Dual-Task Study of Cognitive and Postural Interference in Patients with Vestibular Disorders

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Objective: To study the relation between a mental task (silent backward counting) and posture in patients with vestibular deficits and to study the role of attention.

Study Design: In Experiment 1, postural sway and performance on the mental task were measured in a $2 \times 2$ dual-task design (with or without mental task and calf stimulation). In Experiment 2 a similar design was used, the only difference being that during trials without the mental task, patients were instructed to focus on their balance and provide a rating of body sway.

Setting: The study was carried out at a tertiary referral outpatient audiology clinic.

Patients: The first experiment included 20 patients and the second experiment 10 patients seen consecutively at the clinic on account of vertigo and dizziness.

Main Outcome Measures: Performance on a mental task and on a force platform for measurement of anterior-posterior and lateral sway.

Results: Results showed no effect of the balance conditions on the cognitive task in Experiments 1 and 2. The mental task led to less body sway during calf stimulation in Experiment 1. In Experiment 2, when attention was focused on body sway, an opposite result was found, with more sway during the mental task in the condition of no calf stimulation.

Conclusions: Control of body sway and cognitive functioning are to some extent related, most likely because of postural stability being prioritized in dual-task conditions.

Key Words: Posture—Attention—Cognition—Mental task—Vestibular test—Serial sevens test.

Control of posture can be a demanding task for patients with vestibular disorder, in particular when attention is captured by cognitive activity. The interaction between balancing and cognitive activity is typically investigated in dual-task designs, in which normal subjects perform cognitive and postural tasks simultaneously (1–3). Similar research designs have also been applied to patients with vestibular disorder (4,5), patients with Alzheimer’s disease (6), patients after lower limb amputation (7), and older adults with or without a history of falls (8–11). The literature on the effects of cognitive tasks on balance performance shows fairly consistently that the balance of older subjects is more affected than that of younger subjects when they concurrently perform a cognitive task (8,12). The results of studies on dual-task interference in patients with vestibular deficits are, however, less clear. In some studies, a deterioration in mental task performance has been found (4,5,13), whereas in other studies, no effect on cognitive task performance has been established (9). Measures of sway have been found to either increase (4) or even slightly decrease (5) as a consequence of performing a cognitive task. One potentially important factor in previous studies has been whether verbal or nonverbal mental tasks have been used. There is evidence to suggest that verbal responses affect balance (5), and hence we used silent counting as a mental task in the present studies. The first experiment reported was designed, first, to assess the effects of a balance task, in which posture was perturbed by stimulation of the calf muscles, on the performance of a silent mental arithmetic task (backward silent counting). Second, the effects of the mental task on balance functioning were assessed. There were four conditions in all: (1) standing on a platform with no calf stimulation, (2) standing on a platform with no calf stimulation and simultaneously counting backward silently, (3) standing on a platform with calf stimulation to perturb balance, and (4) standing on a platform with calf stimulation and simultaneously counting backward silently. A second experiment was designed to control for the effects of focused attention on balance. The same conditions as in Experiment 1 were repeated, with the additional instruction to monitor balance and make a rating of postural perturbation on Conditions 1 and 3.
SUBJECTS AND METHODS

Experiment 1

In this experiment, we replicated the procedure from a previous experiment with healthy volunteers (14). The principal aim was to investigate the extent to which balance control and cognitive activity are related in patients with vestibular deficits.

Subjects

The subjects were 20 patients (mean age 56.2 years, SD 11.6, 10 women), with a history of balance dysfunction but without any other central or peripheral dysfunction. All currently described experiencing dizziness or unsteadiness. Vestibular disorder was established in all patients based on clinical history, neuro-otologic testing (e.g., audiogram, caloric, electronystagmographic recording of eye movements). The diagnoses were mixed, including clear vestibular dysfunction (e.g., benign paroxysmal positional vertigo, Ménière’s Disease) and/or less specific tension-related dizziness and unsteadiness. All had been referred for balance symptoms/dizziness, and their mean duration of symptoms was 4.7 years (SD 11.6).

Postural sway measurement

Body sway was measured by a force platform equipped with strain gauges from which center of pressure was detected (15). The system was attached to an IBM compatible computer and driven by a program that generates a measure of body sway velocity (torque variance ([Nm/mass]^2*1000) (Poston, Department of Otoroñalaryngology, University Hospital, Lund, Sweden). Torque variance is proportional to the energy used by the subject to maintain upright posture (16). Changes in center point of force actuated by the feet on the platform were digitized and sampled at 10 Hz. Measures of anterior-posterior and lateral sway were obtained. All sway measures were square root transformed before analysis.

