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WEIGHT-BEARING ON THE LOWER LIMBS IN A SITTING POSITION DURING BILATERAL MOVEMENT OF THE UPPER LIMBS IN POST-STROKE HEMIPARETIC SUBJECTS

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Objective: **Verify weight-bearing on the feet in a sitting position during pointing in different directions with 1 or both upper limbs.**
Design: **Comparative study.**
Subjects: **Fifteen subjects with post-stroke hemiparesis with good to very good motor recovery and 13 healthy subjects participated in the study.**
Methods: **The subjects were seated on a chair with each foot resting on a force plate. They had to touch with 1 or, simultaneously with both hands, 2 target(s) located in front of them or at a 45° angle on either side at a standardized distance beyond their upper limb's length. The percentage of weight loading variation under each foot was measured.**
Results: **Weight-bearing on the paretic foot is reduced during unilateral and bilateral pointing in the anterior direction and 45° ipsilateral to the paretic side. However, both unilateral and bilateral pointing 45° contralateral to the paretic side produced symmetrical weight-bearing on both feet, paretic and non-paretic.**
Conclusion: **Since the paretic muscles of the trunk are probably used to control the leaning of the trunk towards the non-paretic side, the subjects with hemiparesis may put weight on the paretic foot to compensate for trunk weakness and maintain balance.**

Key words: stroke, hemiparesis, bilateral movement, weight-bearing, lower limbs.

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INTRODUCTION

The lower limbs play an important role in supporting body weight during tasks involving the upper limbs in a sitting position (1–4). During reaching movements beyond the upper limb's length in a sitting position, when weight transfer to the feet is at its greatest (4), the lower limbs help to brake the forward motion of the body and control balance (3).

Weight-bearing (WB) on the feet differs depending on the direction of the reaching movements of the upper limb. In healthy subjects, Crosbie et al. (2) found that, during rapid reaching movements towards targets located beyond the upper limb's length, WB was greater on the foot ipsilateral to the direction of the movement (i.e. right foot during movement of the right upper limb towards the right hemicorpus). Other studies with healthy subjects have shown that WB on the right foot was greater during reaching of the right upper limb towards the right and that the maximum WB on the left foot occurred during reaching movements of the right hand across the median line towards the left (5, 6).

The ability to perform reaching tasks in a sitting position is essential to a person's independence and quality of life (7). In individuals with post-stroke hemiparesis, it has been shown that WB on the paretic foot presents a loading deficit during reaching movements of the non-paretic upper limb (3). However, all these studies looked exclusively at unilateral reaching movements of the upper limb. To our knowledge, no study has examined the impact of bilateral movements of the upper limbs on WB on the feet of subjects with hemiparesis.

The general objective of this study was to verify WB on the feet during pointing in different directions with 1 or both upper limbs. The specific objectives were: (i) to compare WB on the paretic and non-paretic foot during unilateral pointing of the paretic upper limb (PUL) in subjects with hemiparesis; (ii) to compare total WB on the feet between unilateral pointing of the PUL and bilateral pointing in subjects with hemiparesis; (iii) to compare total WB on the feet between unilateral pointing of the non-dominant upper limb (NDUL) and bilateral pointing in healthy subjects; and (iii) to compare WB between the feet during bilateral pointing in subjects with hemiparesis and healthy subjects.

METHODS

Participants

Fifteen subjects with post-stroke hemiparesis (mean age: 69.4 (SD 12.0) years; 7 men and 8 women; mean weight: 70 (SD 15.0) kg) were recruited. They were included in the study if they had: (i) had a stroke which occurred 3 months or more prior to the study; (ii) the capacity to perform in a sitting position without support; (iii) the capacity to grasp and hold a cone in their hands; and (iv) a good understanding of simple verbal instructions. Most of the subjects presented left hemiparesis

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($n = 11$). The motor function scores of the paretic side on the Fugl-Meyer test (maximum score: 100) (8, 9) were considered good (63–95) and the lower limb sensation evaluated by this test (maximum score: 12) was very good (range 10–12) for the majority of the subjects. Because most of the participants had left hemiparesis, the confounding effects of left spatial hemineglect and disturbance of verticality can affect postural control (10, 11). Unfortunately, this information was not available and was not measured for our sample of subjects with hemiparesis. However, none of these subjects had any difficulty maintaining a sitting position in a chair without armrests and all completed the task without falling, i.e. pointing a target beyond upper limb length with an object in the hands, in the 3 directions. Thirteen healthy subjects (mean age 67.8 (SD 7.5) years; 6 men and 7 women; mean weight 66.5 (SD 14.6) kg), all but 1 right-handed, formed the control group. All the subjects were volunteers and signed a consent form approved by the Research Ethics Committee of the Sherbrooke University Geriatric Institute.

