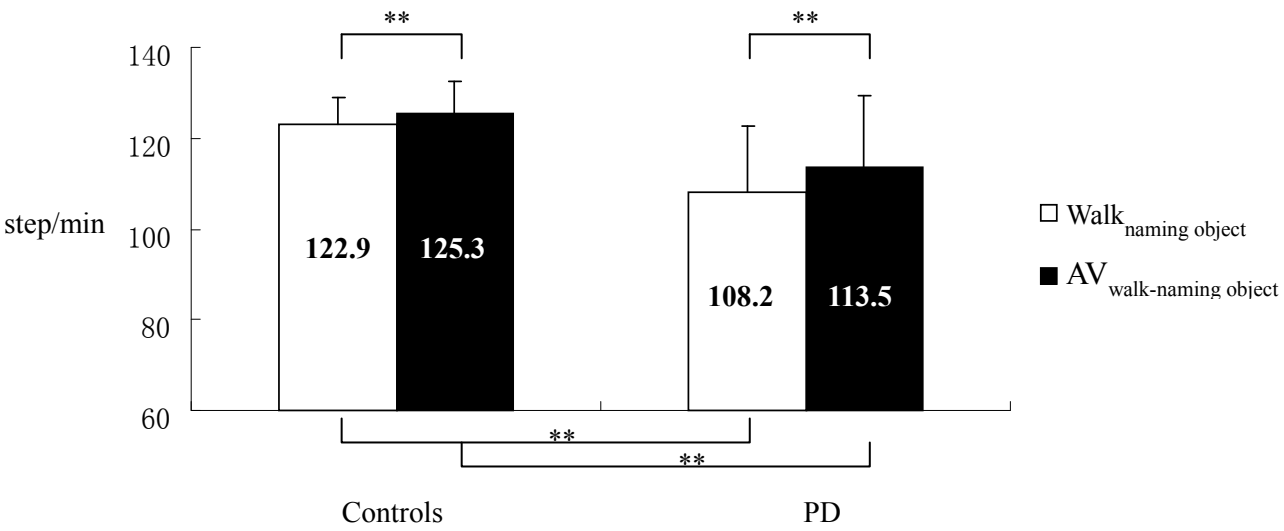
(a) Gait velocity



(b) Stride length



(c) Cadence

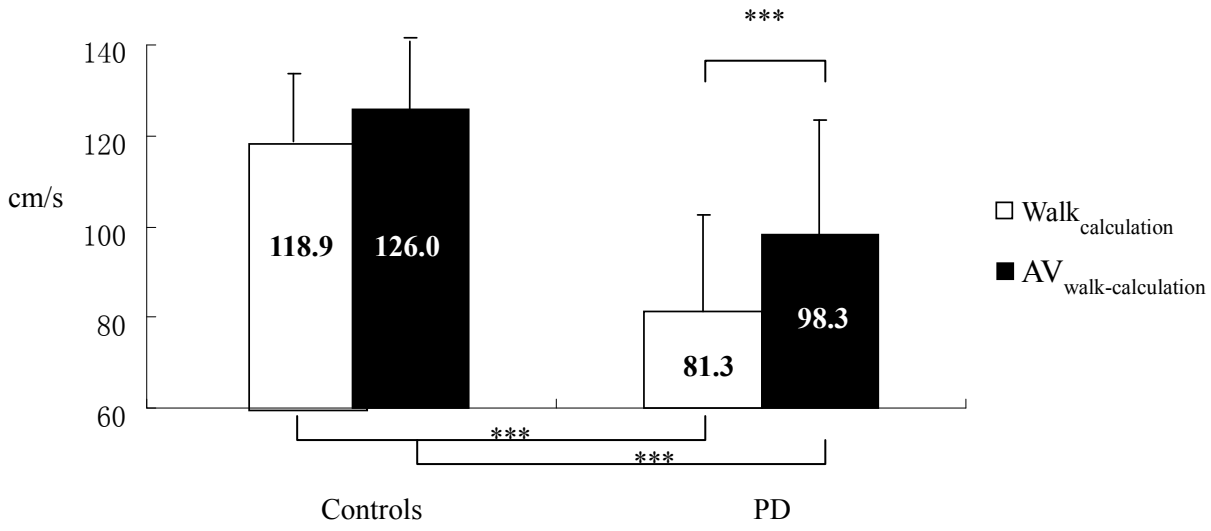


*p<0.05, **p<0.01, ***p<0.001
Interaction (cue * group)

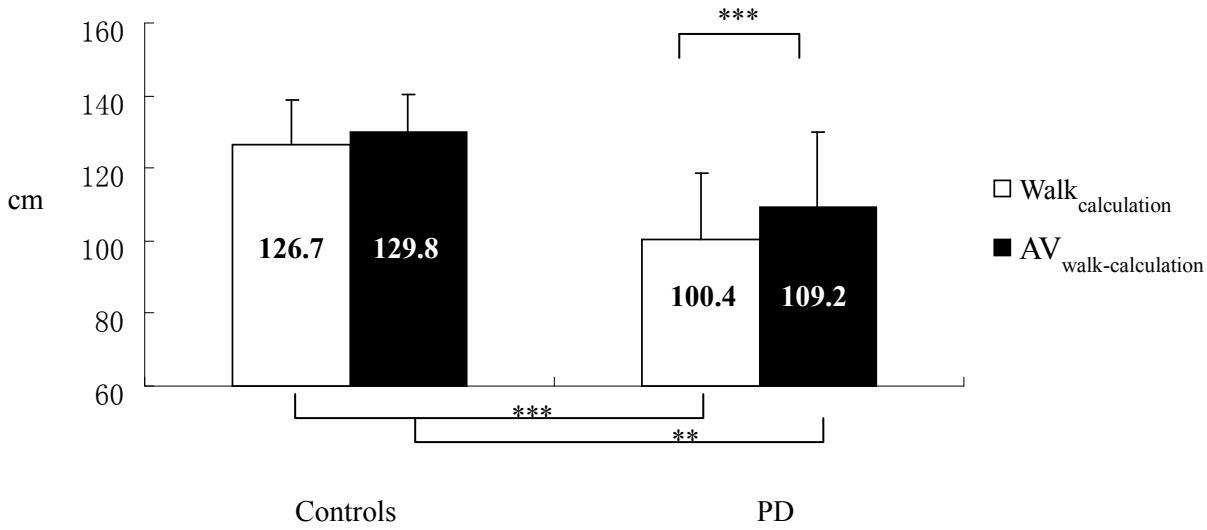
Gait velocity	p=0.015*
Stride length	p=0.006**
Cadence	p=0.181

Fig. 4.2 Effect of AV cues on (a) gait velocity, (b) stride length and (c) cadence under dual calculation-walking task

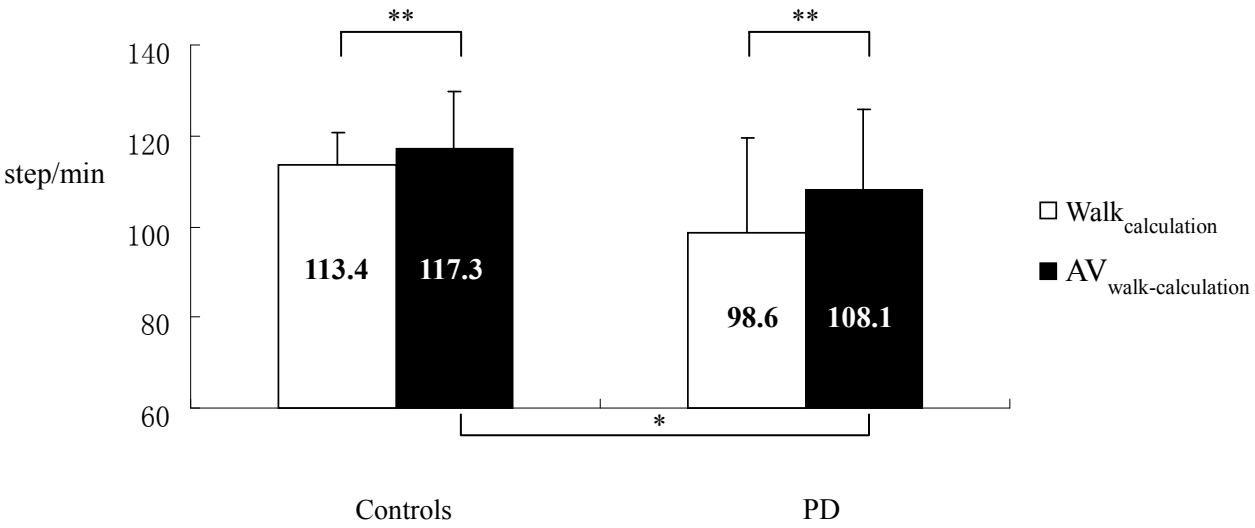
(a) Gait velocity



(b) Stride length



(c) Cadence



*p<0.05, **p<0.01, ***p<0.001
Interaction (cue * group)
Gait velocity p=0.041*
Stride length p=0.009**
Cadence p=0.198

4.3.3 Accuracy of dual cognitive task under AV cues

For accuracy of cognitive task, people with PD achieved similar correct answers for both identified object and calculation under AV-cued and non-cued conditions. Similarly, there were no significant differences between AV-cued and non-cued condition in the number of correct answers obtained by the control subjects. These findings indicate that the AV cues did not influence the accuracy of concurrent cognitive task in both subject groups (Table 4.7).

4.4 Summary

For the pilot study, excellent ICCs (1,1) (higher than 0.90) were found in all gait parameters in both PD and control groups. When PD patients were instructed to walk alone at their natural speed, they walked with significantly slower gait velocity and shorter stride length but similar cadence when compared with control subjects. When a concurrent cognitive task "object naming" or "calculation" was added to walking, significant group*task interactions were found in gait velocity and stride length. PD patients had significant reductions in gait velocity, stride length and cadence in $Walk_{naming\ object}$ and $Walk_{calculation}$ when compared with that of $Walk_0$. No significant difference was found between $Walk_{naming\ object}$ and $Walk_{calculation}$ in PD patients. In contrast, control subjects did not show difference between $Walk_{naming\ object}$ and $Walk_0$, but they had small but significant reductions in gait velocity and cadence under $Walk_{calculation}$ when compared with $Walk_0$.

