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The effects of two different auditory stimuli on functional arm movement in persons with Parkinson's disease: a dual-task paradigm

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Objective: To examine, in a dual-task paradigm, the effect of auditory stimuli on people with Parkinson's disease.
Design: A counterbalanced repeated-measures design.
Setting: A motor control laboratory in a university setting.
Subjects: Twenty individuals with Parkinson's disease.
Experimental conditions: Each participant did two experiments (marching music experiment and weather forecast experiment). In each experiment, the participant performed an upper extremity functional task as the primary task and listened to an auditory stimulus (marching music or weather forecast) as the concurrent task. Each experiment had three conditions: listening to the auditory stimulus, ignoring the auditory stimulus and no auditory stimulus.
Main measures: Kinematic variables of arm movement, including movement time, peak velocity, deceleration time and number of movement units.
Results: We found that performances of the participants were similar across the three conditions for the marching music experiment, but were significantly different for the weather forecast experiment. The comparison of condition effects between the two experiments indicated that the effect of weather forecast was (marginally) significantly greater than that of marching music.
Conclusions: The results suggest that the type of auditory stimulus is important to the degree of interference with upper extremity performance in people with Parkinson's disease. Auditory stimuli that require semantic processing (e.g. weather forecast) may distract attention from the primary task, and thus cause a decline in performance.

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Introduction

One of the cardinal symptoms of Parkinson's disease is bradykinesia, which refers to difficulty with movement initiation and slowness in movement execution. The model of basal ganglia function proposes that movement becomes slow because of impaired internal cueing (preparatory neural activity) in the basal ganglia.[1] Therefore, two approaches have been suggested to compensate for this motor problem in Parkinson's disease: external sensory cueing and attentional strategy.

External sensory cueing may improve performance by replacing the impaired internal cueing.[2] Of the possible forms of sensory cueing, rhythmic auditory stimulation emitted by a metronome is a powerful means for people with Parkinson's disease to improve performance[3] in tasks such as finger tapping[4–6] and walking.[7–9]

Music, as well as a metronome, is a source of rhythm.[10] In the novel *Awakenings*,[11] the author describes the power of rhythmic music to temporarily restore the ability of several patients with motor blocks to move and even to dance. However, despite the vivid and persuasive description of music power in the novel, there is only one preliminary study that has showed an immediate, positive effect of music on gait in people with Parkinson's disease.[12]

In addition to external sensory cueing, the use of an attentional strategy may improve performance because consciously directing the attention toward tasks allows cortical mechanisms to override defective basal ganglia processes.[13–15] The critical role of attention in motor performance is also supported by research with a dual-task paradigm, which shows that performing two tasks simultaneously generally results in deteriorated performance.[16–21] Further, interference with the primary task in a dual-task model is mediated by instructions directing the participant's attention to either the primary or the concurrent task. Directing a participant's attention to the primary task rather than to the concurrent task improves performance of the primary task.[22]

Because daily life is filled with various sounds, it is important to determine whether these sounds act as external auditory cues that facilitate performance, or as distracters that divert attention from the primary task and thus hinder performance. We investigated two types of auditory stimuli: marching music and a weather forecast. Because people usually perform tasks while listening to background auditory stimuli (e.g. music, conversations or ambient noise), we designed this study to have a dual-task paradigm in which the participants performed an upper extremity functional task as the primary task and listened to an auditory stimulus as the concurrent task. The participants were further requested to either listen to or ignore the sound while doing the primary task.

Methods

Participants

We enrolled a sample of convenience composed of 20 people with Parkinson's disease. The study was approved by our University Hospital Institutional Review Board, and all participants signed the informed consent before the experiment began. To be included, participants had to meet the following criteria: (1) diagnosed with idiopathic Parkinson's disease, (2) between 40 and 75 years old, (3) stable medication usage, (4) normal or corrected-to-normal vision and hearing, (5) neither a history of neurological conditions other than Parkinson's disease nor any musculoskeletal disorders affecting arm movement, and (6) able to follow the instructions for the experiment. The Hoehn and Yahr Scale[23] (range 1–5) was used to evaluate the severity of Parkinson's disease: 1 means mild and 5 means severe.