Experimental set-up and subject preparation

The subjects sat on a standard chair without armrests, which was fixed to the floor in front of a standard height table. Two force plates (AMTI, Advanced Mechanical Technology, Inc., model OR6-5-1000; size 508 × 464 mm; resolution (0.18 N for the mediolateral and anteroposterior forces, 0.72 N for the vertical force) for a gain of 4000) were placed on the floor and under their feet to measure the forces exerted by each foot (Fig. 1A). Two starting targets were placed near the subject on which he/she put his/her closed hands (Fig. 1B). The position of subject was such that the subject's arms were aligned with the trunk and in light abduction. The standard chair provided approximately three-quarters support under the thighs. Two end targets were located at a distance measured from the subject's starting position and corresponded to the full length of the non-paretic upper limb for the subjects with hemiparesis and of the dominant upper limb for the healthy subjects +20 cm. Each of the targets was connected to an on/off switch that flashed a signal light when the subject touched or took their hand off the target. A cone weighing 1.45 kg (height 14 cm; base 5 cm) was placed on each of the starting targets.

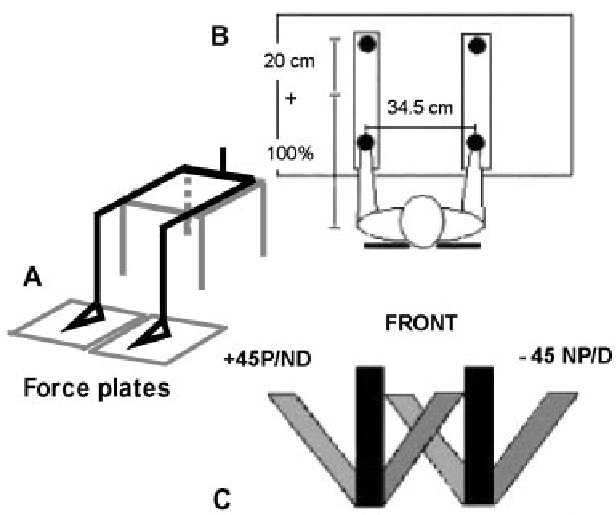

Fig. 1. Experimental set-up. (*A*) The subject was seated and 2 force plates were used to measure the forces exerted by each foot. (*B*) The task of the subject was to bring 1 or 2 cone(s) using 1 or both upper limb(s) from 1 or 2 starting target(s) placed near the subject to 1 or 2 ending target(s) located at a standardized distance beyond the subject's upper limb length. (*C*) Three directions were tested: front, right and left. *Right* is 45° to the non-paretic side for the subjects with hemiparesis and to the dominant side for the healthy subjects (−45NP/D) and *left* is 45° to the paretic side (defined for the upper limb) for the subjects with hemiparesis and to the non-dominant side for the healthy subjects (+45P/ND). P: paretic; ND: non-dominant.

Experimental tasks

During the experiment, the subject sat on the chair with lower limbs parallel and aligned with the shoulders to ensure that the feet were in a standardized position. The subject held a cone in 1, or both, hand(s). After being instructed to "Get ready … Go", the subject had to move a cone or cones unilaterally with the paretic upper limb or bilaterally to 1 or 2 targets placed in the standardized position (Fig. 1B). After 3 seconds, the subject returned to the starting position upon receiving the command "Go back". Before each experimental session, subjects practised the task once or twice allowing the experimenter to verify that the task was understood. All the subjects showed sufficiently adapted trunk function to perform the required task. As mentioned previously, all subjects were able to maintain a sitting position without support and to complete the task without falling. During the unilateral task, the inactive upper limb remained near the trunk in order to prevent the subjects from using their thighs for support. Three directions were tested, namely, in front of the subject and at a 45° angle on either side (Fig. 1C). The sequence used for the directions was as follows: anterior, 45° contralateral and 45° ipsilateral to the paretic/non-dominant side. Three trials were performed for each condition. The participants performed the task at a comfortable speed. No emphasis was placed on reaction time or the time taken to perform the task.