Table 4.7 The total number of correct answers for object naming and calculation with and without AV cues in PD and control subjects

		Without AV cues	With AV cues	P value
Naming object	PD patients	5.6±1.0	5.6±1.2	0.832
	Control subjects	4.7±1.0	4.5±0.9	0.266
Calculation	PD patients	3.4±1.7	3.5±1.6	0.762
	Control subjects	3.3±0.9	2.9±0.8	0.299

Control subjects also walked with significantly slower gait velocity in $Walk_{calculation}$ than $Walk_{naming\ object}$. For the accuracy level of cognitive tasks, the PD patients obtained significantly less correct identifications and subtractions than control subjects. In *Study 2*, the use of AV cues resulted in more improvements in the gait performance in PD patients than controls as shown by significant group*task interactions in gait velocity and stride length in both $AV_{walk\text{-}naming\ object}$ and $AV_{walk\text{-}calculation}$ conditions. PD group achieved significant increases in gait velocity, stride length and cadence in cued ($AV_{walk\text{-}naming\ object}$ and $AV_{walk\text{-}calculation}$) than non-cued ($Walk_{naming\ object}$ and $Walk_{calculation}$) conditions. Control subjects walked significantly faster in $AV_{walk\text{-}naming\ object}$, and had significantly larger cadence in both cued than non-cued conditions. Both PD and control subjects achieved similar correct answers for both identified objects and calculation under AV-and non-cued conditions.

CHAPTER 5 DISCUSSIONS

In this chapter, test-retest reliability of the data recorded with the methodology and the GAITRite system, effects of concurrent task on gait performance in PD patients, and preparatory AV signals on gait performance during dual cognitive-walking, and the performance of cognitive task in PD patients are discussed. Clinical implications, limitations of the study and suggestions for further studies are also presented.

5.1 Test-retest reliability

The GAITRite walkway system was demonstrated in previous studies to be an accurate and reliable instrument to measure gait outcomes in healthy individuals (Bilney et al. 2003, Uden and Besser 2004) and in adults with Down‟s syndrome (Ashwini et al. 2005). In this study we used ICC's to assess the test-retest reliability of the gait parameters recorded in healthy subjects and PD patients. A major advantage of ICC analysis over standard correlation analysis is that ICC accounts for differences between the data sets using analysis of variance between and within data sets (Portney and Watkins 2000).

Portney and Watkins (2000) have indicated that clinical measurements that achieved ICC of at least 0.90 showed high to excellent reliability, 0.80-0.89 showed

good reliability, 0.70-0.79 showed fair reliability, and <0.7 showed poor reliability. In the present study, healthy subjects had ICC's above 0.92 for the gait measurements recorded at self-selected speed, and PD patients had ICCs ranged from 0.90 to 0.99. The findings demonstrate excellent reliability for both subject groups. Our data supported those of previous studies that great consistency of spatiotemporal gait parameters was found at subjects‟ preferred walking speed. Bilney et al. (2003) evaluated the inter-trial repeatability of the GAITRite in a large population of healthy adult. The results showed that ICCs ranged from 0.92 to 0.97 for gait speed, cadence and stride length at subjects‟ preferred walking speed. Uden and Besser (2004) examined the test-retest reliability of GAITRite walkway system over a one-week period in twenty-one healthy young subjects. The ICCs were 0.92 and higher for the gait parameters at subjects‟ preferred speed. Gretz et al. (1998) reported good 2-week test retest reliability (ICC> 0.75) for temporo-spatial measurements of normal adults and adults with Down‟s syndrome.

In the present investigation, the two testing sessions were separated by 3 days. The testing procedures were performed at the same time of the day, and at the same medication cycle in people with PD. Moreover, the tests were performed in the same environment with the same researcher employing standard instructions for data collection. These measures could explain the excellent test-retest reliability obtained in both healthy and PD subjects.

5.2 Baseline walking performance in patients with PD and controls

Gait disturbance is one of most disabling cardinal symptoms of PD (Hoehn and Yahr 1967) resulting from depletion of dopamine in the basal ganglia (Nobuo et al. 2006). Under $Walk_0$ condition, our results showed that PD patients walked with significantly reduced gait velocity (by 15.3%) and stride length (by 10.1%) when compared with control subjects; but cadence (by 5.4%) did not differ significantly between the two groups. Our results agreed with those reported previously. Earlier studies by Morris and colleagues (1994a, b, 1996) demonstrated that PD patients significantly decreased their stride length and gait velocity when compared with the control subjects. In contrast, the difference between the groups for cadence was not significant. Recent studies also reported more reduction in stride length than cadence in PD patients. For example, O'Shea et al. (2002) reported a reduction of gait velocity by 18% ($p<0.001$), stride length by 14.6% ($p<0.001$) and cadence by 4.3% in PD patients when compared with control subjects under self-selected walking speed. Olumide et al. (2005) found significant decrement between PD patients and control subjects for gait velocity (21%, $p=0.004$), stride length (16.9%, $p=0.002$), but no significant difference between group was found in cadence under self-selected walking speed. Findings from the present and previous studies therefore confirm that gait velocity and stride length reduction are the more prominent disabling features of PD gait. In contrast, cadence is relatively unaffected in PD (Ferrandez and Blin 1991, Marsden 1982, Morris et al. 1994a, b, 1996, Murray et al. 1978). The reduced stride length is often accompanied by a tendency toward a longer duration in the

double-support phase (Blin et al. 1991, Morris et al. 1994a, 1996). In present study, the deteriorations in gait velocity and stride length in PD patients were somewhat smaller than those reported by Olumide et al. (2005). It could be attributed to the fact that, in our study, PD patients had a mean H&Y stage of 2.1, which was less severe than the H&Y stage of 2.6 reported in the study by Olumide et al. (2005).

Our findings showed that PD patients had more difficulty to maintain normal stride length during walking is consistent with the suggested role of the BG in the control of movement amplitude. This idea was based initially on the clinical observation that PD patients exhibit hypokinesia (Berardelli et al. 2001, Denny-Brown 1986). For instance, Morris et al. (1994b) examined gait performance of subjects under 3 velocities (slow, medium and fast). They found cadence was intact in PD patients and was easily matched to control values for the full range of velocities. However, stride length was significantly reduced under the 3 velocities tested when compared with healthy subjects. Control of movement amplitude was also examined in animal studies. Fernagut et al. (2002) measured stride length in mice one week after acute MPTP intoxication and found reduction of hind limb stride length. Furthermore, the magnitude of stride length reduction was significantly correlated with that of cell loss ($R=0.83$, $P<0.01$), either in the substantia nigra or in the lateral mid-striatum. These investigators therefore concluded that stride length was a reliable indicator of basal ganglia dysfunction. In agreement with the afore-mentioned animal and clinical studies, PD patients in the present study showed considerably deterioration in stride

length when compared with control subjects. Therefore, our findings support the idea that the role of BG is to modulate the movement amplitude in the form of stride length during walking. Hence, degeneration of the BG could lead to shorter stride length in PD patients.

5.3 Effect of cognitive task on gait performance in patients with PD

Our results found that when people with PD were required to perform either object naming or do calculation task while walking, they experienced significant larger reductions than control subjects in both walking velocity and stride length. This was shown by the significant group*task interactions in gait velocity and stride length when each cognitive task was added during walking.

When $Walk_{naming\ object}$ was compared with $Walk_0$, PD patients had a significantly slower gait velocity (by 17.4%), shorter stride length (by 13.5%) and a smaller cadence (by 4.5%) in $Walk_{naming\ object}$ ($p<0.05$). In contrast, control subjects had only a small but still significant increase in cadence (by 1.5%, $p=0.016$). No previous study used object identification (on a computer screen) as a dual task to examine gait performance in PD patients. In the present study, the objects chosen to be named were concrete objects which participants usually see while they were walking outside (e.g. cars, pets and people). Pateicia (2000) commented that object naming is a basic and natural skill, which is common in the daily life of individuals. In the present study, PD patients demonstrated interference of the naming object task

on their walking abilities, while control subjects maintained similar gait performance under $Walk_{naming\ object}$ condition. This implies that when the attention of PD patients was distracted by naming an object they saw, their gait performance deteriorated. In contrast, the distraction of attention did not affect the walking performance of age-matched control subjects. According to the "capacity-sharing" model (Pashler 1994), attention resources are limited in an individual. If gait performance requires attention in PD patients, adding a concurrent cognitive task during walking would result in deterioration of the walking task (Pashler 1994, Schmidt and Lee 1999). The deterioration of walking during $Walk_{naming\ object}$ in PD patients, but not in control subjects, demonstrates that walking may require more attention in the PD than the healthy population.

During $Walk_{calculation}$, PD patients had a significantly slower gait velocity (by 25.8%), shorter stride length (by 15.0%) and smaller cadence (by 12.1%) than $Walk_0$ ($p<0.05$). Control subjects had smaller but still significant reductions in gait velocity (by 13.4%) and cadence (by 6.6%) ($p<0.01$). The significant group*task interaction implied that PD patients had larger deterioration in gait performance under $Walk_{calculation}$ condition than control subjects. Adding calculation (digit subtraction by 3) as a dual task to walking, previous studies reported similar findings (Gallety and Braner 2005, O'Shea et al. 2002). O'Shea et al. (2000) demonstrated that PD patients had significant decreases in gait velocity (by 18.8%), stride length (by 12.4%) and cadence (by 7.4%). Control subjects showed less reduction in gait velocity (6.9%,

$p<0.01$) stride length (4%) and cadence (4%) than PD patients. Galletly and Brauer (2005) reported similar findings in that PD patients significantly decreased their gait velocity and stride length respectively by 21% and 16.0%, whilst control subjects decreased theirs respectively by only 14% ($p<0.001$) and 7% when walking under dual task condition was compared with walking alone. Moreover, Rochester et al. (2004) evaluated the interference effects on walking while performing a dual cognitive task (answering simple questions) in PD and control subjects. Performance of a dual cognitive task resulted in significantly slower gait velocity (by 21.4%) and reduced step length (by 16%) in PD patients, and smaller reductions in control subjects (by 7.4% and 7.1% respectively). The agreement of our findings with those reported previously could be due to the similarity in age and impairment level of PD patients among the studies. Briefly, our PD patients had a mean age of 61.3 years, which was similar to that of the three previous ranging from 64 to 68 years. Our patients had a UPDRS motor score of 15.7 indicating a mild impairment level (Fahn et al. 1987), similar to the score of 14.4 in the previous study by Galletly and Brauer (2005). However, in the present study, PD patients were in a slightly less severe disease stage (H&Y stage 2.1) than that of the patients in the study by Rochester et al. (2004). Their patients had a moderately severe PD as measured by H&Y stage 2.7. The H&Y scale (Hoehn & Yahr 1967) is commonly used for describing how the symptoms of PD progress. The scale allocates stages from 0 to 5 to indicate the relative level of disability, from no symptom to most disabled. This scale, however, dose not measure walking performance directly. In contrast, the UPDRS motor

component comprises an item assessing gait performance. Therefore, PD patients in the previous studies could have similar motor impairments hence similar gait deterioration as those in present study when a cognitive task was added to walking. Our finding in $Walk_{calculation}$ implies that adding a concurrent task during walking could place pressure on the limited attention resources in people with PD, which could contribute to greater gait deterioration than when they walk without the need to do a cognitive task.