Design and procedures

We used a counterbalanced repeated-measures design.[24] Each participant was randomly assigned to either the marching music or the weather forecast experiment first and to the other experiment second (Figure 1). For each experiment, participants were randomly assigned to one of three experimental sequences: ABC, BCA and CAB. The letter represents the three experimental conditions: (A) control: no auditory stimulus, (B) listening to the auditory stimulus, and (C) ignoring the auditory stimulus.

Upon arriving at the motion analysis lab, the participant sat at a table with their dominant hand resting at the starting position, which was

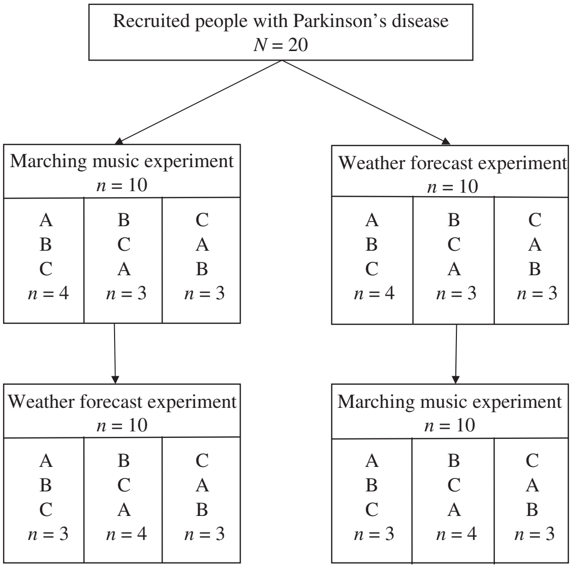

Figure 1 Flowchart of the study participants and experimental groups. For each experiment, participants were randomly assigned to one of three experimental sequences: ABC, BCA or CAB. A, no-sound condition; B, listening-to-the-sound condition; C, ignoring-the-sound condition.

located directly in line with the shoulder. A small, empty bowl (10.5 cm in diameter, 5.2 cm high) and a big soup plate (17.5 cm in diameter, 5.5 cm high) filled with beans were placed in front of the participant, with the small bowl closer to the participant's body. The experimental task required the participant to reach with a spoon for the beans in the soup plate, scoop up the beans, and transport them back and into the bowl.[25] We controlled the distance between the soup plate and bowl by marking the table and placing the soup plate and bowl on the same markings for each test.

Excerpts of marching music (the first 30 seconds of the 'Stars and Stripes Forever' by John Philip Sousa, composed in 2/2 meter, 96–100 beats per minute) and a weather forecast (the first 30 seconds randomly recorded from one morning news report) were used as auditory stimuli. The volume of the auditory stimuli was checked using a volume meter. There was no significant difference in volume between these two ($t = 0.31$, $P = 0.80$): mean volume over the 30 seconds was 62.4 dB (SD = 3.25) for the marching music and 67.4 dB (SD = 4.22) for the weather forecast.

For the 'no-sound' condition, there was no auditory stimulus, and the participant was asked to do the task as they would normally do it. For the 'listening-to-the-sound' condition there was either marching music or a weather forecast, and the participant was asked to listen attentively while doing the task. For the 'ignore-the-sound' condition there was an auditory stimulus, but the participant was asked to ignore the sound and just do the task.

All participants performed, at their own pace, two practice trials and five test trials in each condition. Only the test trials were used for kinematic analysis. The participants were instructed not to drop any beans when transporting them back to the bowl. If beans were dropped, the trial was discarded and then redone. All participants did the task successfully without apparent tremor hindering their performance. Following each trial, participants were asked to rate the manipulation check.

Measures

To understand whether the participant had followed the specific instructions on listening to or ignoring the auditory stimulus when performing the task, a manipulation check was used immediately after each trial. The participant was asked to use a five-point Likert scale (1 = none of the time, 2 = a little of the time, 3 = some of the time, 4 = most of the time, and 5 = all of the time) to answer questions: 'While you did these things, how much did you pay attention to: (a) the task, and (b) the marching music (or the weather forecast)?'

