

## LEARNING OF A NOVEL VISUO-POSTURAL CO-ORDINATION TASK IN ADULTS WITH MULTIPLE SCLEROSIS

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**Objective:** A behavioural study was conducted to investigate how cerebellar dysfunction associated with multiple sclerosis affects the ability to learn a novel visuo-postural co-ordination task.

**Design:** A prospective design, 2 group by 1 treatment (4 practice blocks).

**Subjects:** Ten patients with multiple sclerosis diagnosed with cerebellar ataxia and 10 age-matched healthy controls.

**Methods:** Participants stood over a dual force platform (ERBE Balance System) and performed visually guided lateral weight-shifting movements. The task required subjects to gradually transfer weight between sides while maintaining each foot's force vector within visually specified force constraints ranging from 0% to 100% of bodyweight with maximum allowed variation set to  $\pm 20\%$ . The time required to complete the task and the number of spatial errors (noted each time the foot's vector exceeded the  $\pm 20\%$  force constraint) were recorded. Training consisted of 3 blocks of 5 trials separated by 1-minute intervals and followed by 5 retention trials.

**Results and Conclusion:** Statistics revealed a significant decrease in movement time and spatial errors across trial blocks in both groups; however, the group with multiple sclerosis showed a limited and slower rate of performance improvement characterized by increased within- and between-subject variability. These findings may have important implications in the design of rehabilitation protocols for improving motor skill performance in adults with multiple sclerosis.

**Key words:** Posture, visual feedback, motor learning, multiple sclerosis.

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### INTRODUCTION

Multiple sclerosis (MS) is a progressive disease that causes demyelination of the nerve fibres in the central nervous system (CNS). Because the lack of myelin slows down the conduction of the action potential, this disease can have devastating effects on

motor behaviour (1). MS manifests itself primarily as impaired sensory and motor performance because the demyelination of both sensory and motor axons interferes with impulse conduction and therefore with sensory perception and proper motor co-ordination (2). Because of the variable distribution of demyelination throughout the CNS, people with MS experience a diversity of symptoms affecting motor and perceptual performance, ranging from poor balance, lack of co-ordination, reduced strength and sensation and visual acuity problems (3). The most commonly reported symptoms, however, are fatigue, tremor (postural and kinetic) and dysmetria (limb ataxia), which are attributed particularly to cerebellar dysfunction.

The cerebellum is the first CNS structure to be affected by the demyelination of the nerve fibres in MS, resulting in cerebellar limb ataxia and manifested by lack of co-ordination and control of limb movements (4). It also plays an integral role in the control of upright posture and locomotion (5) and therefore balance is one aspect of motor performance affected by cerebellar dysfunction in MS. This is manifested by postural and gait ataxia (6), although the patterns of postural ataxias may vary greatly among patients with MS (7). Clinical symptoms of balance disorder are associated with difficulty in moving from one position to another, sustaining an upright posture, and performing functional activities such as walking and turning (8). Balance impairments are mostly apparent in experimental conditions that require patients to respond to internally or externally generated perturbations of the centre of mass, rather than tests requiring them to maintain a steady stance without perturbations (8). It has been suggested that patients with MS may not appropriately select and modulate postural responses to unexpected balance perturbations due to sclerotic plaques often located at the cortical regions of the CNS (9, 10). The abnormal dynamic platform posturography scores reported by these studies suggest a possible vestibular dysfunction and/or a deficient integration of visual, vestibular and somatosensory information that is necessary to control posture.

Despite the wealth of experimental evidence pointing to the critical role of the cerebellum in practice-dependent motor learning (11–14), there is lack of scientific information addressing how cerebellar dysfunction associated with MS might affect motor learning and in particular visuo-motor learning. Nevertheless, experimental evidence addressing this aspect of performance come from patients with diagnosed cerebellar lesions showing that cerebellar damage can impair learning of several

motor tasks such as visuo-motor adaptation to prisms (15), adaptation of anticipatory muscle activity during catching (13, 16), learning of a sequence of key presses (17) and adaptation of the gain of ballistic arm movements (18). Cerebellar patients are also impaired in performing two tasks with visuo-spatial requirements simultaneously (19), while on the other hand, they are capable of substantially improving their motor performance of a complex motor task involving visuo-motor control of a tracing movement and the recall of memorized shapes (20).