An interesting finding stems from dual-task walking performance in the present study was that when each cognitive task was added during walking, PD patients showed more deterioration than control subjects in stride length rather than in cadence. This was shown by the significant group*task interaction found in stride length, but not in cadence. In addition, control subjects did not show significant reduction in stride length with the addition of either naming an object or doing calculation while walking. Morris et al. (1996) observed similar findings of significantly shorter stride length with an insignificant change in cadence when PD patients did a cognitive task (recite sentences) while walking. However, these investigators did not include control subjects for comparison with PD patients. O'Shea et al. (2002) also found a significant group*task interaction for stride length under dual cognitive/motor-walking task condition. These PD patients had a significant decrease in stride length (by 12.4%) with an insignificant reduction of cadence (by 7.4%) when compared to walking without a concurrent task. By adding

calculation to walking, Rochester et al. (2004) had similar findings. PD patients had considerably shorter stride length (16%) but similar cadence during dual cognitive-walking when compared with walking alone. Our findings in comparing dual cognitive-walking with walking alone suggest that PD patients manifest more pronounced difficulties in maintaining their stride length. The significantly shorter stride length could be considered to be a form of "hypokinesia" in walking. Based on these findings, we propose that treatment intervention for PD patients should aim at improving their stride length.

Having established that PD patients had difficulties in maintaining their gait performance when a dual cognitive task was added to walking, we further compared their gait performance when 2 different cognitive tasks were separately added to walking. Our results showed no significant difference in gait parameters between $Walk_{\text{naming object}}$ and $Walk_{\text{calculation}}$ in PD patients. In contrast, control subjects managed to maintain their stride length, but significantly decreased their gait velocity and cadence during $Walk_{\text{calculation}}$ than during $Walk_{\text{naming object}}$. Is there any difference between these two cognitive tasks? According to Glaser (1992), object naming has three components: (1) recognition of the object; (2) access to the meaning of object; (3) access to the phonological word and finally say the word. Pateicia (2000) proposed that naming object is a basic and natural skill. Mental calculation, on the other hand, is a relatively more complex skill that activates different components of working memory (Baddeley and Logie 1999). It composed several functional components:

retrieval of arithmetic facts, knowledge of procedures, transcoding between number codes, quantity processing and conceptual knowledge (Dehaene et al. 2003, Domahs and Delazer 2004). Galit et al. (2008) further commented that calculation is a skill dependent technique. The education level and the mathematical skills of subjects might affect the performance of this task. Therefore it is possible that calculation might be more difficult for some subjects than others, besides being more complex than naming object. Our findings that control subjects had more deterioration in walking performance during $Walk_{calculation}$ than $Walk_{naming\ object}$ suggests that calculation could be more complex than naming object, hence it could require a higher attention level.

In PD patients, we found no significantly differences between $Walk_{naming\ object}$ and $Walk_{calculation}$ for all gait parameters. A previous study compared the gait performance under different dual tasks. O"Shea et al. (2002) found both cognitive (subtraction of three) and motor (coin transference) dual task affected the gait performance to a similar extent in PD subjects. They concluded that the type of dual task was not a major determinant of dual task interference. Galletly and Brauer (2005) showed that, with the addition of either "subtraction" or "language" task, PD patients had similar deterioration in gait velocity and stride length. In present study, naming object could be simpler than calculation. However, no significant difference was found between $Walk_{naming\ object}$ and $Walk_{calculation}$ for gait velocity and stride length in PD patients. Hence, even a small distraction of attention during a relatively simpler

object naming task affected walking performance in PD patients. A further increase in complexity of the cognitive task (i.e. serial subtraction of three) did not result in worsening gait performance in PD patients. Our findings add information on those reported previously, and confirmed that PD patients probably required more attention to walk than control subjects. In other words, walking might be less automated in these patients than control subjects similar in age.

5.4 Accuracy of dual task performance

In addition to examining gait performance, we further compared the number of correct object naming and calculation between the two groups during $Walk_{naming\ object}$ and $Walk_{calculation}$. We found PD subjects obtained significantly less correct object identifications (1.4/s vs 1.7/s) and subtractions (0.7/s vs 0.9/s, Table 4.5) than control subjects. To our knowledge, no previous study has used object identification as a dual task during walking performance in PD patients. One recent study examined the performance of "object and action naming" in PD subjects while they sat on a chair (Cotelli et al. 2007). Results of this study showed PD patients had significantly lower scores in object identifications (error rate=22.5%, $p<0.001$) when compared with healthy controls. In the present study, the error rate of the PD patients was 17.6% was less than that reported by Cotelli et al. (2007). One explanation could be that PD subjects in the study by Cotelli et al. (2007) were older (mean age of 70 years old) than those of our study (mean age of 61.3 years old). Another possible reason might

be related to the difficulty level of object naming task and the number of objects had to be named. In Cotelli et al. (2007), 60 actions and 60 objects were tested, with half of the items in each category being “easy” and half “difficult”. In the present study, about 5 objects were identified during each walking trial, and the objects shown on the computer screen were selected from daily life, which were familiar to the participants. These factors may explain why our patients could have better performance in object identifications than the previous study.

In the dual calculation task, PD subjects had significantly lower accuracy in the number of correct calculations ($p=0.044$) than control subjects. When the total number of answers was divided by walking time, our results showed PD patients had a mean of 0.7 correct answers, which was 23% less than that achieved by control subjects. Similar findings were reported in previous studies. Using same task “serial subtractions of 3”, Galletly and Brauer (2005) showed that PD patients committed 23% less correct calculations than control subjects ($p<0.001$). In their study, subjects had to do subtractions by 3, starting with a random number from 20 to 100. This was in a way similar to that of the present study, in that subjects were asked to do subtractions by 3, but they started from one number (100) only. Yogev et al. (2005) also reported less correct calculations in PD subjects than controls when subjects performed the serial 7 subtraction started from 500. PD subjects committed 24% less correct calculation than control subjects ($p<0.05$). To conclude, PD patients in our study demonstrated similar decrease in accuracy as that of previous studies.

One previous study reported a contradictory finding that control subjects committed more cognitive errors than PD patients. Bloem et al. (2001) studied the strategies for performing increasingly complex postural tasks together with a cognitive task (answering serial questions) in PD patients and control subjects. Subjects were required to perform eight separate motor tasks of increasing complexity with the addition of a cognitive task. Their results showed that PD patients made more motor errors (such as hesitation and motor block) than control subjects. However, control subjects made more cognitive errors while performing complex motor tasks than PD patients. Therefore, Bloem et al. (2001) concluded that PD patients were less able to lend priority to motor performance than control subjects. These investigators further proposed that PD patients, unlike control subjects did not use "posture first strategy", implying that PD patients paid more attention to the concurrent cognitive task than to the motor task. However, the motor tasks in that study were more complex. PD patients might not be able to equally divide their attention to the complex motor and cognitive tasks. In our present study, PD patients achieved similar accuracy in naming object but significantly lower accuracy in calculations when compared with control subjects. At the same time, these patients showed more deterioration in gait performance during dual-task walking than that during walking alone. Our findings disagree with the proposition by Bloem (2001), and suggested that PD patients tried to pay attention to both walking and cognitive task (specifically naming object and calculation) simultaneously. However, their limited attention capacity probably contributed to deterioration in performing both tasks.

5.5 Effect of preparatory AV cues on gait performance with concurrent cognitive task in patients with PD and controls

Under $AV_{walk\text{-}naming\ object}$ condition, PD subjects achieved significantly faster gait velocity (by 12.8%), longer stride length (by 7.6%) and larger cadence (by 4.7%) than $Walk_{naming\ object}$ ($p<0.001$). Similar to that of $AV_{walk\text{-}naming\ object}$ condition, PD subjects walked with significantly faster velocity (by 17.4%), longer stride length (by 8.2%) and larger cadence (by 9.2%) during $AV_{walk\text{-}calculation}$ than $Walk_{calculation}$ ($p<0.005$). Under $AV_{walk\text{-}naming\ object}$ condition, control subjects walked with significantly faster velocity (by 3.3%) and larger cadence (by 2.0%) when compared with $Walk_{naming\ object}$. Under $AV_{walk\text{-}calculation}$ condition, control subjects had significant improvement only in cadence. Furthermore, we found that the improvements in PD subjects were greater than control subjects in gait velocity and stride length, as shown by the significant group*task interactions for these parameters when AV cues were given to $AV_{walk\text{-}naming\ object}$ or $AV_{walk\text{-}calculation}$. These finding that AV cues were effective in improving these 2 parameters are encouraging since PD patients had more deterioration in stride length and gait velocity than control subjects when walking under concurrent task conditions (see Chapter 4, Section 2.1.3).

No study has examined the effect of external cues on walking while PD patients perform the dual task of "naming objects". There was only one study that explored the effect of visual cue on walking performance under a concurrent cognitive task of serial subtraction by 3 (Galletly and Brauer 2005). Our positive results under

the $AV_{walk\text{-}calculation}$ condition concur with their positive findings. Furthermore, we observed no significant difference between $AV_{walk\text{-}naming\ object}$ and $AV_{walk\text{-}calculation}$. Hence, when AV cues were given, PD patients had similar improvement in all gait parameters whether they are naming objects or doing calculation while walking. In the study by Galletly and Brauer (2005), the visual cue was white strips, with the distance between each strip equal to the step length of matched control subjects. With addition of visual cue, PD patients walked with longer stride length by 13.1% ($p<0.05$) but a significantly smaller cadence by 11.8% ($p<0.005$) and no significant change in gait velocity than non-cued dual cognitive-walking. In the study by Galletly and Brauer (2005), the lines on the floor could have directly given visual signal to PD patients to focus their attention on increasing their step size. This could explain why their patients had improvement in stride length without improvement in gait velocity. No study has examined the effect of auditory cues on walking under dual cognitive-and-walking task.

