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OPTOELECTRONIC MOVEMENT ANALYSIS TO MEASURE MOTOR PERFORMANCE IN PATIENTS WITH CHRONIC LOW BACK PAIN: TEST OF RELIABILITY[1]

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Objective: **To assess test-retest reliability of the Posturo-Locomotion-Manual (PLM) test in patients with chronic low back pain.**

Design: **A controlled study in which the PLM test was used repeatedly on patients with chronic low back pain and persons without back pain.**

Subjects: **Twelve patients with treatment-resistant chronic low back pain, selected by 2 orthopaedic spine surgeons and 12 age- and sex-matched individuals with no back pain history.**

Methods: **An optoelectronic camera and a computer were used to quantify the performance during a simple test in which subjects picked up an object from the floor and transported it up to a shelf, thereby forcing the body through postural, locomotor and manual movements. The outcome measures were: movement time, simultaneity index and phase times for postural, locomotion and arm movement phases. Statistical analyses regarding intra-individual agreement between the measurements (reliability analysis) and changes over time were carried out.**

Results: **The effect of test movement habituation was minimized when the lowest mean value of any of 3 consecutive measures (tri-average) was used. In the control group, variation between test occasions was small. In the group of patients with chronic low back pain there was a random measurement error before intervention (sensory motor learning). After intervention the PLM test had the same precision in both groups.**

Conclusion: **When the tri-average measure is used, the influence of test movement habituation is minimized and the optoelectronic PLM test is found to be reliable and responsive. It proved to be a useful tool to quantify dynamic performance in freely moving patients with chronic low back pain.**

Key words: chronic low back pain, optoelectronic measurement, test-retest reliability, PLM, quantitative movement analysis.

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INTRODUCTION

Objective and quantitative methods to evaluate patients' ability to perform activities of daily life are still missing. This hampers the development of effective evidence-based practices aiming at improving movement capacity.

According to the International Classification of Functioning, Disability and Health (ICF) (1), activity is defined as the execution of a task or action by an individual and is classified under the component "Activities and Participation". There are 9 domains for this component and to be able to quantify the performance and the capacity of each domain in a universal manner assessment procedures need to be developed through research (1).

Optoelectronic systems provide the possibility to record and measure dynamic performance in an objective and quantitative way. Computer software can standardize and automate the evaluation. The Posturo-Locomotion-Manual (PLM) test measures postural function, gait and a goal directed reaching arm movement and the efficacy with which these movements compose a smooth whole-person dynamic performance (Fig. 1). As the subject has to carry out postural changes, locomotion and a targeted arm movement, the PLM test reflects the domain *mobility* for the "Activities and Participation" component of the ICF (1). The PLM test was developed for assessment of the movement capacity of patients with Parkinson's disease (2–4). It has been in clinical use for more than a decade to objectively assess movement capacity in patients with various diagnoses (5–7).

The World Health Organization (WHO) has declared the present decade as the Bone and Joint Decade, which stresses the importance of developing new techniques for assessment of disabilities due to musculo-skeletal disorders. Severe chronic back pain is a diagnostic label that refers to a large heterogeneous group of patients with different aetiologies, symptoms and clinical signs (8–10). Patients with disabling chronic back- or neck pain prove to have altered movement patterns, disturbed motor control, impaired balance and reduced proprioception (11–18). They have difficulties with smooth whole-body movements and tend to perform complex acts in separate movement phases. Thus, their movement disturbance has some similarities to that of patients with Parkinson's disease.

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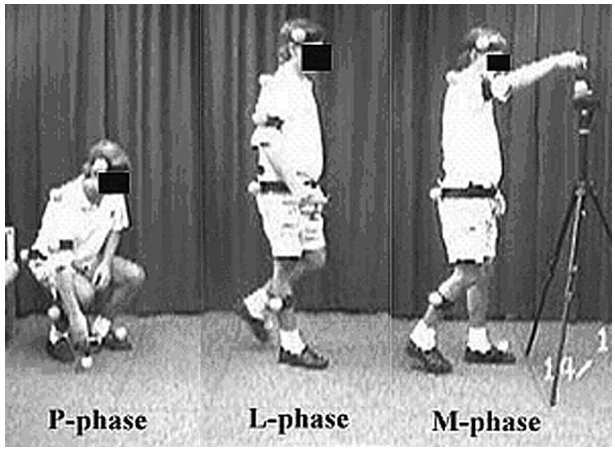

Fig. 1. The Posturo-Locomotion-Manual test. The subject transports an object as quickly as possible from floor to a stand.

Reliable and valid measurement tools are needed to assess the capacity to perform dynamic activities of daily life in patients' with chronic low back pain (CLBP) (9, 19). Commonly used outcome measures and scoring systems for low back pain are coarse, observer-dependent and sometimes yield a high inter-rater variance (20, 21).

The aims of this study were:

- To determine if the PLM test could be a valid measurement tool suitable to precisely and reliably quantify dynamic performance in freely moving patients with CLBP.
- To assess the test-retest reliability of the PLM test procedure when used in patients with CLBP and age- and sex-matched healthy controls.
- To investigate if the PLM test is reliably able to measure differences in PLM test performance between healthy subjects and patients with CLBP as well as changes in performance resulting from Sensory Motor Learning (SML) intervention (22, 23).