Whereas it is well-reported that cerebellar damage affects error-based learning of several types of specific arm (13) and eye (21) movements, several studies have also addressed the role of the cerebellum in adaptation during posture and locomotion (14, 22–25). Cerebellar patients are compromised in learning novel sensorimotor (14) or visuomotor recalibrations of the locomotor trajectory (24), in scaling postural responses to known perturbation amplitudes (22), in shifting movement performance from an attentionally demanding (unpracticed) to a more automatic (practiced) state (25) and more generally, in adapting posture and locomotion through trial-and-error practice (5). It remains unclear, however, how cerebellar lesions commonly associated with MS influence the ability to visually guide dynamic postural tasks, and whether practice may help patients with MS diagnosed with cerebellar lesions acquire skills that require the coupling between visual information and posture. The present study is among the first attempts to examine performance and learning of visually guided postural adjustments in adults with this demyelinating disease. We have developed a visually guided lateral weight-shifting experimental paradigm to examine how patients with MS with cerebellar ataxia and age-matched controls learn to use visual response-produced feedback in order to control postural sway in accordance with visually specified force constraints.

## METHODS

### Participants

Ten patients with cerebellar ataxia due to clinically proven MS (age  $35.8 \pm 12$  years, weight  $63.8 \pm 7.4$  kg) and 10 age-matched healthy

controls (age  $35 \pm 11$  years, weight  $62.8 \pm 8.4$  kg) participated in this study. The patients were recruited from the Greek Multiple Sclerosis Society and were clinically diagnosed with relapsing/remitting MS by a neurologist (26). Details of the clinical course of all the patients are listed in Table I. Patients had mild to moderate levels of disability according to the Expanded Disability Status Scale (EDSS; 27), with an EDSS score ranging between 2 and 4.5. In addition, all patients were diagnosed with cerebellar ataxia based on the Functional Systems (FS) score for cerebellar dysfunction. The FS (Cerebellum) score grades the patient's symptoms that are related to cerebellar dysfunction as follows: 0 = normal, 1 = abnormal signs without disability, 2 = mild limb and/or truncal ataxia, 3a = moderate truncal ataxia, 3b = moderate limb ataxia, 4 = severe ataxia in all limbs or trunk, 5 = unable to perform co-ordinated movements due to ataxia. The patients participating in the present study had mild to moderate levels of cerebellar dysfunction with reported FS scores that ranged between 1 and 3b (Table I). They were able to stand independently for longer than half an hour and none of them had severe trunk instability or visual acuity less than 0.6. To be included in the study, patients should be able to provide informed consent in accordance with the Helsinki Declaration (1975), have no coexisting neurological, cardiothoracic or musculoskeletal impairment or have no severe tremor or visual disturbance. All patients received their usual immunomodulatory medication on both days of testing. None of the participants were on medication that could have influenced their ataxia.

Participants of the control group were recruited from a sample of convenience and included staff and students of Aristotle University. Participants of the two groups were matched for age and sex. The experiment was conducted in accordance with the ethical standards on human experimentation defined by the Helsinki Declaration (1975) after obtaining an approval from the University's Ethics Committee on Human Research.

### Experimental protocol

Both groups of participants were trained in a visually guided lateral weight-shifting task. They were asked to stand on a dual force platform (ERBE Balance System) recording the vertical ground reaction force under each foot (sampling rate 1000 Hz). On-line visual feedback about each foot's force vector was provided by a cursor displayed on a computer screen located in front of the subject (1.5m ahead, eye-level; Fig. 1). During practice, participants were instructed to keep their body straight, their arms hanging loosely by their sides and fixate on the computer screen. The aim of the task was to shift weight between sides (from left to right and from right to left) while maintaining each foot's vector (cursor) within visually specified force constraints that varied between 0 and 100% of bodyweight (Fig. 1). The bandwidth of each foot's force constraints (waveform curve) was individually adjusted to  $\pm 20\%$  of bodyweight. Each trial always began with a weight shift to the left and consisted of 6 left to right and 6 right to left weight shifts. Each time the foot's force vector exceeded the  $\pm 20\%$  limit in either direction, the movement of the cursor on the screen stopped and a spatial error was noted. Execution time (the time in seconds taken to complete one