A three-dimensional ultrasonic measuring system (CMS-HS; Zebris Medical GmbH, Isny, Germany) was used to collect movement kinematics. The CMS-HS uses microphone markers that receive ultrasonic signals from a fixed set of transmitters in a measuring unit. One marker was attached to the radial styloid of the participant's dominant hand to record arm movement. The position of the marker over time was sampled by the system at a frequency of 50 Hz; the spatial resolution was 0.085 mm. After being collected, the data were stored for off-line analysis.

The three-dimensional position data were filtered using a non-parametric regression method with kernel estimates of order $(v+4)$.[26] The bandwidths for data smoothing were 50 ms for the position signal and 70 ms for the velocity signal.[27] For the test trial, reach movement was analysed from the first point in time when the hand left the starting position (speed >5 mm/s) to the last point in time when the hand stopped to scoop the food (speed <5 mm/s). The following kinematic variables were included as dependent variables: movement time, amplitude of peak velocity, deceleration time and number of movement units. Movement time is the duration of execution of movement. A faster movement would have a shorter movement time.[28] Peak velocity is the highest instantaneous velocity during the movement. A forceful movement would have higher peak velocity.[29] When the hand reaches for a target it generally first accelerates toward the target and then decelerates to change the direction or correct the trajectory.[30] Deceleration time is believed to be used to process feedback information and to adjust movement trajectory.[31] A more on-line controlled movement would have a longer deceleration time. A movement unit consists of one acceleration phase and one deceleration phase.[32] A smooth and efficient movement would have only one change in the direction of the forces and, therefore, one movement unit.[33]

Statistical analysis

To understand how the participants distributed their attention when doing the experimental tasks, non-parametric statistical tests (the Wilcoxon signed-ranks test and Friedman test) were computed using the scores of the manipulation check. In addition, to obtain the condition effect on movement kinematics, first, a 3 (sequence: ABC versus BCA versus CAB) $\times$ 3 (order: first versus second versus third presented) mixed analysis of variance (ANOVA) was done separately for the two experiments. In a sequence-by-order analysis, the condition effect was embedded in the sequence-by-order interaction.[24] Such an analysis removed the confounding effects of sequence and order (e.g. practice or fatigue effect) from the error term, and thus was considered to be more sensitive than a common one-way ANOVA with the repeated factor of condition. Omnibus *F*s derived from the 3×3 mixed ANOVA told us whether there were any statistically significant differences between the three conditions (non-directional).

Second, contrast weights numerically reflecting the trend of performance were assigned and included the numbers -1, 0, and $+1$. The focused *F* for our contrast analysis was computed using the formula $F_{\text{contrast}} = (r^2)\ (F_{\text{omnibus}} * df_{\text{numerator}})$, where r^2 is the square of the correlation between the contrast weights and the residual means.[34] Finally, focused *F* was used to calculate effect size *r* using the formula $r = [F_{\text{contrast}}/(F_{\text{contrast}} + df_{\text{denominator}})]^{1/2}$. Effect size indicates the magnitude of the effect and is free from sample-size influence. An *r* of 0.10 indicates a small effect, of 0.30 a moderate effect, and of 0.50 a large effect.[35]

To understand whether the effect of the marching music was significantly different from that of the weather forecast, we compared the derived effect sizes from the two experiments using previously described meta-analytic procedures.[36]

Results

The participants consisted of 11 women and 9 men with a mean age of 66.47 years (SD $=$ 6.26) and a mean duration of Parkinson's disease of 3.79 years (SD $=$ 2.55). Their Hoehn and Yahr stages ranged from 1 to 3 (mode $=$ 2.5). All participants were right-handed.

In the marching music and weather forecast experiments, the results of the Wilcoxon signed-ranks test indicated that significantly more attention was paid to the auditory stimulus in the listening-to-the-sound than in the ignoring-the-sound condition, which suggested that the participants perceived that they had directed their attention as requested (Table 1).