Variable and measures

Movement duration was defined as the time interval taken to lift off the cone from the first target(s) (T1) and bring it down to the end target(s) (T2). The kinetic variable measured was the percentage of weight loading variation under each foot between the start (T1) and end (T2) of the upper limb movement. This variable was then normalized by body weight.

Data and statistical analysis

The kinetic data were filtered with 4th order Butterworth filters. The cut-off frequencies were determined from residual analyses (12) and spectral analyses. All the analysis programs were developed using Matlab 5.3 (Mathworks Inc. 2000). Because of the small sample size and abnormal distribution of the data, non-parametric statistics were used.

In order to assess the reliability of the measures of WB variation across trials, intraclass correlation coefficients were calculated based on a one-way ANOVA. The Wilcoxon non-parametric test was used for each group to verify the differences between the 2 feet and the total weight on each foot between the unilateral task and bilateral task. Data were analysed using the SPSS statistical package, version 8.0 (SPSS Inc. 1998). Since most of our subjects with hemiparesis had left hemiparesis, the unilateral movement of the left (non-dominant) side of the healthy subjects was compared with the paretic side of the subjects with hemiparesis.

RESULTS

The reliability of WB variation across 3 trials was very good, as demonstrated by intraclass correlation coefficients varying from 0.82 to 0.96. Therefore, the averaged value was taken for further analyses.

For each condition, the WB on both feet was compared at T1. For both groups of subjects, the WB on each foot was not significantly different at T1 with 1 exception. The WB on the non-dominant foot was more marked than that on the dominant foot in the healthy subjects for the direction 45° contralateral to the non-dominant side.

Anterior direction

The results show that during anterior unilateral pointing of the PUL, there was asymmetry in the WB of the subjects with

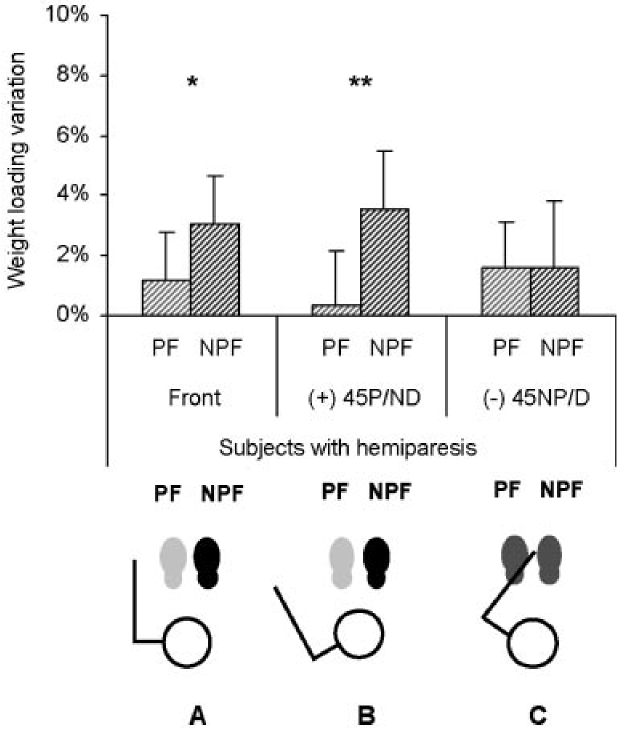

Fig. 2. Unilateral task with the paretic upper limb of subjects with hemiparesis in the 3 directions (same conventions as in Fig. 1). Percentage of weight loading variation (normalized by body weight), i.e. the difference in the loading variation under each foot between the start and end of the movement. The symbols (* or **) respectively for the front (*A*) and (+) 45P/ND (*B*) directions indicate that there was significantly less weight on the paretic foot (PF; light grey colour) than the non-paretic foot (NPF; black colour). For the (−) 45NP/D (*C*), there is symmetrical weight-bearing on both feet, PF and NPF (dark grey colour for both) *$p=0.003$; **$p=0.002$. P: paretic; ND: non-dominant; NP: non-paretic; D: dominant.