The patients were tested while standing on the force platform (height 24 cm, diameter 49 cm), facing forward with extended knees and feet at a 30° angle, arms positioned along the sides and with eyes closed (blindfolded). On half of the trials, body sway was evoked by applying vibratory stimulation to the gastrocnemius muscles of both legs. The vibrators were cylinder shaped and were held in place by straps around the calf muscles. Vibration stimulation was delivered at the frequency of 80 Hz (1.0-mm amplitude) with an effect of 1040 mW. Each vibratory stimulus was controlled by letting the patients perform a rating task silently while standing on the platform (e.g., not during the mental task). The task consisted of reporting a rating of how much the balance had been affected while standing on the platform (e.g., each trial). This numerical rating (not at all affected = 0, much affected = 5) was obtained immediately after each trial and was made both after vibratory calf stimulation and on the trials without vibratory stimulation.

Mental task

The mental task condition was silent backward counting in steps of seven as fast and as accurately as possible for 20s, beginning with randomly selected numbers. After each trial, the subjects were asked their final number which was later checked for accuracy. No feedback on performance was given during the testing. The subjects were first instructed how to do the counting-backward task and were corrected until it was mastered.

Design and procedure

Trials were blocked by condition with four counterbalanced conditions: just standing without vibration, silent counting without vibration, vibration only, and finally vibration and silent counting. Each condition consisted of five trials, with a short rest between each block of trials.

Blood pressure and heart rate data were obtained before and after the actual testing (Omron, M4, Japan). Because no changes were obtained, these data are not reported. Self-report questionnaires were administered after the test procedures, including the Dizziness Handicap Inventory (DHI) (17) and the Perceived Stress Scale (PSS) (18). The mean score on the DHI for the total patient group (n = 30) was 35.7 (SD 15.7), and on the PSS a mean of 25.6 (SD 7.58) was found. The two scores were significantly correlated: \( r = 0.56, p < 0.01 \).

Experiment 2

In this experiment, an attempt was made to control the attention given to the balance task. An identical procedure was used in our previous experiment with healthy young participants (14). Because arousal has been linked to the performance of both cognitive and postural tasks (19), we predicted a weaker dual-task effect on balance (e.g., less improved sway). Because the performance of the cognitive task in single and dual-task conditions did not involve any manipulation of attention, we made no prediction of the outcome apart from the commonly expected dual-task decrement (not found in Experiment 1).

Subjects

Experiment 2 included 10 additional patients (mean age 52.2 years, SD 0.01, 5 women). Similar diagnoses were included as in Experiment 1. The mean duration of symptoms was 10 years (SD 9.8), and all patients had been referred for balance symptoms/dizziness.

Design and procedure

An identical procedure as in Experiment 1 was endorsed, the only difference being that attention to balance and the vibratory stimuli was controlled by letting the patients perform a rating task silently while standing on the platform (e.g., not during the mental task). The task consisted of reporting a rating of how much the balance had been affected while standing on the platform (e.g., each trial). This numerical rating (not all affected = 0, much affected = 5) was obtained immediately after each trial and was made both after vibratory calf stimulation and on the trials without vibratory stimulation.

RESULTS

Experiment 1

Mean results on the backward silent counting task (in multiples of seven) are presented in Table 1. No dual-task effect was found.

Data on anterior-posterior and lateral sway are presented in Figure 1. Analysis of the anterior-posterior sway data with Wilcoxon’s signed rank test revealed a significant effect of doing the mental task while receiving vibratory calf stimulation compared with the calf stimulation only (Z = 3.10, \( p < 0.01 \)). The patients swayed less when doing the mental task (Fig. 1). The effect was not statistically significant for the conditions

<table>
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<th>Table 1. Mean multiples of seven subtracted as a function of standing on the platform only and dual-task (vibratory calf stimulation)</th>
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<td>Counting only (SD)</td>
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<td>Experiment 1 (n = 20)</td>
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without calf stimulation, i.e., when silent counting only was compared with standing on the platform.

The effect of vibratory calf stimulation was evident both without the mental task ($Z = -3.28, p < 0.001$) and while doing the mental task ($Z = -3.36, p < 0.001$). As expected, patients swayed more when stimulated.

Analysis of lateral sway data showed an effect of silent counting compared with no stimulation while receiving the calf stimulation ($Z = -2.56, p < 0.01$). Patients swayed less laterally while doing the mental task. Again, there was no effect of the mental task when calf stimulation was not applied.

The effect of vibratory calf stimulation was significant without the mental task (e.g., no stimulation versus stimulation only ($Z = 3.11, p < 0.01$) but not with (e.g., silent counting versus silent counting + stimulation).

Experiment 2

As in Experiment 1, no statistically significant difference was found between single and dual-task conditions on the silent backward counting task (Table 1).

In Experiment 2, the effect of silent counting was compared with focused attention on the balance. Mean rating of how balance was affected (pooled across trials within conditions) showed a mean rating of 3.44 (SD 1.6) after calf stimulation and a mean of 1.64 (SD 0.54) after just standing on the platform. The difference was significant by means of paired t test ($t(9) = 3.2, p < 0.05$).

Analysis of the sway data in Experiment 2 (Fig. 2) with Wilcoxon’s signed rank test showed that the patients swayed more in an anterior-posterior direction while doing the silent counting compared with focused attention without any calf stimulation ($Z = -1.99, p < 0.05$). When calf stimulation was applied, no statistically significant difference emerged.