The results of the Friedman test indicated that, in both experiments, significantly more attention was directed toward the task in the no-sound condition than in the ignoring-the-sound condition, and that least attention was directed toward the task in the listening-to-the-sound condition.

In the marching music experiment, the condition effect was non-significant for movement

Table 1 Results for the manipulation check

	Condition			Significance testing
	Listening to the sound	Ignoring the sound	No sound	
Marching music experiment				
Attention to sound	4.23 ± 0.64	2.63 ± 1.16	–	-3.668**
Attention to task	4.26 ± 0.69	4.48 ± 0.58	4.73 ± 0.48	9.17*
Weather forecast experiment				
Attention to sound	4.19 ± 0.72	2.68 ± 0.97	–	-3.63**
Attention to task	4.02 ± 0.85	4.45 ± 0.56	4.60 ± 0.54	11.49*

Values are means ± SD. The manipulation check (range 1–5) is used to evaluate how much attention the participant paid to the task and the auditory stimulation: 1 means none of the time and 5 means all of the time.

*$Z = (P < 0.01)$; **$\chi^2 = (P < 0.0001)$.

Table 2 Results for the marching music and weather forecast experiments

	Condition			Effect size r
	Listening-to-the-sound	Ignoring-the-sound	No-sound	
Marching music experiment				
Movement time (s)	0.85 ± 0.24	0.83 ± 0.20	0.84 ± 0.20	0.04
Peak velocity (mm/s)	509.53 ± 139.47	517.52 ± 137.09	527.64 ± 161.75	0.30
Deceleration time (s)	0.44 ± 0.14	0.44 ± 0.12	0.44 ± 0.12	0.003
Number of movement units	3.39 ± 2.93	3.24 ± 2.51	3.31 ± 2.31	0.01
Weather forecast experiment				
Movement time (s)	0.88 ± 0.24	0.84 ± 0.21	0.84 ± 0.22	0.55*
Peak velocity (mm/s)	493.23 ± 129.30	511.79 ± 133.13	527.14 ± 139.42	0.70*
Deceleration time (s)	0.48 ± 0.16	0.45 ± 0.12	0.44 ± 0.12	0.56*
Number of movement units	3.89 ± 2.85	3.47 ± 2.44	3.33 ± 2.79	0.49*

Values are means ± SD.

*$P < 0.05$.

time (focused $F(1, 34) = 0.03$, $r = 0.04$, $P = 0.4325$), peak velocity ($F = 1.71$, $r = 0.30$, $P = 0.1$), deceleration time ($F = 0.00013$, $r = 0.003$, $P = 0.4960$), and number of movement units ($F = 0.004$, $r = 0.01$, $P = 0.4761$; Table 2).

However, the condition effect in the weather forecast experiment was large and significant for movement time (focused $F(1, 34) = 7.53$, $r = 0.55$, $P = 0.0048$), peak velocity ($F = 15.94$, $r = 0.70$, $P = 0.0005$), deceleration time ($F = 7.70$, $r = 0.56$, $P = 0.0044$) and number of movement units ($F = 5.47$, $r = 0.49$, $P = 0.0125$). The movement time was longer, peak velocity lower, deceleration time longer and movement units more when participants were instructed to listen to the weather forecast than when they were instructed to ignore them or when no weather forecast was provided. Their peak velocity was highest and number of movement units was smallest when no weather forecast was provided.

The effect of the weather forecast was significantly larger than that of the marching music for movement time ($Z = 1.71$, $P = 0.0436$) and deceleration time ($Z = 1.84$, $P = 0.0329$). The difference in effect between the weather forecast and marching music approached significance for peak velocity ($Z = 1.63$, $P = 0.0516$) and number of movement units ($Z = 1.54$, $P = 0.0618$).