MATERIAL AND METHODS

Two orthopaedic spine surgeons at the Department of Orthopaedics in Gothenburg, Sweden selected 12 patients with severe CLBP. Inclusion criteria were in line with the multicentre randomized controlled trial from the Swedish Lumbar Spine Study Group on Lumbar Fusion versus non-surgical treatment for CLBP (24):

- Swedish-speaking patients of both sexes 25–65 years of age with severe CLBP.
- Severe low back pain duration for more than 2 years.
- Degenerative changes in the lower lumbar spine with at least a decrease of the disc height of 50% or more in 1 or 2 levels noted on plain radiographs. Other pathologies, e.g. disc herniations or spinal stenosis, were excluded by computed tomography and/or magnetic resonance imaging.
- The patient should have been on sick leave or have had major disability for at least one year.
- Physical therapy treatments of any kind should have been unsuccessful.
- Exclusion criteria were as follows: specific radiological findings, such as spondylolisthesis, signs of spinal stenosis, disabling arthritic joints, fractures, infection, inflammatory processes, or neoplasm.
- Psychiatric illness.

Five males and 7 females (mean age 42 years, median 42 years) that for 9 years (mean, median 8 years) had suffered from CLBP were included in the study. Twelve age- and sex-matched volunteers (mean age 43 years, median 44 years) with no back pain history were recruited as controls. None of them was highly trained or had physical disabilities.

The 12 patients with CLBP participated in weekly SML lessons (22, 23) for a maximum of 12 months.

The patients were investigated with the PLM test, before intervention, directly after intervention and 10–12 months after completion of the intervention. The healthy controls were investigated with the PLM test at the same time intervals as the patients. Patients were compared with controls (25).

Ethics

All subjects consented to participate in the study after being given oral and written information. The study was approved by the local ethics committee.

Measurements

To perform the PLM test, the subject was asked to move a small (500 g) object repeatedly, from a clearly marked starting place on the floor, to a stand located at chin level, 1.5 m in front of the starting place. Thus the body had to carry out postural changes when picking up the handle, the P phase, forward locomotion, the L phase and a targeted arm movement placing the object on the stand, the M phase (Fig. 1).

Measurement technique. An opto-electronic measurement system was used to record movement performance (Qualisys AB, Göteborg, Sweden). The PLM software was developed at Chalmers University of Technology, Göteborg, Sweden.

Seven spherical markers (5 cm diameter) covered with light-reflective tape were placed on defined parts of the subject's body, the head, one shoulder, one arm, one hip, both legs and on the object. The markers' position in two-dimensional space was recorded every 20 milliseconds by the opto-electronic system using infrared flashlight (Fig. 2).

Movement time (MT). MT was calculated as the mean time spent for 3 consecutive forward movements of the object from floor to stand (Figs. 1 and 2).

Three movement phases. The P, L and M phases were identified by the software from the velocity profiles of the markers placed on the body. (The PLM phases have in common that they start from zero velocity, reach a maximum velocity and then decelerate to standstill, i.e. they are monophasic. As every measurement system has an inherent noise in the signal a "zero level" cannot be identified. Instead, a minimum value of the velocity is set to identify the movement start of each specific PLM

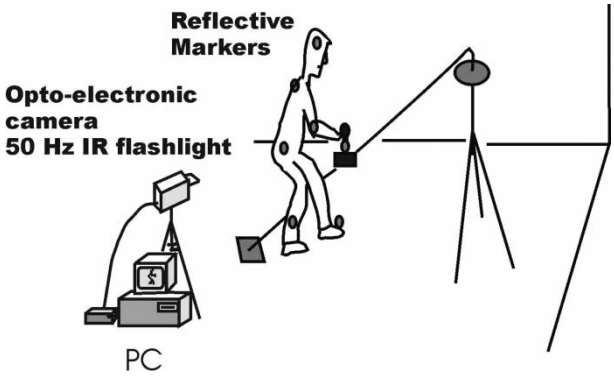

Fig. 2. The 7 infrared reflective markers placed on defined parts of the subject's body were viewed every 20 milliseconds by an optoelectronic camera.

phase and, in analogous manner, the end-point of the phase. These parameters, included in the PLM software are constant for all measurements.) Only forward movements were analysed (Fig. 2).

The P-phase measures the time spent to raise the body from the moment the object is gripped until the body is fully straightened. The L phase is a measure of the forward locomotion by assessing the movements of the markers on the legs. The M phase measures the time spent for the arm movement placing the handle on the stand. The M phase was derived by inspection of the angular velocity between the arm and the trunk (2) (Figs. 1 and 2).

To assess the degree by which the 3 different P, L and M phases were integrated into a single smooth movement, a simultaneity index (SI) was calculated from the following formula: $SI = (P+L+M)/MT^2$. The SI will increase if the gait (L phase) and/or arm movement (M phase) is initiated earlier during the PLM test action. Increasing the simultaneity will speed up the movement task without the need for increased muscle work (Fig. 3).