Table I. Clinical profile of the patients with multiple sclerosis

| Age (years)/sex | Duration (years) | DYS | TRE | FS | TR-IN | EDSS | Affected side |
|-----------------|------------------|-----|-----|----|-------|------|---------------|
| 59/F            | 8                | ++  | –   | 2  | +     | 4.0  | Left          |
| 52/M            | 3                | +   | (+) | 2  | –     | 3.5  | Left          |
| 39/F            | 20               | +   | (+) | 2  | (+)   | 3.5  | Right         |
| 36/F            | 15               | ++  | ++  | 3b | ++    | 4.5  | Right         |
| 35/M            | 9                | (+) | –   | 2  | –     | 2.5  | Left          |
| 20/F            | 5.5              | –   | –   | 1  | –     | 2.0  | Left          |
| 32/F            | 2                | (+) | (+) | 3a | –     | 3.0  | Right         |
| 32/M            | 7                | +   | +   | 2  | +     | 4.0  | Bilateral     |
| 31/M            | 14               | –   | –   | 1  | (+)   | 2.5  | Left          |
| 22/F            | 4                | ++  | +   | 3b | ++    | 4.0  | Left          |

DYS = dysmetria, TRE = tremor, TR-IN = trunk instability, EDSS = expanded disability status scale, FS = functional systems score for cerebellar dysfunction: 0 = normal, 1 = abnormal signs without disability, 2 = mild limb ataxia and/or trunk ataxia, 3a = moderate truncal ataxia, 3b = moderate limb ataxia, 4 = severe ataxia in all limbs or trunk, 5 = unable to perform co-ordinated movements due to ataxia.

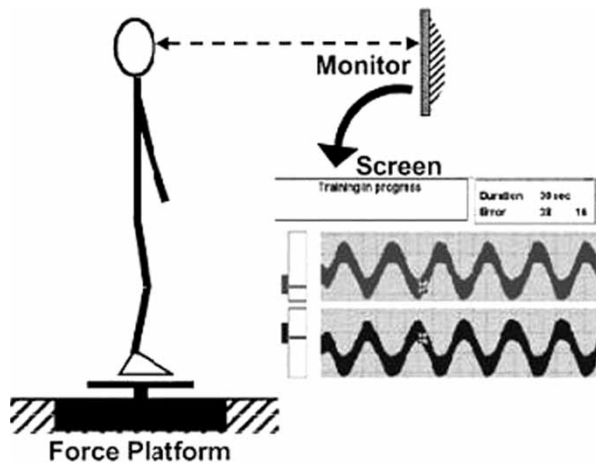


Fig. 1. Experimental set-up. The waveform force constraints along with each foot's force vector are shown on the computer monitor during performance of a single trial.

trial) and number of spatial errors on each side (right and left) were measured as means of speed and spatial accuracy of task performance. Movement time continued to count while the cursor stayed out of the force limits. Training consisted of 3 blocks of 5 trials (15 trials) separated by 1-minute intervals and followed by 5 retention trials performed 24 hours after training. The time interval between trials in each block was set to 10 seconds. Duration of training during the first day was about 30 minutes per participant. All patients successfully completed all trials during both days of testing without any signs of physical or mental fatigue.

#### Statistics

Speed and spatial accuracy of performance was reflected in the movement time (mean, standard deviation (SD) and coefficient of variation (CV)) and the number of errors (mean, SD and CV) calculated over the 5 trials of each block separately for the left and right side. Performance differences between the 2 groups and across trial blocks were analysed by means of a 2 (group)  $\times$  4 (trial block) ANOVA model with repeated measures on trial block. Significant interactions were further analysed using *post hoc* multiple comparisons tests (HSD Tukey).