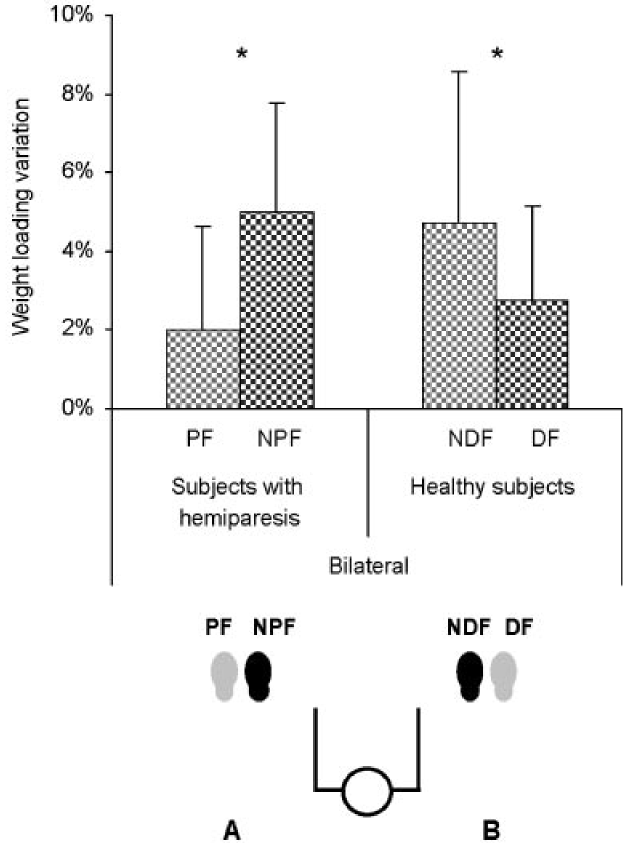

Fig. 3. Percentage of weight loading variation (see Fig. 2 for definition) between the 2 feet during the anterior bilateral task. (*A*) The subjects with hemiparesis put much less weight on the paretic foot (PF; light grey colour) than the non-paretic foot (NPF; black colour). (*B*) The healthy subjects put more weight on the non-dominant foot (NDF; black colour) than the dominant foot (DF; light grey colour). *$p=0.01$.

hemiparesis: they put significantly less weight on their paretic foot ($p=0.003$) (Fig. 2A). When changing from unilateral pointing of the PUL/NDUL to bilateral pointing (not shown), the total weight on the feet increased in both the subjects with hemiparesis (SwH) and the healthy subjects (HS) (SwH: Uni: 4.2% (2.8); Bil: 7.0% (4.3); $p=0.003$); HS: Uni: 4.1% (3.5); Bil: 7.5% (5.6); $p=0.001$). However, analysis of the WB between the 2 feet during bilateral pointing showed that the increased weight was on the non-paretic foot in the subjects with hemiparesis (Fig. 3A). During bilateral pointing, the subjects with hemiparesis put much less weight on the paretic foot than the non-paretic foot ($p=0.01$). Conversely, the healthy subjects put more weight on the non-dominant foot ($p=0.01$) (Fig. 3B).

45° directions

During movements of the upper limb 45° ipsilateral to the paretic side, the results for unilateral pointing showed that the paretic foot of the subjects with hemiparesis bore less weight than the non-paretic foot ($p=0.002$) (Fig. 2B). During bilateral pointing in this direction by the subjects with hemiparesis (not shown), the total weight on the feet was greater than during unilateral pointing (SwH: Uni: 3.9% (2.7); Bil: 5.7% (4.0); $p=0.01$). In the same task, the healthy subjects showed a tendency to increase total WB (HS: Uni: 3.9% (3.6); Bil: 5.1% (4.2); $p=0.12$).

As with the anterior condition, WB on the feet during bilateral pointing showed that the increased weight was on the non-paretic foot ($p=0.001$) (Fig. 4A) in the subjects with hemiparesis. No significant difference was found between the 2 feet in the healthy subjects ($p=0.38$) (Fig. 4B).