A number of previous studies examined the effect of auditory cue on walking while patients perform a dual motor task i.e. carrying a tray (Baker et al. 2007, Canning 2005, Rochester et al. 2005, 2007). The auditory cues were rhythmical signals delivered at a frequency that was matched to subjects‟ cadence while they walk at their natural speed. The addition of auditory cue could act as preparatory signals to normalize the cadence of PD patients, thus increasing their gait velocity and stride length. In a large RCT, these patients were found to have improvements in

stride length and gait velocity by 5.9% and 3.6% respectively, but a decrease in cadence by 2.9% (Rochester et al. 2007). In the present study, PD patients not only had significant increase in stride length, they also achieved significant improvements in their gait velocity and cadence. Furthermore, the increase in gait velocity was 13% and 18% for $AV_{walk\text{-}naming\ object}$ and $AV_{walk\text{-}calculation}$ respectively. These positive outcomes suggest that the use of combined AV signals could be more effective than the use of either visual or auditory cue (Baker et al. 2007, Canning 2005, Galletly and Brauer 2005, Rochester et al. 2007).

Note that the different outcomes among the studies could not be attributed to patient characteristic or study design. PD patients in the previous studies (Baker et al. 2007, Canning 2005) had mean age ranging from 64 to 68.8 years and mean UPDRS III scores ranging from 14.4 to 23.4, which were similar to those of the present study. Moreover, all studies had used similar methodology such as randomization of the walking sequence (Baker et al. 2007, Canning 2005). The major difference among the studies was the type of external cues used. In the light of only moderate improvements in gait performance under concurrent cognitive task when visual cue (Galletly and Brauer 2005) or auditory cue (Rochester et al. 2005, 2007) was applied alone, we used combined AV cues to augment the effect of external cue. We gave 3 visual signals: static red light, static green light, and blinking green light, which were placed at subjects‟ eye level. In addition to visual signals, we also gave auditory cues in the form of rhythmical tones at a frequency of 13 Hz when subjects walked while

doing a concurrent cognitive task. The positive outcomes on gait performance in our study could be the summed effects of combining auditory and visual cues. Earlier studies demonstrated that when visual and auditory cues were used together, facilitatory effect could be enhanced (Berstein 1970, Bertelson and Tissevre 1969, Nickerson 1973, Sander 1975, 1977). For example, the use of either visual or auditory signal could shorten the reaction time of upper limb voluntary movement. Interesting, a combination of these signals was found to further shorten the reaction time (Hershenson 1962, Kuess 1972). Part of this facilitatory effect could be explained in term of immediate arousal (Bertelson and Tissever 1969, Sander 1975, 1977), energy summation (Berstein 1970, Nickerson 1973, Sander 1977) or enhancement of motor preparation (Nickerson 1973).

Another reason for the improvement consequent to use of AV cues could be related to the availability of advance information to enhance patients‟ motor preparatory process prior to walking. In our study, the AV cues were given in a feed-forward manner. Subjects were allowed to listen to and to watch the AV cues once prior to the walking trial. This was used to give them information about the pre-set duration for completing the walking task. In addition, the AV cues were started 5 seconds before the gait initiation. These advance information could enhance the motor preparatory process of PD patients prior to walking under concurrent cognitive task. Previous studies found that PD patients had the ability to use advance information to improve their motor control (Jahanshahi et al. 1992, Weiss et al. 1999).

In the study of Jahanshahi (1992), PD patients had to press the buttons in response to a target on a screen. Results showed the reaction time was significantly reduced when a warning signal was given. Similar results were found by Weiss et al. (1999). In this study, PD patients were able to use advance information about object size to reduce their response times for grasping an object. Hurik et al. (1997) reported that auditory and visual cues could improve initiation and generation of gait sequence in PD patients, because these preparatory signals facilitate the motor preparatory process. In addition to walking, AV cues were used to enhance STS transfer (Mak and Hui Chan 2004). In this study, PD patients had to look at the light in front of them and to listen to the verbal command "get ready, stand up" (AV cues) before the initiation of STS. The result showed that with the addition of AV cues, hip flexion and knee extension torques were significantly increased. Furthermore, there were significant increases in peak horizontal and vertical velocities of the body center of mass; as well as decrease in the time taken to complete STS. Mak and Hui-Chan (2004) thus suggested that the use of preparatory signals could facilitate the motor preparatory process, and help PD patients to pre-plan the movement to be executed. In the present study, it appeared that the use of preparatory AV cues could facilitate PD patients to plan for the walking task, thus leading to better gait performance (Rochester et al. 2008).

The AV cues could have heightened the attention level of PD patients, leading to improvement in gait performance. In the present study, AV cues were given prior to gait initiation. When the static red light and 1 Hz auditory tone were on, subjects

were instructed to “wait and prepare to walk immediately when the static green light is on”. These preparatory AV cues could have increased the arousal level of the subjects to plan and to prepare the movement. Once the static green light and 13-Hz auditory tone were on, subjects could have focused their attention on the walking task, enabling them to walk at their fast speed and with their big step to complete walking within the pre-set duration. Finally, the AV cues of blinking green light and 13-Hz auditory tone were used to give feedback to subjects. When these signals were on, they indicated that the subjects walked too slowly and they had to speed up in the next trial. Therefore, these AV cues may act to focus the attention of patients when they perform the complex task of walking while doing a concurrent cognitive task, thereby improving their gait performance.

Previous studies reported the positive effect of attentional strategy during dual-motor task (carrying a tray while walking). Canning (2005) showed that when patients were instructed to attend to maintaining big steps, they walked with significantly faster gait velocity ($p=0.003$), longer stride length ($p=0.003$), but similar cadence. However, when PD patients were asked to attend to balancing the tray during walking, their gait performance deteriorated immediately. Similarly, Baker et al. (2007) showed that with the addition of attentional strategy to taking big steps, PD patients walked with significantly faster gait velocity (by 8.2%), longer step length (by 16.7%) and smaller cadence (by 9.0%) than no-instruction dual-task walking. In the present study, AV cues increased the gait velocity by 13% and 18%

respectively for $AV_{walk\text{-}naming\ object}$ and $AV_{walk\text{-}calculation}$ which were higher than those reported by Canning (2005) and Baker et al. (2007). This could be related to the use of AV cues, which simulated the road-crossing traffic light and sound familiar to the subjects when they "walk" across a road in their daily life. For instance, the red light signals the subject to wait and to prepare for the walk, and the green light signals the subjects to cross the road as fast as possible within a pre-set duration. Therefore, even without explicit instruction to focus on the walking task, familiarity of the AV signals to patients would have focused their attention on the walking task, leading to significant increases in their gait velocity, stride length and cadence.

Some PD patients were found to have freezing of gait (FOG) when they attempt to cross a street upon a change in the traffic light signal. These patients had FOG could be due to the ongoing activities on the street that distract their attention. Furthermore, other study suggested that emotional stress could exacerbate FOG (Okuma 2006). One previous study found PD patients had reduced self-perceived balance confidence level especially under the situations "walk in a crowded mall where people rapidly walk past", and "bump into by people as walk through the mall" (Mak et al. 2008). Therefore, the distraction of their attention or their increased anxiety level could possibly induce FOG, not a change in the traffic light. The positive outcome of the use of AV cues in present study suggests that patients could have focused their attention on the complex task of walking while doing a concurrent

cognitive task, leading to significant increases in their gait velocity, stride length and cadence.

The afore-mentioned clinical findings were supported by neurophysiological studies in animals. Brotchie et al. (1991) trained monkeys to perform predictable sequences of wrist movement, and found that the supplementary motor area and pallidal neurons were activated prior to movement onset and the initiation of the next movement in the sequence. Therefore, they proposed that the basal ganglia (BG) have 2 roles: (1) to assist in the preparation and maintenance of motor plans, and (2) to generate internal cues to carry out movement sequences without attention (Brotchie et al. 1991). Hence, degeneration of BG would result in inadequate motor preparatory processes and a lack of internal cue to link up movement sequence, e.g. as required in walking. Other investigators (Musiake et al. 1991, van Donkelaar et al. 1999, 2000) further recorded neuronal activity from three different cortical motor areas: the primary motor cortex, SMA, and premotor cortex (PMC) in monkeys. These animals were trained to perform a sequential motor task (reached to and touched the three pads placed in a front panel) with visual cue (by following lights illuminated individually from the respective pad), or without visual cues (they had to remember a predetermined sequence and press the pads). The results showed that more than half of the SMA neurons were preferentially or exclusively activated under the non-cued condition. In contrast, neurons in the PMC were more active under cued condition. Therefore, the authors suggested that the PMC would dominate during externally

guided movements, whereas the SMA would predominate in self-generated motor action.

Debaere et al. (2003) used functional magnetic resonance imaging to assess the active region of the brain when healthy subjects performed a bimanual movement pattern (90° out-of-phase pattern with both hands) with or without visual feedback. The superior parietal cortex, the PMC, the thalamus, and cerebellar lobule VI showed higher activity when visual feedback was given. Conversely, BG, SMA, cingulated motor cortex, and inferior parietal showed more involvement when movements were internally generated. Cunnington et al. (1995) used electroencephalography to measure movement-related potentials in various cortical areas in PD patients when they were instructed to press a button with and without cues (for the position and pathway of the target). The results showed that the supplementary motor area was only involved in movements which must be internally determined (non-cued movements). The authors therefore suggested that in PD patients, impaired internal control mechanisms, operating via the SMA are bypassed when external cues are given. In the present study, the AV cues could have activated the external pathways (superior parietal cortex, the PMC, and the thalamus). Patients with PD could use the preparatory AV cues to provide them advance information about the pre-set walking time to formulate their motor plan: for instance, how fast the walking velocity, how big the step length…etc. This may explain why the use of preparatory AV cues in the present study significantly improved the gait performance of patients with PD.