## RESULTS

#### Individual learning curves

Fig. 2 shows the individual learning curves for right, left side errors and movement time plotted across the 15 practice and 5 retention trials performed by the patients with MS (left column) and control group participants (right column). The widespread nature of the individual learning curves in the group of patient with MS revealed a considerably higher between-subject variability of performance compared with non-MS individuals. This variability was particularly evident in the number of spatial errors performed during weight shifting on both the left and right sides. When looking closer at the individual learning curves, it was noted that 3 patients with MS did not decrease execution time and number of errors across trial repetition while their performance remained highly variable throughout practice. Those were the patients with the higher EDSS ( $>3.5$ ) and FS (cerebellar function  $>3$ ) scores. By contrast, most control

group performers decreased the number of errors within the first block of practice and maintained their spatial accuracy performance stable across the rest of practice and retention trials. Execution time and number of spatial errors on each side was averaged across the 5 trials of each block for statistical analysis purposes. In addition, within block variability was measured by calculating the SD and CV scores across the 5 trials of each block for all measured variables.

#### Movement time

As indicated by the group means shown in Table II, movement time significantly decreased across *trial blocks* for both groups ( $F(3,54)=42.89$ ,  $p<0.001$ ). This decrease was significant between the first and second ( $p<0.001$ ) as well as between the second and third ( $p<0.01$ ) trial block. No further decrease in movement time was noted throughout the rest of the practice and retention blocks. No significant between-groups differences were revealed by the statistical analysis, although the groups means in Table II indicate a tendency towards longer mean execution times for the MS patient group in the second, third, and retention block. This suggests that the mean decrease in movement time as a result of learning was greater for the control compared with the group of patient with MS (Table II).

#### Spatial errors

A significant main *trial block* effect suggests that both groups significantly reduced the mean number of right- and left-side errors across practice blocks (right side:  $F(3,54)=15.78$ ,  $p<0.001$ ; left side:  $F(3,54)=18.92$ ,  $p<0.001$ ). This decrease occurred between the first and second practice blocks ( $p<0.001$ ) on both the right and left sides and was preserved throughout the rest of practice and retention trials (Table II).

A significant main *group* effect was noted for the spatial errors depicted on the right side ( $F(1,18)=4.79$ ,  $p<0.05$ ). According to the groups means shown in Table II, patients with MS consistently made more spatial errors on the right side than non-MS participants did, and this performance deficit was statistically significant across all practice blocks ( $p<0.05$ ). In the retention block, however, this group difference had the tendency to decrease, being non-statistically significant.

On the left side, patients with MS also demonstrated a higher number of spatial errors than their age-matched controls (Table I), although this group difference was not confirmed by the statistical analysis. A marginally significant *group  $\times$  block* interaction contrast between the first and second trial block ( $F(1,18)=4.2$ ,  $p\approx 0.05$ ) however, suggests that group differences were significant at the particular trial blocks. Indeed, *post hoc* comparisons using the Tukey test confirmed a significant between groups difference only in the second trial block ( $p<0.05$ ). Plotting the trial block means for the 2 groups across practice (Fig. 3a) revealed that, whereas control group participants improved spatial accuracy performance between the first and second practice block, patients with MS continued to decrease the number of errors between the second and third trial