Discussion

We investigated the effects of two different auditory stimuli (marching music and a weather forecast) on functional arm movement and whether directing attention to the auditory stimuli or to the primary task affects performance in people with Parkinson's disease. We found that the marching music did not significantly affect movement, but that the weather forecast did, suggesting that the type of auditory stimulus is important to the degree of interference with functional arm movement in people with Parkinson's disease. The degree of interference produced by the weather forecast can further be manipulated by instructions directing the participants to listen to or ignore it. Motor performance was slower, less forceful, more on-line controlled and less efficient when they listened to the weather forecast than when they ignored it.

We chose the marching music because of its strong rhythm. However, its rhythm seems not to have affected the participants' movement kinematics, including movement time. The movement time of our participants in the marching music experiment was around 0.84 seconds: a rate of 1.2 per second. The tempo of the marching music was 96 to 100 beats per minute: a rate of about 1.6 beats per second. The movement rate of our participants was slower than the tempo of the marching music. The non-significant difference in movement time between the conditions in the marching music experiment fails to support the notion that music has a beneficial effect on movement in people with Parkinson's disease.

There may be some reasons for the small and non-significant effect of marching music. One is that although the marching music distracted the participants' attention from the task, as suggested by the manipulation check, the inhibitory effect of this distraction was offset by the facilitative effect of the music's rhythm. Second, listening to musical passages globally or holistically apparently imposes a smaller attentional demand than does listening with focused attention to any particular instrument, or by listening selectively and tracking the part played by a single instrument.[37] It is likely that our participants in the listening-to-the-sound condition listened globally or holistically to the marching music rather than focusing on any particular aspect of it. Therefore, the attentional load of the marching music was not substantial enough to adversely affect their performance of the primary task.

In addition, the observed effects of marching music might be related to the experimental task we chose. Rhythmic auditory stimulation affects performance in tasks such as finger tapping[4–6] and walking.[7–9] Although our marching music provided a strong rhythm, its effect might not be evident because our experimental task, the food transfer movement, is not as rhythmic as finger tapping or walking.

On the other hand, the large and significant effects of the weather forecast suggest that listening to the forecast interfered with the participants' performance. Listening required not only auditory attention, but also complex cognitive functions, such as semantic processing and working memory. Therefore, the mental activity required for executing the functional task and listening to the weather forecast simultaneously exceeded the participants' available attentional resource capacity, resulting in a diminished performance of the primary task.

The results of the weather forecast experiment are in line with the findings of the other studies that used cognitive concurrent tasks.[17–21] Listening to the weather forecast required semantic processing and is in some way similar to the language concurrent task used in another study.[21] It should be noted, however, that while the language task in that study involved motor responses (e.g. list the words beginning with a specific letter), our participants did not have to give a motor response for the concurrent task. Our results suggest that merely redirecting cognitive attention from the primary task negatively affects its performance. In addition, while other studies used contrived experimental upper extremity tasks[17,18] or gait tasks,[19–21] our study used a functional upper extremity task and concurrent tasks commonly encountered in daily life. Therefore, our study provides ecologically relatively more valid findings than does the previous research.

Moreover, we found that, in situations with an attention-demanding auditory stimulus, performance of the primary task can be influenced by directing the participants to pay attention to the sound or to ignore it. Motor performance of the primary task was better when the participants ignored the auditory stimulus than when they listened to it. Our findings correspond to those in a previous report[22] in which people with Parkinson's disease walked faster and with longer strides when they were instructed to pay attention to their walking rather than to the concurrent task (i.e. carrying a tray of glasses). The required attention for optimal task performance also suggests the importance of the conscious control of movements for people with Parkinson's disease.

This study had some limitations. In the present study, the participants needed a certain level of cognitive ability to direct their attention selectively as requested by the experiment's instructions. Although the rating of the manipulation check indicated that the participants had followed our instructions, future research should test the cognitive function directly and examine whether participants' cognitive function mediates the dual-task interference. In addition, future research should include a larger sample size to get a more reliable estimate of the effect of auditory stimuli and should include age-matched controls to determine whether the effect found in the present study is specific to people with Parkinson's disease.