5.6 Accuracy of dual task performance with addition of AV cues

We further compared the number of correct object identification and calculation between AV-and no-cued conditions in PD and control subjects. Our results showed that both groups of subjects achieved similar correct answers for both identified objects and calculation under AV-and non-cued conditions. Galletly and Brauer (2005) reported similar results. When visual cues were added; there was no significant change in the error rate of any concurrent task, be it calculation or language (list specific letter with “F” and “S”). Rocherster et al. (2005) proposed that external cues could help PD patients to reduce the attention demand on walking by better allocation between walking and a concurrent task, leading to improved gait performance during dual-task walking. According to the resource-sharing model (Pashler 1994), if capacity is limited, allocating additional resources to one task will improve performance on that task, but only at the cost of reducing the resources available for other concurrent tasks (Broadbent 1958, Kahneman 1973, Moray 1967, Wickens 1984). In the present study, there was improvement in walking performance without deterioration of the cognitive task. The external guidance given by the AV cues could have taken the executive role to reduce cognitive loading on walking in PD patients, hence a better allocation of attentional resources between the motor and cognitive task (Rochester et al. 2008).

5.7 Summary

When a concurrent cognitive task (object naming or calculation) was added during walking, PD patients showed deterioration in all gait parameters. However, no difference was found in gait performance between "object naming" and "calculation" task. Our findings indicate that PD patients probably require more attention to walk than healthy normal subjects. Another finding was that PD patients committed significantly lower accuracy in both object identification and calculation than control subjects, suggesting that these patients may have more problems in performing a concurrent cognitive task accurately while walking than normal subjects.

With the addition of preparatory AV cues, PD patients improved all gait parameters without deterioration in the concurrent cognitive task during dual-task walking. This finding suggests that the AV cues could have facilitated the motor preparatory process in planning and preparing for the walking task. During dual cognitive-walking task, the AV cues could have focused the attention of PD patients on the walking task, thereby improving their gait performance.

5.8 Clinical implications

Various therapeutic interventions are used in the treatment of PD, including medication, deep brain stimulation, and physical training. Exercise and balance training could improve balance, gait speed, and activities of daily living in patients with PD (Rao et al. 2006). Findings of our *Study 1* identified that PD patients had

deterioration in gait performance under dual task condition and had particularly more difficulties in maintaining their stride length. Based on this finding, the clinical importance of present study is that (1) treatment intervention for PD patients should aim at improving their stride length; (2) physiotherapists could suggest PD patients to avoid simultaneous tasks, as they could perform the walking task well when they need to walk with big step. Our *Study 2* showed that the use of preparatory AV cues could enhance all the gait parameters under dual-task walking. Thus, the use of such AV cues over a treatment period would probably improve gait performance in people with PD with carried-over effects to the non-cued condition.

5.9 Limitations of the study and directions for further research

The present study investigated (1) the effect of dual cognitive-walking task on gait performance in PD patients; (2) the effect of preparatory AV cues on gait performance under dual cognitive-walking task in PD patients. Regarding to this study, several points of application and research methodology need to be addressed. First, since the PD patients participating in the present study presented only mild to moderate impairment level, the findings may not be generalized to other patients with more severe disease. Finding from PD patients recruited from the community may not be generalized to other patients housed in hospitals or rehabilitation centers. It was recommended that further studies could include a larger sample of PD patients, such as PD fallers or with more severe impairment level. Second, all testings was performed during the “on” mediation phase and different results might have been

obtained during the “off” medication phase. Further research is required to clarify the role of medication on dual cognitive-walking task performance. Third, the present study only measured spatio-temporal parameters such as gait velocity, stride length and cadence. It was recommended more variables including step time and stride width to be recorded as other measures of gait performance. PD patients show reduced electromyographic (EMG) amplitudes of the gastrocnemius muscle during walking (Dietz et al. 1997). Thus, EMG could be used to examine whether the AV cues could excite lower limb muscles and/or improve muscle activation pattern during gait initiation as well as walking. Kinetic parameters such as the joint (hip, knee and ankle) torques could be measured to provide insights of muscle strength, and force build-up rate during walking. Therefore, these parameters could be considered to determine the effect of AV cues on normalization of gait pattern in PD patients. Fourth, the current study only examined the immediate effect of preparatory AV cues on gait performance. Nevertheless, the positive findings of this study served as a background to investigate the efficacy of preparatory AV-cued gait training program in a large scale randomized controlled trial. Further interventional study is required to examine whether the effect of training could be carried over to non-cued situation, and whether the effect could be maintained for a period after treatment ended.

CHAPTER 6 CONCLUSIONS

This chapter concludes the main findings of the present study based on the two objectives: (1) to examine the effect of adding a concurrent cognitive task (naming object or calculation) while walking on gait performance in PD patients; (2) to examine whether the use of preparatory audio-visual cues could enhance walking under dual cognitive-walking task condition in PD patients. Results from the test-retest reliability study indicated that the methodology and instrument used in present study was reliable.

6.1 Baseline walking performance in patients with PD

Our findings showed that PD patients had more difficulty in maintaining their normal stride length during walking alone support the suggested role of the BG in the control of movement amplitude as manifested by stride length during walking.

6.2 Effect of dual cognitive-walking task on gait performance in patients with PD

When a concurrent cognitive task was added during walking, PD patients demonstrated the same deterioration in all gait parameters regardless of whether the cognitive task is object naming or calculation. Our findings suggest that walking may require more attention in PD patients than normal healthy subjects. In addition, PD

patients had more deterioration in stride length during dual cognitive-walking task, we propose that treatment intervention for PD patients should focus on improving their stride length.

6.3 Effect of preparatory AV cues on gait performance during dual cognitive-walking task

We found that with the addition of preparatory AV cues, PD patients improved all the gait parameters while performing dual cognitive-walking task. These results suggest that the use of AV cues could have facilitated motor preparatory process by focusing their attention on walking, thereby improving their gait performance.

6.4 Accuracy of dual task performance with or without addition of AV cues

Our results showed that PD patients committed significantly more errors in calculation than control subjects under the non-cued condition, suggesting that PD patients could not attend to both walking and cognitive tasks simultaneously. Limited attention capacity may have led to deterioration in the performance of both these tasks. When preparatory AV cues were applied, PD patients improved all their gait parameters without deterioration in the cognitive task during dual cognitive-walking task. These findings suggested that the use of AV cues could have enabled PD patients to achieve a better allocation of attention resources between motor and cognitive tasks.

APPENDIX I

Informed Consent (*Study 1*)

Project title: Effect of feed-forward audio-visual signals on gait performance under dual-task condition in people with Parkinson's disease

Researcher: Dr. Margaret Mak Associate Professor
Yu Liling MPhil candidate
Department of Rehabilitation Science The Hong Kong Polytechnic University

Project information: Gait deficits are exacerbated during addition of one or more dual motor or cognitive tasks in PD. i.e. carrying a tray while walking or talking while walking. The defective function of the basal ganglia might force people with PD to overly rely on cortically mediated mechanisms of motor control when carrying out movements such as walking. Adding another task during walking could place pressure on limited attentional resources in people with PD, and might account for greater gait deterioration than walking alone. Other than medication, physiotherapy is useful in improving walking difficulty and walking pattern of patient with PD. This research will be done in the laboratory of the Hong Kong Polytechnic University for once. The whole test may take about an hour. The test will include 2 parts below,

- Fill up a simple questionnaire about your disease, medication, freezing of gait etc.
- Walking test: walking under following conditions

1. Walk on a walking mat at a natural speed;
2. Walk on a walking mat and name objects on a screen
3. Walk on a walking mat and do calculation

Before the tests above, you will be demonstrated the above procedures and to be given enough practices. There will be no harm or adverse effects in the whole testing procedures.

Consent:

I, _____, have been explained the details of this study. I voluntarily consent to participate in this study. I understand that I can withdraw from this study at any time without giving reasons, and my withdrawal will not lead to any punishment or prejudice against me. I am aware of any potential risk in joining this study. I also understand that my personal information will not be disclosed to people who are not related to this study and my name or photograph will not appear on any publications resulted from this study.

I can contact the chief investigator, Prof/Dr __Margaret Mak__at telephone 2766_6708_ for any questions about this study. If I have complaints related to the investigator(s), I can contact Mrs Michelle Leung, secretary of Departmental Research Committee, at 27665397. I know I will be given a signed copy of this consent form.

Signature (subject): Date:

Signature (witness): Date:

參與研究同意書

研究帕金遜症病人在各種情況下步行的方法 (研究一)

研究員：麥潔儀博士，副教授

俞李羚研究生

香港理工大學 康復治療科学系

研究的目的及内容

當帕金遜症患者在同時做兩件以上事情分散注意力（如：走路時説話）時，會出現步行困難。除了藥物之外，物理治療亦可幫助減輕這些病徵。如閣下同意參與是次研究，將會到香港理工大學的腦科康復實驗室進行一次檢查。整個檢查大約一小時。檢查大致分爲以下兩個程序：

- 進行簡單的問卷調查關於你的病症，用藥以及步態僵硬問卷等
- 步行測試：

1. 以自然的速度在步行墊上步行
2. 以自然的速度在步行墊上步行并看前方屏幕圖片說話
3. 以自然的速度在步行墊上步行并作計算

在進行以上試驗前，我們將會示範以上程序，並給與閣下充分的機會練習。整個檢查絕對安全，並無不良副作用。测试当中我们會给閣下充分的休息。

參與研究的好處

參與是次研究的最大好處是閣下可以知道自己的步行能力。如果研究結果良好，這些研究資料將會成爲帕金遜症患者設計適當的運動時帶來幫助。當檢查完畢後，閣下將學到一套針對帕金遜症的運動

安全問題

整個檢查的危險性極低，但有可能會失去平衡而摔倒。為免摔倒，在進行檢查期

間，研究員將會站於閣下旁邊，以保安全。

資料保密及退出研究

所有從研究中得到的數據、結果及個人資料將會絕對保密。所有參與研究的人仕只會以代號作記認。研究所得的所有資料將會於研究完成及刊登後銷毀。我們只會將研究結果中所得數據的平均值保留，研究結果可能會以個人及/或整個實驗參與組所得的數值作刊登形式。請於同意參與是項研究前提出閣下之疑問。如閣下同意參與是次研究，亦有權隨時退出，並不會對閣下構成任何損失及不需要爲此作出任何補償。