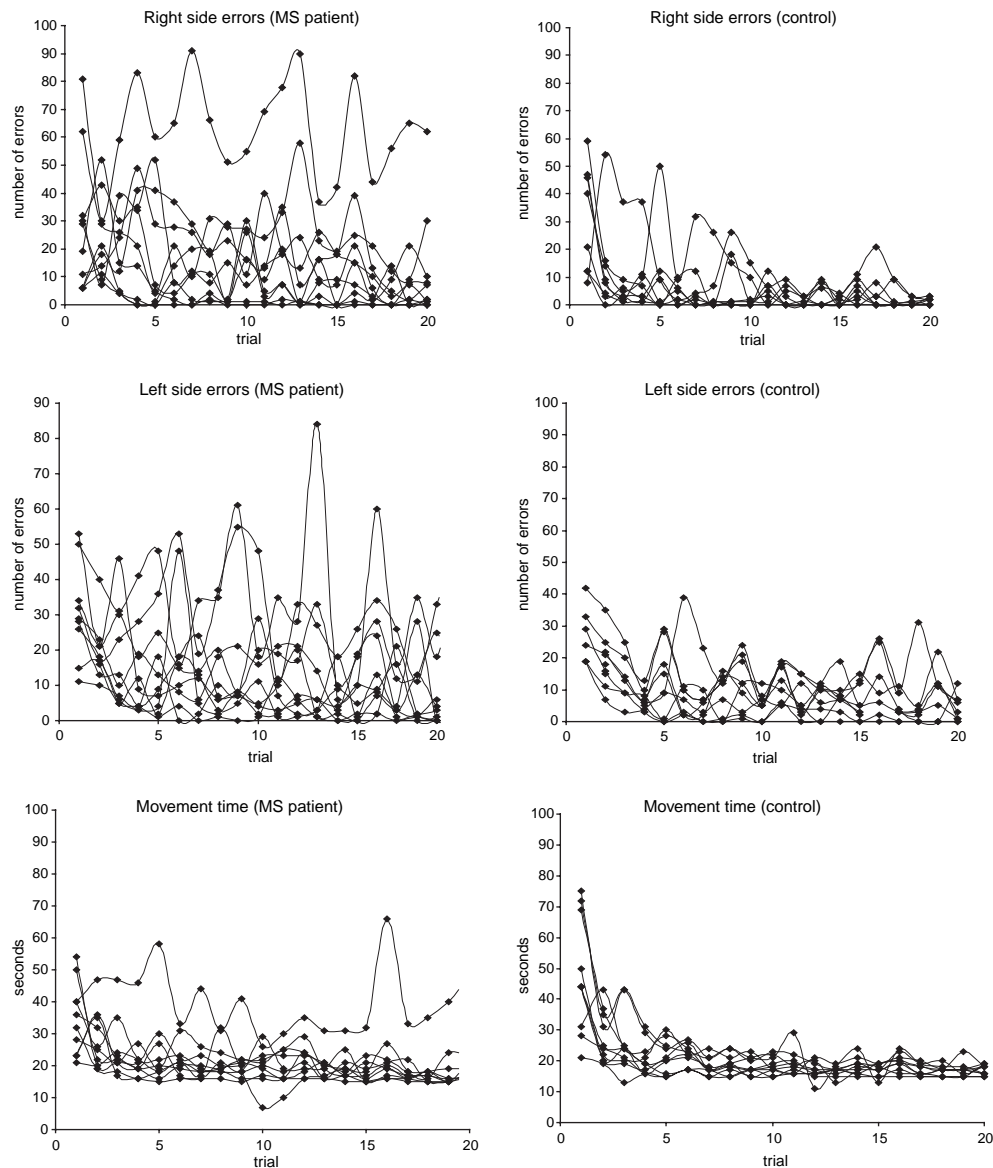


Fig. 2. Individual learning curves showing the right and left-side spatial errors and movement time produced by the 10 patients with multiple sclerosis (MS) and 10 control group participants across the successive practice ( $n = 15$ ) and retention ( $n = 5$ ) trials.

blocks, which suggests a slower rate of performance improvement. In addition, the number of errors was consistently higher for the group of patient with MS, indicating that patients with MS never reached the level of performance noted in age-matched controls.

*Performance variability*

Within-block stability of performance was reflected in the SD and CV, (expressing variability normalized to the mean) of the movement time and number of errors performed on each side as this was calculated over the 5 trials of each block (Table II). Statistical analysis indicated that SD of both movement time and spatial errors significantly decreased across *trial blocks* for both groups (movement time:  $F(3,54) = 26.33, p < 0.001$ ; right

side errors:  $F(3,54) = 21.59, p < 0.001$ ; left side errors:  $F(3,54) = 3.24, p < 0.05$ ). Within-block performance variability significantly decreased between the first and second trial block ( $p < 0.05$ ) and was kept constant throughout the rest of practice and retention trials. In addition, a significant *group × block* interaction was noted for SD of movement time ( $F(3,54) = 2.65, p \approx 0.05$ ) and SD of left side errors ( $F(3,54) = 3.67, p < 0.05$ ), suggesting that the improvement in performance stability from one block to the next was different between the 2 groups. In particular, *post hoc* comparisons revealed significantly lower variability scores for the control than the MS patient group for movement time (second and retention block) and left side errors (second and third trial block). For the left side, when the mean SD scores for spatial errors were plotted across trial blocks (Fig. 3b), it was noted that patients with MS