Regarding the non-significant findings in the marching music experiment, it is important for future research to disentangle the facilitative effect of music rhythm from the inhibitory effect of depriving attention. In the present study, the participants were asked to listen to or ignore the music. Their motor performances might have been different had they been given no specific instructions on where to direct their attention. It is possible that without specific attentional instructions, people with Parkinson's disease are able to both enjoy the music and benefit from its rhythm. In addition, future research may include an experimental task that requires rhythmic arm movement to determine whether the effect of marching music is larger in a more rhythmic task.

Our findings have implications for training people with mild to moderate Parkinson's disease. Because our daily life is usually filled with various auditory stimuli, it is important to be aware of their possible influence. The results of the present study suggest that while rhythmic instrumental music has a minimal effect on performance, auditory stimuli that require a certain amount of cognitive processing (e.g. news reports and conversations) are likely to divert listeners' attention from executing the task and thus negatively affect their performance. In the case of distracting stimuli, eliminating the sound is important for fast, forceful and efficient task performance. When distracting auditory stimuli are unavoidable, however, people with the goal of fast and efficient task performance should use the strategy of ignoring the auditory stimuli and focus their attention on doing the task.

Clinical messages

- Auditory stimuli that require semantic processing (e.g. weather forecast) may distract attention from the primary task, thus causing a decline in performance.
- Eliminating the sound or focusing attention on doing the task helps people with Parkinson's disease have fast, forceful and efficient task performance.

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Competing interests

None declared.

References

1 Morris ME, Iansek R. Characteristics of motor disturbance in Parkinson's disease and strategies for movement rehabilitation. *Hum Mov Sci* 1996; **15**: 649–69.

2 Cunnington R, Iansek R, Bradshaw JL, Phillips JG. Movement-related potentials in Parkinson's disease: presence and predictability of temporal and spatial cues. *Brain* 1995; **118**: 935–50.

3 Thaut MH, Kenyon GP, Schauer MG, McIntosh GC. The connection between rhythmicity and brain function. *IEEE Eng Med Biol* 1999; **18**: 101–108.