查詢

如有任何對是項研究的疑問，可隨時致電 2766　　或 6645　　，與俞李羚小姐聯係。如你對研究員有任何投訴，你可以向香港理工大學學系研究小組梁太聯絡，電話 2766　　。

衷心感謝閣下的支持和合作。

本人_____已閱讀及明白以上的資料並同意參與是項研究。 本人以下的簽署代表本人已收到這份同意書的副本。

簽署：_____

見證人簽署：_____

日期：_____

APPENDIX II

Informed Consent (*Study 2*)

Project title: Effect of preparatory audio-visual cues on gait performance under dual-task condition in people with Parkinson's disease

Researcher: Dr.Margaret Mak Associate Professor
Yu Liling MPhil candidate
Department of Rehabilitation Science The Hong Kong Polytechnic University

Project information: Application of external cues could enhance gait performance in patient with PD. In addition, by using the preparatory audio-visual (AV) cues improved the performance of sit-to-stand task in PD patients. In present study, we will examine the effect of the preparatory AV cues on gait performance during dual cognitive task walking. This research will be done in the laboratory of the Hong Kong Polytechnic University for once. The whole test may take about an hour. The test will include 2 parts below,

- Fill up a simple questionnaire about your disease, medication, freezing of gait etc.
- Walking test: walking under following conditions

1. Walk on a walking mat and name objects on a screen
2. Walk on a walking mat and do calculation
3. Under AV cues, walk on a walking mat and name objects on a screen
4. Under AV cues, walk on a walking mat and do calculation

Before the tests above, you will be demonstrated the above procedures and to be given enough practices. There will be no harm or adverse effects in the whole testing procedures.

Consent:

I, _____, have been explained the details of this study. I voluntarily consent to participate in this study. I understand that I can withdraw from this study at any time without giving reasons, and my withdrawal will not lead to any punishment or prejudice against me. I am aware of any potential risk in joining this study. I also understand that my personal information will not be disclosed to people who are not related to this study and my name or photograph will not appear on any publications resulted from this study.

I can contact the chief investigator, Prof/Dr __Margaret Mak__at telephone 2766_6708_ for any questions about this study. If I have complaints related to the investigator(s), I can contact Mrs Michelle Leung, secretary of Departmental Research Committee, at 27665397. I know I will be given a signed copy of this consent form.

Signature (subject): Date:

Signature (witness): Date:

參與研究同意書

研究帕金遜症病人在視聽指示燈下的步態 (研究二)

研究員：麥潔儀博士，副教授

俞李羚研究生

香港理工大學康復治療科学系

研究的目的及内容

當帕金遜症患者在同時做兩件以上事情分散注意力（如：走路時説話）時，會出現步行困難。除了藥物之外，物理治療亦可幫助減輕這些病徵。如閣下同意參與是次研究，將會到香港理工大學的腦科康復實驗室進行一次檢查。整個檢查大約一小時。檢查大致分爲以下兩個程序：

- 進行簡單的問卷調查關於你的病症，用藥以及步態僵硬問卷等
- 步行測試：

1. 以自然的速度在步行墊上步行并看前方屏幕圖片說話
2. 以自然的速度在步行墊上步行并作計算
3. 在紅綠燈指示下以自然的速度在步行墊上步行并看前方屏幕圖片說話
4. 在紅綠燈指示下以自然的速度在步行墊上步行并作計算

在進行以上試驗前，我們將會示範以上程序，並給與閣下充分的機會練習。整個檢查絕對安全，並無不良副作用。测试当中我们會给閣下充分的休息。

參與研究的好處

參與是次研究的最大好處是閣下可以知道自己的步行能力。如果研究結果良好，這些研究資料將會成爲帕金遜症患者設計適當的運動時帶來幫助。當檢查完畢後，閣下將學到一套針對帕金遜症的運動

安全問題

整個檢查的危險性極低，但有可能會失去平衡而摔倒。為免摔倒，在進行檢查期間，研究員將會站於閣下旁邊，以保安全。

資料保密及退出研究

所有從研究中得到的數據、結果及個人資料將會絕對保密。所有參與研究的人仕只會以代號作記認。研究所得的所有資料將會於研究完成及刊登後銷毀。我們只會將研究結果中所得數據的平均值保留，研究結果可能會以個人及/或整個實驗參與組所得的數值作刊登形式。請於同意參與是項研究前提出閣下之疑問。如閣下同意參與是次研究，亦有權隨時退出，並不會對閣下構成任何損失及不需要爲此作出任何補償。

查詢

如有任何對是項研究的疑問，可隨時致電 2766 或 6645 ，與俞李羚小姐聯係。如你對研究員有任何投訴，你可以向香港理工大學學系研究小組梁太聯絡，電話 2766 。

衷心感謝閣下的支持和合作。

本人_____已閱讀及明白以上的資料並同意參與是項研究。 本人以下的簽署代表本人已收到這份同意書的副本。

簽署：_____

見證人簽署：_____

日期：_____

APPENDIX III

Demographic sheet: Effect of feed-forward audio-visual cues on gait performance under dual-task condition in people with Parkinson‟s disease

Date of examination: Subject's code :

Name: Sex

Year of Birth (Year) :

Weight : kg / lb Height : cm

Month since last diagnosis :

Past Medical History : Medical problem : ☐ Yes Type and date of onset:

☐ No

Orthopedic problem : ☐ Yes Type and date of onset:

☐ No

Fall History : ☐ Yes Frequency, date of last fall: / year

☐ No

Current medication and frequency :

Time since last medication for Parkinson's disease :

Others :

Walking sequence

Baseline walking time (S) (1) (2) (3) (4)

Modified Hoehn and Yahr Staging :

☐	Stage 0	No signs of Disease
☐	Stage 1	Unilateral
☐	Stage 1.5	Unilateral + axial
☐	Stage 2	Bilat, /wo balance impairment
☐	Stage 2.5	Mild bilat, /w recovery on pull test
☐	Stage 3	Mild to mod bilat, some postural instab, physical indep
☐	Stage 4	Severe disability, able to walk or stand unassist
☐	Stage 5	Wheelchair bound or bedridden

APPENDIX IV

Unified Parkinson's disease Rating Scale (UPDRS) III. Motor Exam

18	Speech		
19	Facial Expession		
20	Tremor at rest - face, lips, chin		
	Hands	R	
		L	
	Feet	R	
		L	
21	Action tremor		
		R	
		L	
22	Rigidity		
	Neck		
	UL	R	
		L	
	LL	R	
		L	
23	Finger Taps		
		R	
		L	
24	Hand Grips		
		R	
		L	
25	Hand Pronate / supinate		
		R	
		L	
26	Leg agility		
		R	
		L	
27	Arise From chair		
28	Posture		
29	Postural Stability		
30	Gait		
31	Body bradykinesia		
Total Score (max:108)			

APPENDIX V

步態僵硬問卷

1．在你最差的狀態下，你走路：
   0．正常
   1．差不多正常----有一點點慢
   2．慢但是能獨立行走
   3．需要幫助或者拐杖
   4．不能走路

2．行走困難是否影響到你的日常活動和獨立性？
   0．完全沒有
   1．輕微的
   2．中度的
   3．嚴重的
   4．不能走路

3．儅你轉身或者起步的時候，有否覺得你的腳被粘在地上了？
   0．從來沒有
   1．很少----差不多一個月一次
   2．少----差不多每星期一次
   3．經常----差不多每天一次
   4．一直----每當走路的時候

4．你最長的僵硬時間是多少？
   0．從來沒有發生過僵硬
   1．1-2 秒
   2．3-10 秒
   3．11-30 秒
   4．停止 30 秒以上

5．如果起步的時候出現僵硬，通常需要多久才能行路
   0．沒有出現過僵硬
   1．需要 1 秒以上才能開始行走
   2．需要 3 秒以上才能開始行走
   3．需要 10 秒以上才能開始行走
   4．需要 30 秒以上才能開始行走

6．如果在轉彎的時候出現僵硬，通常需要多久才能轉過身去
   0．沒有出現過僵硬
   1．1-2 秒后可以繼續轉彎
   2．3-10 秒后可以繼續轉彎
   3．11-30 秒后可以繼續轉彎
   4．需要 30 秒以上才能繼續轉彎

APPENDIX VI

SPSS output

Study 1

gp1: control subjects

gp2: PD subjects

Velocity (gp*condition)

Descriptive Statistics

	gp	Mean	Std. Deviation	N
$Walk_{0}$	1	134.353	14.7542	15
	2	113.806	19.1493	22
	Total	122.136	20.0788	37
$Walk_{naming\ object}$	1	133.082222	15.5957151	15
	2	94.024242	21.7456976	22
	Total	109.858559	27.3564902	37
$Walk_{calculation}$	1	116.416	15.3543	15
	2	84.409	21.7145	22
	Total	97.385	24.9105	37

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.
condition	Sphericity Assumed	10032.411	2	42.368	.000
	Greenhouse-Geisser	10032.411	1.871	42.368	.000
	Huynh-Feldt	10032.411	2.000	42.368	.000
	Lower-bound	10032.411	1.000	42.368	.000
condition * gp	Sphericity Assumed	1556.896	2	6.575	.002
	Greenhouse-Geisser	1556.896	1.871	6.575	.003
	Huynh-Feldt	1556.896	2.000	6.575	.002
	Lower-bound	1556.896	1.000	6.575	.015
Error(condition)	Sphericity Assumed	8287.629	70		
	Greenhouse-Geisser	8287.629	65.475		
	Huynh-Feldt	8287.629	70.000		
	Lower-bound	8287.629	35.000		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1358941.103	1	1358941.103	1640.176	.000
gp	24951.290	1	24951.290	30.115	.000
Error	28998.679	35	828.534		

Stride length (gp*condition)

Descriptive Statistics

	gp	Mean	Std. Deviation	N
$Walk_{0}$	1	133.288678	12.3147757	15
	2	119.790614	17.4370737	22
	Total	125.262802	16.7773334	37
$Walk_{naming\ object}$	1	130.128878	12.1782857	15
	2	103.603295	18.8703067	22
	Total	114.356910	20.9693006	37
$Walk_{calculation}$	1	124.214622	13.3032022	15
	2	101.669523	19.2547896	22
	Total	110.809428	20.2735868	37