For the 45° direction contralateral to the paretic side, unilateral pointing in the subjects with hemiparesis produced equal WB on both feet ($p=0.91$) (Fig. 2C). Bilateral pointing increased the total weight on the feet in both groups of subjects (not shown) (SwH: Uni: 3.2% (2.8); Bil: 5.2% (3.8); $p=0.002$); HS: Uni: 2.8% (2.8); Bil: 4.7% (4.1); $p=0.002$). The weight was approximately equal on both feet during bilateral pointing in both groups (SwH: $p=0.69$; HS: $p=0.92$) (Figs 5A and 5B).

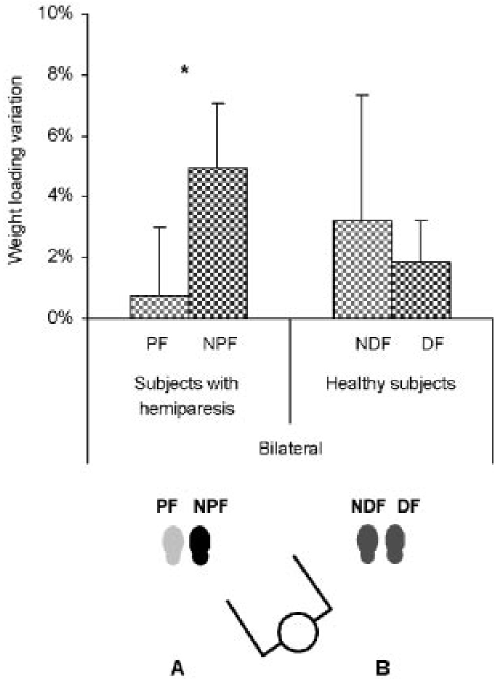

Fig. 4. Percentage of weight loading variation (see Fig. 2 for definition) between the 2 feet during the bilateral task towards (+) 45P/ND (same convention as in Fig. 1). (*A*) The subjects with hemiparesis put much less weight on PF (light grey colour) than the NPF (black colour). (*B*) No significant difference was found between the 2 feet (NDF and DF: dark grey colour) in the healthy subjects. The convention for the feet is the same as in Fig. 3. *p=0.001. PF: paretic foot; NDF: non-dominant foot; NPF: non-paretic foot; DF: dominant foot.

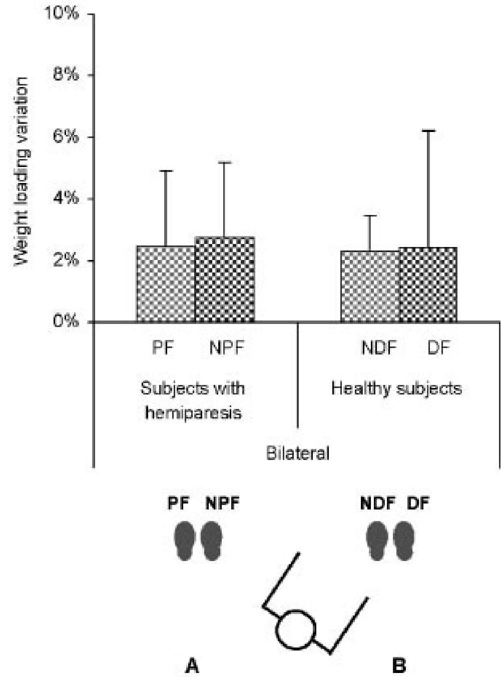

Fig. 5. (*A and B*) The percentage of weight loading variation (see Fig. 2 for definition) between the 2 feet during the bilateral task towards (−) 45NP/D (same convention as in Fig. 1) was approximately equal on both feet (dark grey colour) for both groups. The convention for the feet is the same as in Fig. 3. PF: paretic foot; NDF: non-dominant foot; NPF: non-paretic foot; DF: dominant foot.

DISCUSSION

This study showed that WB on the paretic foot was reduced during unilateral pointing of the PUL in the anterior direction and 45° ipsilateral to the paretic side, resulting in more weight being put on the non-paretic foot. Bilateral pointing increased the total weight on the feet. One might assume that this type of movement would increase the weight on the paretic foot. However, the results show that this increased weight was mainly on the non-paretic foot. This behaviour differed from that of the healthy subjects where WB on the feet was the inverse of the subjects with hemiparesis in the bilateral anterior direction (Fig. 3B) and the weight was equal on both feet in the bilateral 45° ipsilateral movement (Fig. 4B).