4 Freeman JS, Cody FWJ, Schady W. The influence of external timing cues upon the rhythm of voluntary movements in Parkinson's disease. *J Neurol Neurosurg Psychiatry* 1993; **56**: 1078–84.
5 Georgiou N, Bradshaw JL, Inasek R, Phillips JG, Mattingley JG, Bradshaw JA. An evaluation of the role of internal cues in the pathogenesis of parkinsonian hypokinesia. *Brain* 1993; **116**: 1575–87.
6 Georgiou N, Bradshaw JL, Inasek R, Phillips JG, Mattingley JG, Bradshaw JA. Reduction in external cues and movement sequencing in Parkinson's disease. *J Neurol Neurosurg Psychiatry* 1994; **57**: 368–70.
7 Morris ME, Iansek R, Matyas TA, Summers JJ. Ability to modulate walking cadence remains intact in Parkinson's disease. *J Neurol Neurosurg Psychiatry* 1994; **57**: 1532–34.
8 Thaut MH, McIntosh GC, Rice RR, Miller RA, Rathbun J, Braut JM. Rhythmic auditory stimulation in gait training for Parkinson's disease patients. *Mov Disord* 1996; **11**: 193–200.
9 McIntosh GC, Brown SH, Rice RR, Thaut MH. Rhythmic auditory-motor facilitation of gait patterns in patients with Parkinson's disease. *J Neurol Neurosurg Psychiatry* 1997; **62**: 22–26.
10 Thaut MH. The future of music in therapy and medicine. *Ann N Y Acad Sci* 2005; **1060**: 303–308.
11 Sacks O. *Awakenings*. Harper Perennial, 1990.
12 Eni G. Gait improvement in Parkinsonism: the use of rhythmic music. *Int J Rehabil Res* 1988; **11**: 272–74.
13 Cunnington R, Iansek R, Bradshaw JL. Movement-related potentials in Parkinson's disease: external cues and attentional strategy. *Mov Disord* 1999; **14**: 63–68.
14 Morris ME, Iansek R, Matyas TA, Summers JJ. Stride length regulation in Parkinson's disease normalization strategies and underlying mechanisms. *Brain* 1996; **119**: 551–68.
15 Behrman AL, Teitelbaum P, Cauraugh JH. Verbal instructional sets to normalise the temporal and spatial gait variables in Parkinson's disease. *J Neurol Neurosurg Psychiatry* 1998; **65**: 580–82.
16 Wu T, Hallett M. Neural correlates of dual task performance in patients with Parkinson's disease. *J Neural Neurosurg Psychiatry* 2008; **79**: 760–66.
17 Dalrymple-Alford JC, Kalders AS, Jones RD, Watson RW. A central executive deficit in patients with Parkinson's disease. *J Neurol Neurosurg Psychiatry* 1994; **57**: 360–67.
18 Oliveira RM, Gurd JM, Nixon P, Marshall JC, Passingham RE. Hypometria in Parkinson's disease: automatic versus controlled processing. *Mov Disord* 1998; **13**: 422–27.
19 O'Shea S, Morris ME, Iansek R. Dual task interference during gait in people with Parkinson disease: effects of motor versus cognitive secondary tasks. *Phys Ther* 2002; **82**: 888–97.
20 Bond JM, Morris M. Goal-directed secondary motor tasks: their effects on gait in subject with Parkinson disease. *Arch Phys Med Rehabil* 2000; **81**: 110–16.
21 Galletly R, Brauer SG. Does the type of concurrent task affect preferred and cued gait in people with Parkinson's disease? *Aust J Physiother* 2005; **51**: 175–80.
22 Canning CG. The effect of directing attention during walking under dual-task conditions in Parkinson's disease. *Parkinsonism Relat Disord* 2005; **11**: 95–99.
23 Hoehn MM, Yahr MD. Parkinsonism: onset, progression and mortality. *Neurology* 1967; **17**: 427–42.
24 Rosenthal R, Rosnow RL. *Essentials of behavioral research: Methods and data analysis*, second edition. New York, McGraw-Hill, 1991.
25 Ma H-I, Hwang W-J, Chen-Sea M-J, Sheu C-F. Handle size as a task constraint in spoon-use movement in patients with Parkinson's disease. *Clin Rehabil* 2008; **22**: 520–28.
26 Marquardt C, Mai N. A computational procedure for movement analysis in handwriting. *J Neurosci Methods* 1994; **52**: 39–45.
27 Marquardt C. 3DAwin. V 1.0. 3-Dimensional movement analysis. Munich: *MedCom* 2000.
28 Nelson WL. Physical principles for economies of skilled movements. *Biol Cybern* 1983; **46**: 135–47.
29 Flowers K. Ballistic and corrective movements on an aiming task: intention tremor and parkinsonian movement disorders compared. *Neurology* 1975; **25**: 413–21.
30 Georgopoulos AP. On reaching. *Annu Rev Neurosci* 1986; **9**: 147–70.
31 Arbib MA. Schemas for the temporal organization of behaviour. *Hum Neurobiol* 1985; **4**: 63–72.
32 Brooks VB, Cooke JD, Thomas JS. The continuity of movements. In Stein RB, Pearson KG, Smith RS, Redford JB. eds. *Control of posture and locomotion*. New York, Plenum Press, 1973, 257–72.
33 Hogan N. An organizing principle for a class of voluntary movements. *J Neurosci* 1984; **4**: 2745–54.

34 Rosenthal R, Rosnow RL, Rubin DB. *Contrasts and effect sizes in behavioral research: A correlational approach*. New York, Cambridge University Press, 2000.

35 Cohen J. *Statistical power analysis for the behavioral sciences*, second edition. Hillsdale, NJ, Lawrence Erlbaum, 1988.

36 Rosenthal R. *Meta-analytic procedures for social research*, revised edition. Newbury Park, CA, Sage, 1991.

37 Janata P, Tillmann B, Bharucha JJ. Listening to polyphonic music recruits domain-general attention and working memory circuits. *Cogn Affect Behav Neurosci* 2002; **2**: 121–40.