The effect of calf stimulation was not significant during the mental task, whereas an effect of calf stimulation was found between the two conditions when the mental task was applied ($Z = 5.8, p < 0.001$).

Analysis of lateral sway showed no statistically significant effect of the mental task. The effect of calf stimulation was significant during focused attention ($Z = -3.91, p < 0.01$) and marginally during the mental task ($Z = -2.2, p = 0.06$).

DISCUSSION

Experiment 1

This experiment suggests that patients do not prioritize mental tasks when their balance is challenged. No dual-task effect was found on the cognitive measure, suggesting that a "posture-first" principle (9) might have been applicable because the balance task could be prioritized in all conditions (e.g., even without vibratory stimulation). In support of this interpretation is the markedly inferior performance compared with the results from our previous study on healthy young adults (with corresponding multiples of 7: 4.21 and 3.52 (Study 1), and 3.77 and 3.9 (Study 2) (14). By contrast, dual-task effects were found on the balance measure, but in the opposite direction than could be expected from the literature on dual-task performance in older adults. Because arousal...
might have mediated this effect, a second experiment was designed in which we attempted to control for the role of attention directed to balance, more specifically arousal in comparison with the cognitive task. Instead of having the patients just stand on the platform, we asked them to provide an assessment of sway. We expected this to be a less arousing task, but still more demanding than just standing on the platform.

**Experiment 2**

In Experiment 2, we again failed to find any dual-task decrement on the cognitive task.

In comparison with Experiment 1, an opposite finding was found in that a dual-task effect was found on the trials without vibratory calf stimulation. Here, sway increased when the patients counted backward.

**General discussion**

The findings in this study again indicate that control of body sway and cognitive functioning are not independent systems. The most obvious interpretation is that posture is prioritized (e.g., the posture-first principle). However, no dual-task effect was found on the cognitive task, which we interpret as showing that the balance task was difficult for the patients even in the no-vibration condition. Another alternative is that the cognitive task was not sensitive enough for dual-task effects. Against this interpretation was the finding of a dual-task effect on the cognitive task in our previous identical study with normal subjects (14). However, Yardley et al. (1) found no dual-task effect, using the same cognitive task in normal subjects. In other studies, again with the same cognitive task, dual-task decrement has been found after passive rotation in the dark in healthy subjects (20) and as a result of a concurrent orientation monitoring task in both healthy and balance-impaired subjects (13). It can, of course, be debated whether the cognitive task used in the current study was demanding enough. Unfortunately, the literature on dual-task decrement in patients with vestibular dysfunction does not provide a clear answer. In several studies, reaction times have been used that are different from the type of elaborative “mental load” task used in the current study. Typically, reaction times are slower in dual-task conditions (10,12,21), which could be interpreted as showing that the baseline condition (e.g., stable platform) does not compete with the mental task in terms of resources. Unfortunately, in other previous studies in which alternative cognitive tasks have been used, these tasks have often been verbal (9), for example, random digit generation (8).

The balance data obtained in the two experiments were relatively simple, and a reservation must be made that our postural sway measures were limited and that other alternative parameters (e.g., center of pressure variability) might have yielded different results. However, our results are not in conflict with previously published results. Maylor and Wing (8) observed that for younger participants, dual-task performance resulted in decreased sway, whereas for the older participants, sway increased in the dual-task condition. In the study by Yardley et al. (5) with patients having vestibular dysfunction, equilibrium scores (e.g., computerized dynamic posturography) increased during a high mental load task (categorization of a numerical stimulus). Age could therefore be an influential factor. In the present experiments, participants were slightly older than in the study by Yardley et al (5), (46.6 years). Future studies need to include age as a factor in dual-task studies on patients with vestibular deficits.

Because this study was preceded by an identical study on healthy young adults (14), the differences in outcome between the two studies might shed some light on the results. However, we are aware that age differences might render this comparison less feasible. In our previous study on healthy young adults, the results showed that balance perturbation led to decreased performance on the cognitive task in Experiment 1, but not in Experiment 2. In the current study, no effect on the cognitive task could be found (see above for discussion). In the previous study, mental task led to less body sway, as was the case in this study (Experiment 1 in both studies). However, in Experiment 2, there was a marked difference in that the focused attention manipulation resulted in a nonsignificant finding in healthy adults, whereas for the present patients with vestibular conditions, sway actually increased during the dual-task/balance perturbation condition.

In conclusion, the results of this study suggest that the performance of a silent mental arithmetic task (counting backward in multiples of seven) is not substantially impaired when balance is perturbed in patients with vestibular disorders. The effect of the cognitive task on sway was either to decrease sway (in comparison to standing only) or to increase sway (when the control condition included focused attention on sway). The role of cognitive manipulation on body sway should be studied further in mixed age samples, because older individuals with vestibular disorders are likely to differ from the middle-aged sample in the present studies.

**REFERENCES**