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.
condition	Sphericity Assumed	3494.666	2	33.667	.000
	Greenhouse-Geisser	3494.666	1.683	33.667	.000
	Huynh-Feldt	3494.666	1.808	33.667	.000
	Lower-bound	3494.666	1.000	33.667	.000
condition * gp	Sphericity Assumed	795.001	2	7.659	.001
	Greenhouse-Geisser	795.001	1.683	7.659	.002
	Huynh-Feldt	795.001	1.808	7.659	.001
	Lower-bound	795.001	1.000	7.659	.009
Error(condition)	Sphericity Assumed	3633.027	70		
	Greenhouse-Geisser	3633.027	58.889		
	Huynh-Feldt	3633.027	63.297		
	Lower-bound	3633.027	35.000		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1510077.122	1	1510077.122	2140.413	.000
gp	11638.737	1	11638.737	16.497	.000
Error	24692.752	35	705.507		

Cadence (gp*condition)

Descriptive Statistics

	gp	Mean	Std. Deviation	N
$Walk_{0}$	1	121.697778	7.5066369	15
	2	115.018182	12.0106202	22
	Total	117.726126	10.8220258	37
$Walk_{naming\ object}$	1	123.460	7.5688	15
	2	109.885	16.3519	22
	Total	115.388	14.9636	37
$Walk_{calculation}$	1	113.067778	6.9260793	15
	2	101.080303	21.9635982	22
	Total	105.940090	18.3209240	37

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.
condition	Sphericity Assumed	2643.536	2	22.031	.000
	Greenhouse-Geisser	2643.536	1.620	22.031	.000
	Huynh-Feldt	2643.536	1.736	22.031	.000
	Lower-bound	2643.536	1.000	22.031	.000
condition * gp	Sphericity Assumed	232.614	2	1.939	.152
	Greenhouse-Geisser	232.614	1.620	1.939	.161
	Huynh-Feldt	232.614	1.736	1.939	.158
	Lower-bound	232.614	1.000	1.939	.173
Error(condition)	Sphericity Assumed	4199.633	70		
	Greenhouse-Geisser	4199.633	56.707		
	Huynh-Feldt	4199.633	60.759		
	Lower-bound	4199.633	35.000		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	1391772.930	1	1391772.930	2893.041	.000
gp	3090.586	1	3090.586	6.424	.016
Error	16837.663	35	481.076		

Velocity (PD patients VS Control subjects)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means			
		F	Sig.	t	df	Sig.(2-tailed)	Mean Difference
$Walk_0$	Equal variances assumed	1.401	.245	3.502	35	.001	20.5473
	Equal variances not assumed			3.680	34.387	.001	20.5473
$Walk_{naming\ object}$	Equal variances assumed	.383	.540	5.976	35	.000	39.0579798
	Equal variances not assumed			6.360	34.869	.000	39.0579798
$Walk_{calculation}$	Equal variances assumed	2.155	.151	4.922	35	.000	32.0065
	Equal variances not assumed			5.251	34.923	.000	32.0065

Stride length (PD patients VS Control subjects)

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means			
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference
$Walk_0$	Equal variances assumed	1.758	.193	2.585	35	.014	13.4980641
	Equal variances not assumed			2.759	34.926	.009	13.4980641
$Walk_{naming\ object}$	Equal variances assumed	2.460	.126	4.795	35	.000	26.5255823
	Equal variances not assumed			5.195	34.937	.000	26.5255823
$Walk_{calculation}$	Equal variances assumed	2.015	.165	3.932	35	.000	22.5450995
	Equal variances not assumed			4.212	34.980	.000	22.5450995

PD subjects (comparison among 3 conditions)

One-way ANOVA

				df	F	Sig.
Velocity	Between Groups	(Combined)		2	11.309	.000
		Linear Term	Contrast	1	21.751	.000
			Deviation	1	.867	.355
	Within Groups			63		
	Total			65		
stride length	Between Groups	(Combined)		2	6.340	.003
		Linear Term	Contrast	1	10.512	.002
			Deviation	1	2.168	.146
	Within Groups			63		
	Total			65		

Post Hoc Tests

Bonferroni

Dependent Variable	(I) cond	(J) cond	Mean Difference (I-J)	Std. Error	Sig.
Velocity	$Walk_{0}$	$Walk_{naming\ object}$	19.7818(*)	6.3032	.008
		$Walk_{calculation}$	29.3970(*)	6.3032	.000
	$Walk_{naming\ object}$	$Walk_{0}$	-19.7818(*)	6.3032	.008
		$Walk_{calculation}$	9.6152	6.3032	.396
	$Walk_{calculation}$	$Walk_{0}$	-29.3970(*)	6.3032	.000
		$Walk_{naming\ object}$	-9.6152	6.3032	.396
stride length	$Walk_{0}$	$Walk_{naming\ object}$	16.1873182(*)	5.5891858	.016
		$Walk_{calculation}$	18.1210909(*)	5.5891858	.006
	$Walk_{naming\ object}$	$Walk_{0}$	-16.1873182(*)	5.5891858	.016
		$Walk_{calculation}$	1.9337727	5.5891858	1.000
	$Walk_{calculation}$	$Walk_{0}$	-18.1210909(*)	5.5891858	.006
		$Walk_{naming\ object}$	-1.9337727	5.5891858	1.000

* The mean difference is significant at the .05 level.

Control subjects (comparison among 3 conditions)

One-way ANOVA

				df	F	Sig.
Velocity	Between Groups	(Combined)		2	6.472	.004
		Linear Term	Contrast	1	10.392	.002
			Deviation	1	2.552	.118
	Within Groups			42		
	Total			44		
stride length	Between Groups	(Combined)		2	2.002	.148
		Linear Term	Contrast	1	3.884	.055
			Deviation	1	.119	.732
	Within Groups			42		
	Total			44		

Post Hoc Tests

Bonferroni

Dependent Variable	(I) cond	(J) cond	Mean Difference (I-J)	Std. Error	Sig.
Velocity	$Walk_{0}$	$Walk_{naming\ object}$	1.2711111	5.5644402	1.000
		$Walk_{calculation}$	17.9377778(*)	5.5644402	.007
	$Walk_{naming\ object}$	$Walk_{0}$	-1.2711111	5.5644402	1.000
		$Walk_{calculation}$	16.6666667(*)	5.5644402	.014
	$Walk_{calculation}$	$Walk_{0}$	-17.9377778(*)	5.5644402	.007
		$Walk_{naming\ object}$	-16.6666667(*)	5.5644402	.014
stride length	$Walk_{0}$	$Walk_{naming\ object}$	3.1598000	4.6040539	1.000
		$Walk_{calculation}$	9.0740556	4.6040539	.166
	$Walk_{naming\ object}$	$Walk_{0}$	-3.1598000	4.6040539	1.000
		$Walk_{calculation}$	5.9142556	4.6040539	.618
	$Walk_{calculation}$	$Walk_{0}$	-9.0740556	4.6040539	.166
		$Walk_{naming\ object}$	-5.9142556	4.6040539	.618

* The mean difference is significant at the .05 level.

The number of correct answers for cognitive tasks between PD and control subjects

Independent Samples Test

	gp	N	Mean	Std. Deviation	Std. Error Mean
$Walk_{naming\ object}$	1	15	4.822222	1.0302309	.2660045
	2	22	5.454545	1.2410333	.2645892
$Walk_{naming\ object}/t_2$	1	15	1.730686	.3085953	.0796790
	2	22	1.365698	.3072779	.0655119
$Walk_{calculation}$	1	15	3.23	.942	.243
	2	22	3.06	1.596	.340
$Walk_{calculation}/t_3$	1	15	1.033372	.3360635	.0867712
	2	22	.664157	.3147333	.0671014

		t	df	Sig. (2-tailed)	Mean Difference
$Walk_{naming\ object}$	Equal variances assumed	-1.626	35	.113	-.6323232
	Equal variances not assumed	-1.685	33.528	.101	-.6323232
$Walk_{naming\ object}/t_2$	Equal variances assumed	3.541	35	.001	.3649881
	Equal variances not assumed	3.538	30.143	.001	.3649881
$Walk_{calculation}$	Equal variances assumed	.376	35	.709	.173
	Equal variances not assumed	.413	34.455	.682	.173
$Walk_{calculation}/t_3$	Equal variances assumed	3.409	35	.002	.3692152
	Equal variances not assumed	3.366	28.868	.002	.3692152

Study 2

gp1: control subjects

gp2: PD subjects

Naming objects

Velocity (gp*cue)

Descriptive Statistics

	gp	Mean	Std. Deviation	N
$Walk_{naming\ object}$	1	132.649	13.7722	13
	2	89.944	18.8144	15
	Total	109.771	27.1704	28
$AV_{walk\text{-}naming\ object}$	1	137.130769	11.7959226	13
	2	103.097778	24.7503839	15
	Total	118.898810	26.0428509	28

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.
cue	Sphericity Assumed	1082.970	1	28.227	.000
	Greenhouse-Geisser	1082.970	1.000	28.227	.000
	Huynh-Feldt	1082.970	1.000	28.227	.000
	Lower-bound	1082.970	1.000	28.227	.000
cue * gp	Sphericity Assumed	261.826	1	6.824	.015
	Greenhouse-Geisser	261.826	1.000	6.824	.015
	Huynh-Feldt	261.826	1.000	6.824	.015
	Lower-bound	261.826	1.000	6.824	.015
Error(cue)	Sphericity Assumed	997.545	26		
	Greenhouse-Geisser	997.545	26.000		
	Huynh-Feldt	997.545	26.000		
	Lower-bound	997.545	26.000		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	745888.701	1	745888.701	1176.757	.000
gp	20504.974	1	20504.974	32.350	.000
Error	16480.127	26	633.851		

Stride length (gp*cue)

Descriptive Statistics

	gp	Mean	Std. Deviation	N
$Walk_{naming\ object}$	1	130.632769	12.5639379	13
	2	100.692178	17.3464592	15
	Total	114.593167	21.3869837	28
$AV_{walk\text{-}naming\ object}$	1	132.415154	11.7452204	13
	2	108.952578	18.1459576	15
	Total	119.845917	19.3400852	28