Table II. Group means standard deviations (SD), and coefficient of variance (CV) (in parentheses) for movement time (MT; mean, SD and CV), number of left (LE; mean, SD and CV) and right (RE; mean, SD and CV) side errors calculated for each trial block (4th block is retention) across the 2 groups (patients with multiple sclerosis (MS) group: n=10, control group: n=10)

| Trial block | MS patients  |              |              |              | Controls    |             |             |             |
|-------------|--------------|--------------|--------------|--------------|-------------|-------------|-------------|-------------|
|             | 1            | 2            | 3            | Retention    | 1           | 2           | 3           | Retention   |
| LE          | 15.8* (12.3) | 12 (10.1)    | 12.3 (11.3)  | 19.2 (11.09) | 8.1 (5.8)   | 7.4 (4.1)   | 8.1 (6.3)   | 18.2 (7.2)  |
|             | 9.5* (6.1)   | 8.5* (8.3)   | 8.5 (4.8)    | 8.7* (4.6)   | 4.5 (3.4)   | 4.1 (1.8)   | 7.3 (6.1)   | 12.0 (3.7)  |
| RE          | 75.1 (11.4)  | 81.5 (9.6)   | 94.6 (9.9)   | 55.2 (9.2)   | 43.7 (16.2) | 46.9 (13.5) | 65.2 (14.0) | 65.6 (13.0) |
|             | 18.1* (18.7) | 16.8* (19.2) | 12.9 (18.2)  | 24.2* (16)   | 7.9 (8.1)   | 3.5 (2.1)   | 5.1 (5.6)   | 15 (9.1)    |
| MT          | 7.5 (4.4)    | 8.4* (6.9)   | 6.8 (4.8)    | 15.1 (6.5)   | 7.2 (6.8)   | 3.6 (1.8)   | 4.2 (3.6)   | 13.5 (6.6)  |
|             | 79.2 (18.1)  | 82.2 (11.1)  | 106.3 (16.0) | 79.8 (9.5)   | 86.9 (25.6) | 81.3 (15.7) | 77.5 (22.6) | 76.7 (13.4) |
|             | 21.3 (5.3)   | 20.1 (4.6)   | 20.2 (8.6)   | 26.9 (7.6)   | 19.1 (2.5)  | 17.5 (1.2)  | 17.4 (1.5)  | 27.8 (6.8)  |
|             | 3.3* (2.8)   | 2.7 (1.2)    | 3.1* (3.7)   | 7.9* (4.2)   | 2.1 (0.94)  | 2.0 (2)     | 1.6 (0.90)  | 11.1 (5.8)  |
|             | 15.4 (13.2)  | 13.8 (6.5)   | 13.08 (8.3)  | 30.6 (17.4)  | 10.9 (4.5)  | 11.3 (10.5) | 9.1 (4.6)   | 38.5 (14.6) |

\*Significantly higher than the control group for the same trial block ( $p < 0.05$ ).

did not improve variability of performance as a result of practice. The decrease in the mean number of spatial errors in association with the unchanged SD scores across trial blocks resulted in an increase in the CV of left-side errors for the group of patient with MS (Table II). By contrast, CV of movement time decreased across trial blocks for both groups.