On the other hand, for the 45° direction contralateral to the paretic side during unilateral pointing of the PUL, as much weight was put on the paretic foot as the non-paretic foot. Also in this direction, bilateral pointing increased WB on both feet in both groups of subjects when compared to unilateral pointing. Thus WB between the feet remained balanced during bilateral pointing in the subjects with hemiparesis as well as in the healthy subjects (Fig. 5B).

This study shows that, unlike the healthy subjects (2, 5, 6), the subjects with hemiparesis do not show increased WB on the foot ipsilateral to the upper limb, i.e. on the paretic foot during unilateral pointing of the PUL in the anterior direction and 45° ipsilateral to the paretic side. Thus our results confirm, like Dean & Shepherds' study (3), that WB on the paretic foot presents a loading deficit during unilateral pointing. Our study also shows a bilateral pointing task did not resolve this deficit in the anterior direction and 45° ipsilateral to the paretic side. These results may be due to a number of factors. The lower limb muscles used to initiate and brake movement and the stabilization of the ankle and foot during a reaching task (2, 4, 6) are frequently affected in the paretic lower limb (3, 13). This deficit often results in persons with hemiparesis having a lack of loading on the paretic lower limb (14, 15). It is possible that movements of the upper limbs could elicit associative reactions of the paretic lower limb, since the associated reactions at the lower limb would be expected to consist of an extension of the hip and knee, such associative reactions could result in unloading of the paretic limb. However, the sitting position implies a flexion of the hip, which is though to minimize these reactions (16). In addition, the pointing task toward a target situated in front of the subject used in the present study is increasing the flexion of the hip, which would further inhibit these associated reactions. Therefore, one would then expect that associated reactions would not contribute to the unloading of the paretic limb.

In our study, the subjects sat on a standard chair that provided good support under the thighs. Using less support under the thighs, which increases WB on the feet, as was done in some studies (5, 6), would probably have increased use of the paretic foot.

However, these factors do not seem to have affected performance 45° contralateral to the paretic side. In this direction, our subjects with hemiparesis put more weight on the paretic foot during both unilateral and bilateral pointing. Thus it appears that making a pointing movement in the direction contralateral to the paretic side increases WB on this foot, regardless of the type of pointing (unilateral vs bilateral). This may be attributable to the trunk capacity of persons with hemiparesis. To execute reaching tasks in a sitting position requires a co-ordinated movement of the trunk and lower limbs to keep the body stable and maintain balance. Reaching movements beyond upper limb length in a sitting position increase postural demands since part of the body weight supported by the thighs on the chair is transferred to the perimeter of the base of support provided by the feet (4, 6). The muscles responsible for controlling the speed of trunk movements in the direction of gravitational force are located on the opposite side of the trunk. The eccentric contraction (controlled and active elongation) of these muscles provides a "braking effect" as long as the body mass of the trunk is moving in the direction of gravity (17). Trunk flexion in the anterior direction and towards the paretic side requires activation of the trunk extensors on the non-paretic side to control trunk flexion (17). The combined use of the extensors on the healthy side of the trunk and of the non-paretic foot would thus provide the necessary balance to complete the pointing movement in these directions.

However, trunk flexion towards the non-paretic side requires greater use of the hemiparetic muscles of the trunk. It is possible that muscle weakness on the paretic side of the trunk (17–20) creates an inability to generate enough muscle activity to provide the necessary "braking" when moving the trunk in the non-paretic direction. This inability probably created the need to use the paretic foot in the subjects with hemiparesis to maintain their balance, which thus made the WB on their feet comparable to that of the healthy subjects.

In conclusion, our results show that it is the 45° direction contralateral to the paretic side, more than the bilateral movement itself, which produced similar WB on both feet, making the paretic foot active during both unilateral and bilateral pointing movements. These results could have an impact on treatment objectives and methods when it is necessary to stimulate patients to put more weight on their paretic foot. This means that when a clinician wants to increase WB on the paretic foot of his/her clients, especially those who are most affected and who cannot work in a standing position, material and tasks should be placed on the opposite side to the paretic limbs. Unilateral and bilateral activities of the upper limbs on this side should therefore be encouraged. Studies on the electromyographic activity of the trunk and lower limbs during bilateral pointing movements would add to the information obtained in our study.

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