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.
cue	Sphericity Assumed	351.200	1	21.431	.000
	Greenhouse-Geisser	351.200	1.000	21.431	.000
	Huynh-Feldt	351.200	1.000	21.431	.000
	Lower-bound	351.200	1.000	21.431	.000
cue * gp	Sphericity Assumed	146.127	1	8.917	.006
	Greenhouse-Geisser	146.127	1.000	8.917	.006
	Huynh-Feldt	146.127	1.000	8.917	.006
	Lower-bound	146.127	1.000	8.917	.006
Error(cue)	Sphericity Assumed	426.069	26		
	Greenhouse-Geisser	426.069	26.000		
	Huynh-Feldt	426.069	26.000		
	Lower-bound	426.069	26.000		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	778044.319	1	778044.319	1693.380	.000
gp	9930.717	1	9930.717	21.614	.000
Error	11946.019	26	459.462		

Cadence (gp*cue)

Descriptive Statistics

	gp	Mean	Std. Deviation	N
$Walk_{naming\ object}$	1	122.866667	6.0019287	13
	2	108.188889	14.2987382	15
	Total	115.003571	13.3263850	28
$AV_{walk\text{-}naming\ object}$	1	125.338462	7.2900217	13
	2	113.453333	15.8621282	15
	Total	118.971429	13.8028199	28

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.
cue	Sphericity Assumed	208.404	1	14.471	.001
	Greenhouse-Geisser	208.404	1.000	14.471	.001
	Huynh-Feldt	208.404	1.000	14.471	.001
	Lower-bound	208.404	1.000	14.471	.001
cue * gp	Sphericity Assumed	27.157	1	1.886	.181
	Greenhouse-Geisser	27.157	1.000	1.886	.181
	Huynh-Feldt	27.157	1.000	1.886	.181
	Lower-bound	27.157	1.000	1.886	.181
Error(cue)	Sphericity Assumed	374.440	26		
	Greenhouse-Geisser	374.440	26.000		
	Huynh-Feldt	374.440	26.000		
	Lower-bound	374.440	26.000		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	768705.784	1	768705.784	2822.761	.000
gp	2456.958	1	2456.958	9.022	.006
Error	7080.425	26	272.324		

Calculation

Velocity (gp*cue)

Descriptive Statistics

	gp	Mean	Std. Deviation	N
$Walk_{calculation}$	1	118.946	14.9304	13
	2	81.273	21.4000	15
	Total	98.764	26.5068	28
$AV_{walk\text{-}calculation}$	1	126.004	15.7546	13
	2	98.336	25.2118	15
	Total	111.182	25.2461	28

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.
cue	Sphericity Assumed	2025.807	1	26.912	.000
	Greenhouse-Geisser	2025.807	1.000	26.912	.000
	Huynh-Feldt	2025.807	1.000	26.912	.000
	Lower-bound	2025.807	1.000	26.912	.000
cue * gp	Sphericity Assumed	348.530	1	4.630	.041
	Greenhouse-Geisser	348.530	1.000	4.630	.041
	Huynh-Feldt	348.530	1.000	4.630	.041
	Lower-bound	348.530	1.000	4.630	.041
Error(cue)	Sphericity Assumed	1957.188	26		
	Greenhouse-Geisser	1957.188	26.000		
	Huynh-Feldt	1957.188	26.000		
	Lower-bound	1957.188	26.000		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	627657.121	1	627657.121	858.597	.000
gp	14866.872	1	14866.872	20.337	.000
Error	19006.686	26	731.026		

Stride length (gp*cue)

Descriptive Statistics

	gp	Mean	Std. Deviation	N
$Walk_{calculation}$	1	126.715128	12.3284937	13
	2	100.372533	18.2683801	15
	Total	112.603024	20.4838833	28
$AV_{walk\text{-}calculation}$	1	129.809891	10.3882650	13
	2	109.236811	20.8664843	15
	Total	118.788598	19.5679066	28

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.
cue	Sphericity Assumed	498.011	1	34.609	.000
	Greenhouse-Geisser	498.011	1.000	34.609	.000
	Huynh-Feldt	498.011	1.000	34.609	.000
	Lower-bound	498.011	1.000	34.609	.000
cue * gp	Sphericity Assumed	115.911	1	8.055	.009
	Greenhouse-Geisser	115.911	1.000	8.055	.009
	Huynh-Feldt	115.911	1.000	8.055	.009
	Lower-bound	115.911	1.000	8.055	.009
Error(cue)	Sphericity Assumed	374.135	26		
	Greenhouse-Geisser	374.135	26.000		
	Huynh-Feldt	374.135	26.000		
	Lower-bound	374.135	26.000		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	756604.335	1	756604.335	1455.787	.000
gp	7664.477	1	7664.477	14.747	.001
Error	13512.773	26	519.722		

Cadence (gp*cue)

Descriptive Statistics

	gp	Mean	Std. Deviation	N
$Walk_{calculation}$	1	113.351282	7.2534489	13
	2	98.575556	21.1470530	15
	Total	105.435714	17.6515424	28
$AV_{walk\text{-}calculation}$	1	117.319	12.3778	13
	2	108.091	17.5712	15
	Total	112.376	15.8161	28

Tests of Within-Subjects Effects

Source		Type III Sum of Squares	df	F	Sig.
cue	Sphericity Assumed	633.071	1	10.314	.004
	Greenhouse-Geisser	633.071	1.000	10.314	.004
	Huynh-Feldt	633.071	1.000	10.314	.004
	Lower-bound	633.071	1.000	10.314	.004
cue * gp	Sphericity Assumed	107.166	1	1.746	.198
	Greenhouse-Geisser	107.166	1.000	1.746	.198
	Huynh-Feldt	107.166	1.000	1.746	.198
	Lower-bound	107.166	1.000	1.746	.198
Error(cue)	Sphericity Assumed	1595.934	26		
	Greenhouse-Geisser	1595.934	26.000		
	Huynh-Feldt	1595.934	26.000		
	Lower-bound	1595.934	26.000		

Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	666007.905	1	666007.905	1511.386	.000
gp	2006.357	1	2006.357	4.553	.042
Error	11457.172	26	440.660		

Naming objects

Velocity (PD patients VS Control subjects)

Independent Samples Test

		t	df	Sig. (2-tailed)	Mean Difference
$Walk_{naming\ object}$	Equal variances assumed	6.757	26	.000	42.704
	Equal variances not assumed	6.910	25.355	.000	42.704
$AV_{walk\text{-}naming\ objec}$	Equal variances assumed	4.524	26	.000	34.0330
	Equal variances not assumed	4.740	20.646	.000	34.0330

Stride length (PD patients VS Control subjects)

Independent Samples Test

		t	df	Sig. (2-tailed)	Mean Difference
$Walk_{naming\ object}$	Equal variances assumed	5.156	26	.000	29.9405915
	Equal variances not assumed	5.276	25.274	.000	29.9405915
$AV_{walk\text{-}naming\ object}$	Equal variances assumed	3.989	26	.000	23.4625761
	Equal variances not assumed	4.112	24.207	.000	23.4625761

Calculation

Velocity (PD patients VS Control subjects)

Independent Samples Test

		t	df	Sig. (2-tailed)	Mean Difference
$Walk_{calculation}$	Equal variances assumed	5.318	26	.000	37.6728205
	Equal variances not assumed	5.456	24.957	.000	37.6728205
$AV_{walk\text{-}calculation}$	Equal variances assumed	3.416	26	.002	27.6682906
	Equal variances not assumed	3.529	23.817	.002	27.6682906

Stride length (PD patients VS Control subjects)

Independent Samples Test

		t	df	Sig. (2-tailed)	Mean Difference
$Walk_{calculation}$	Equal variances assumed	4.398	26	.000	26.342595
	Equal variances not assumed	4.522	24.641	.000	26.342595
$AV_{walk\text{-}calculation}$	Equal variances assumed	3.220	26	.003	20.573080
	Equal variances not assumed	3.367	21.136	.003	20.573080

PD subjects (comparison between AV and non-cued conditions)

Velocity

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	$Walk_{naming\ object}$ - $AV_{walk\text{-}naming\ object}$	-5.055	14	.000
Pair 2	$Walk_{calculation}$ - $AV_{walk\text{-}calculation}$	-6.088	14	.000

Stride length

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	$Walk_{naming\ object}$ - $AV_{walk\text{-}naming\ object}$	-4.447	14	.001
Pair 2	$Walk_{calculation}$ - $AV_{walk\text{-}calculation}$	-6.331	14	.000

Control subjects (comparison between AV and non-cued conditions)

Velocity

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	$Walk_{naming\ object}$ - $AV_{walk\text{-}naming\ object}$	-2.338	12	.038
Pair 2	$Walk_{calculation}$ - $AV_{walk\text{-}calculation}$	-1.852	12	.089

Stride length

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	$Walk_{naming\ object}$ - $AV_{walk\text{-}naming\ object}$	-1.970	12	.072
Pair 2	$Walk_{calculation}$ - $AV_{walk\text{-}calculation}$	-2.107	12	.057

The number of correct answers for cognitive tasks with/without AV cues in PD and control subjects

PD subjects

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	$Walk_{naming\ object}$	5.644444	15	1.0115732	.2611871
	$AV_{walk\text{-}naming\ object}$	5.58	15	1.244	.321
Pair 2	$Walk_{calculation}$	3.38	15	1.666	.430
	$AV_{walk\text{-}calculation}$	3.47	15	1.617	.418

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	$Walk_{naming\ object}$ - $AV_{walk\text{-}naming\ object}$	.216	14	.832
Pair 2	$Walk_{calculation}$ - $AV_{walk\text{-}calculation}$	-.308	14	.762

Control subjects

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	$Walk_{naming\ object}$	4.717949	13	1.0169504	.2820513
	$AV_{walk\text{-}naming\ object}$	4.54	13	.918	.255
Pair 2	$Walk_{calculation}$	3.33	13	.903	.250
	$AV_{walk\text{-}calculation}$	2.923077	13	.7724893	.2142500

Paired Samples Test

		t	df	Sig. (2-tailed)
Pair 1	$Walk_{naming\ object}$ - $AV_{walk\text{-}naming\ object}$	1.167	12	.266
Pair 2	$Walk_{calculation}$ - $AV_{walk\text{-}calculation}$	1.085	12	.299

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