### DISCUSSION

The present study examined how patients with MS diagnosed with cerebellar ataxia and age-matched control individuals learn a novel visuo-postural co-ordination task requiring the application of response-produced feedback to control lateral weight shifting in accordance with visually specified force constraints. Overall, the group results indicate that patients with MS were capable of improving their performance as a result of practice, although to a lesser extent compared with their age-matched controls. In addition, a slower rate of performance improvement and an inability to reduce variability across trial blocks was particularly noted on the left side. A closer look at the

individual learning curves revealed large individual variations in the group of patient with MS that were apparent by the lack of improvement in visuo-motor performance in those patients with high EDSS scores and evidence of cerebellar dysfunction. These results are discussed in light of previous findings in an effort to provide further insights into how cerebellar ataxia associated with MS may affect the processes underlying practice-dependent skill acquisition.

#### *Patients with multiple sclerosis patients can improve visuo-postural performance with practice to a limited extent*

When practicing visually-guided weight shifting, the learner is expected to shift from a feedback-based type of control where he/she is using online visual information to control weight shifting to feed forward control during which, he/she uses visual information only to correct the weight shifts. Therefore, the task lends itself to feed forward planning of each interlimb weight transfer, which can be modified in response to error feedback given by the visual display. This suggests that with practice,

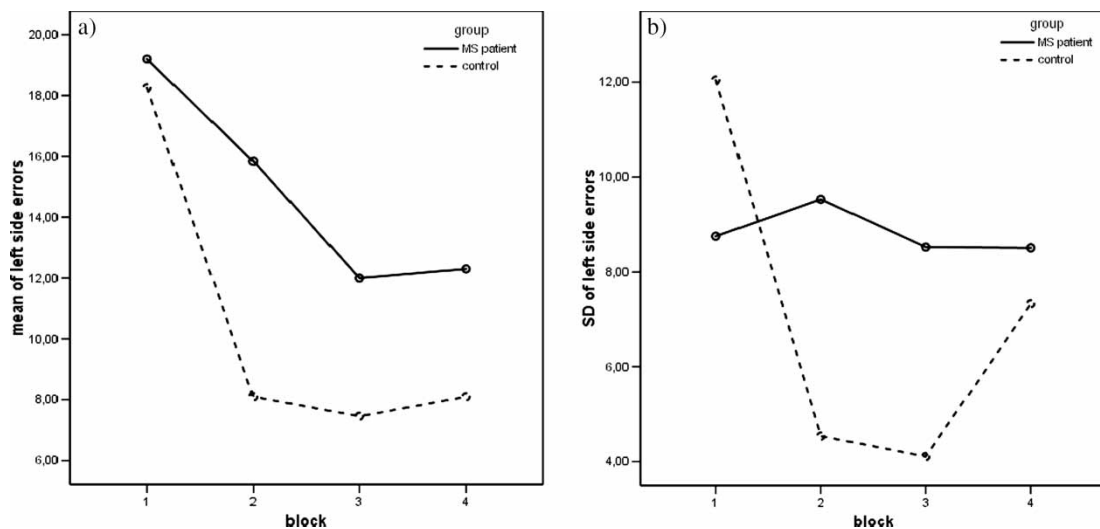


Fig. 3. Group means (group of patients with multiple sclerosis (MS) indicated by the solid line, Control group indicated by the dotted line) for the average number of spatial errors (a) and SD of spatial errors (b) depicted on the left side across the practice and retention (4th) trial blocks.

movement performance is expected to shift from a cognitive and attentionally demanding to an automatic state. This shift in visuo-motor performance was reflected in a significant reduction of movement time and number of spatial errors across trial blocks noted in control group participants. On the other hand, patients with MS also improved visuo-motor performance, but to a lesser extent when compared with non-MS individuals. In particular, although the number of spatial errors and movement time decreased significantly across trial blocks for both groups, these values remained consistently higher for the patients with MS across all practice blocks. On the left side, the patients showed slower rate of performance improvement and could not decrease the variability of spatial errors across trial blocks. This could be due to the fact that the majority of patients with MS (6 out of 10) examined in the present study were left side affected. The limited improvement in visuo-motor performance noted in the patient group is consistent with other studies showing impaired but not absent motor learning in cerebellar patients (18, 25). It also extends previous research findings, pointing to the critical role of the cerebellum in motor learning and the ability to perform complex visuo-motor skills automatically (13–16). Using a dual task paradigm (motor and an auditory vigilance task), Lang & Bastian (25) have shown that cerebellar damage impairs the ability to make a practiced movement more automatic. Cerebellar patients improved the motor-balance task to a very limited extent with practice and in addition, performance returned to pre-practiced levels in the dual-task condition. Cerebellar damage also impairs the ability to adapt the locomotor trajectory to novel visual input (24). Healthy subjects were able to adapt their walking path to maintain a straight trajectory after only a few trials of wearing laterally displacing prism glasses. On the other hand, cerebellar patients improved walking direction at a reduced extent and showed increased rate of adaptation and reduced capacity for storage of the adaptation. In order to explain the limited improvement of cerebellar patients during error-based learning, Lang & Bastian (25) have proposed that cerebellar patients are capable of improving motor performance, but the movement pattern can never reach the automatic state. It has been suggested that the motor improvement observed in cerebellar patients could be due to some other mechanisms such as “priming” in other intact brain structures; an explanation which seems pertinent in supporting the results of the present study. In particular, the limited improvement shown by the patients with MS could be due to the involvement of other intact brain structures in the process of visuo-motor learning. This idea is further supported by experimental evidence showing that cortical mechanisms are also involved in learning to control posture using visual feedback (28).

*Patients' with multiple sclerosis performance is characterized by increased within- and between-subject variability*

The great individual differences in visuo-motor performance noted for patients with MS can be attributed to the widespread

nature of demyelination throughout the CNS, affecting different aspects of motor performance. Rand et al. (23) have also noted considerable variability in the timing and duration of muscle activation patterns to changes in gait speed during treadmill walking in cerebellar patients. A closer look at the individual learning curves revealed that those patients with MS at the earlier stages of the disease (indicated by their low EDSS score: 2–2.5) maintained their ability to improve visuo-motor performance although to a lesser extent when compared with control group participants. On the other hand, those patients who had a higher EDSS score (>4.0) and clear evidence of cerebellar dysfunction (FS score >3.0) did not manage to reduce movement time and spatial errors across practice blocks. In addition, performance remained highly variable across practice blocks for those patients. Based on this evidence, it seems reasonable to suggest that the ability to learn the novel visuo-postural co-ordination task and perform it automatically is greatly dependent on the EDSS level of the disease. As the disease progresses and spreads to the cerebellum, the ability to shift visuo-postural performance from an attentionally demanding to an automatic state is seriously limited.

*Can patients with multiple sclerosis benefit from visuo-motor training?*

A critical question to consider is whether patients with MS will be able to benefit from training involving practice of complex visuo-motor skills. Unfortunately, only a few studies in these patients' rehabilitation are reported in the literature. An 8-week home-based resistance-training program improved lower leg power, but did not have any benefits for balance and mobility (29). It has been pointed out that the effectiveness of rehabilitation training would depend on the location and extent of cerebellar damage (5). The observation that patients with MS with a low cerebellar FS score (mild cerebellar damage) preserved their ability to improve visuo-motor performance stresses the importance of visuo-motor practice at the early stages of the disease. Moreover, based on the results of the present study, it can be speculated that practice of visuo-motor tasks such as the weight transferral task used in the present study could be helpful for improving performance of daily mobility functions such as transferring him/herself, walking around obstacles, climbing stairs, moving around within the home. However, no conclusive evidence that support such a skill transfer are provided by the present study and further work is needed before we can be certain that such visuo-motor training could improve performance of daily life activities. To our knowledge, there is no evidence in relevant literature examining the benefits of visuo-motor practice as a training tool for patients with MS. However, similar intervention studies in post-stroke hemiparesis, Parkinson's disease and cerebellar ataxia patients suggest that training involving the control of postural sway using visual feedback of the centre of pressure improves postural stability (30, 31). Several other studies indicate that tasks using visual feedback to control posture enhance the

coupling between perception and action (32, 33). Issues that may be worthwhile addressing in the future concern investigating whether visuo-motor training can improve certain aspects of daily life functioning in patients with MS.

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