Procedure. The subjectss were tested by a trained biomedical analyst (BMA) in a clinical movement laboratory. The subject to be tested was instructed to stand by the starting place with the object on the floor beside them. At a command, the subject gripped the object, moved it forward as quickly as possible and placed it on the stand. To minimize the influence of starting from standstill and of tiredness, the PLM movement was performed 3 times during each recording. After each recording, the subject rested for 1–2 minutes. At each test occasion 10 recordings (with 3 repetitions each) were made.

Collection and analysis of PLM data. For each recording the software calculated mean and standard deviation (SD) for each of the 5 aspects of the PLM test movement, i.e. MT, P, L and M phases and SI.

To determine the effects of spontaneous variations in performance or of test movement habituation and the effects of sensory motor learning, the reliability of the PLM test was estimated by means of repeated measurements. At each test session the patients with CLBP were tested in the PLM test movement laboratory once a week for 3 consecutive weeks. The first test session was before the intervention, the second test session directly after the intervention, and the third test session 10–12 months after completion of the intervention. The controls were tested with the same time intervals (25).

To capture the most reliable measure, 3 different approaches to the 10 measures of the 5 aspects were compared:

- Approach 1: the mean of all the 10 measures.
- Approach 2: the mean of the last 4 of the 10 measures.
- Approach 3: the lowest mean found out of any of 3 consecutive measures among the 10 measures (denoted as "tri-average").

Every PLM test performance was also recorded with a regular stationary video camera. This was done to permit later inspection of the test movements.

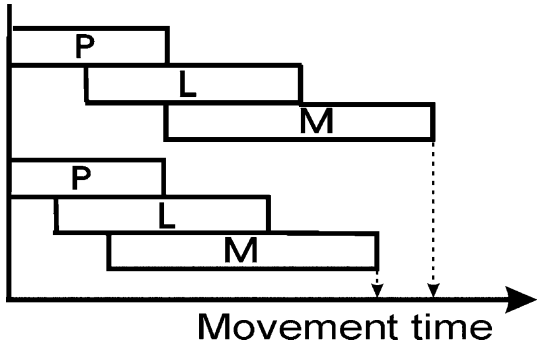

Fig. 3. The degree by which in action the P, L and M phases are performed simultaneously is calculated and defined as the simultaneity index (SI). SI = (P+L+M)/MT (movement time).

Statistical methods

For descriptive purposes mean, median, SD and range were calculated.

In order to evaluate reliability, the following measures were calculated and evaluated: limits of agreement (26), Intra-individual standard deviation (IISD) (27) and the Wilcoxon signed-rank test. Tests between groups were performed with Mann-Whitney *U* test. Statistical tests were two-tailed and conducted at 5% significance level. Differences between visit 1 and visit 2 as well as differences between visit 1 and visit 3 were analysed. Limits of agreement (LOA) were calculated as $mean_{diff} \pm 1.96 * SD_{diff}$ (26). This is a confidence interval (CI) for the difference between measurement session occasions. IISD was a defined as the SD within measures. The difference between 2 measurements for the same subject is less than $\sqrt{2} * 1.96 * IISD$ with 95% accuracy.

RESULTS

Statistical calculations comparing several different approaches to the 10 measures of the 5 aspects (MT, P, L, M and SI) were performed and 3 populations were statistically analysed; the patients with CLBP ($n = 12$), the healthy controls ($n = 12$) and all subjects together ($n = 24$). The results of the statistical calculations for the 2 approaches of main concern (all 10 and tri-average) are presented in Table I.

Effects of PLM test movement habituation

Effects of test movement habituation did exist in the group of healthy controls and in the group of patients with CLBP. This systematic change was prominent only at visit 1 at test session 1. At this first visit in the movement laboratory the patients successively increased their speed during the first 10 PLM test trials, with a reduction of the group mean value of MT from 2.8 seconds to 1.9 seconds. In the control group MT was reduced during the 10 first trials at visit 1 from 2.0 to 1.5 seconds. The tendency was much less marked on successive visits. The systematic effects of test movement habituation are demonstrated graphically as changes over time within the same day (Fig. 4A–C).

If the mean of all 10 measures were used, a significant systematic difference was found between visit 3 and 1 (at PLM test session 1 before intervention) for MT in both groups (patients with CLBP $p = 0.03$ and controls $p = 0.01$) and for SI in the patient group ($p = 0.001$). No significant systematic difference was found between the 3 visits in the group of patients or controls if the tri-average was used (Table I).

In Fig. 5 boxplots are used to describe changes in MT for all the 24 subjects between the 3 consecutive visits (at session 1) when comparing the mean of all 10 measures and the tri-average. Fig. 5 shows that the mean MT was more stable over time when the tri-average was used. In week 1 and 2 there were some outliers (all 3 were patients with CLBP). At visit 3 no outliers were found (Fig. 5). The outlier values indicate unsuccessful performance of test movement perhaps caused by a sudden feeling of insecurity or by pain in the test situation.

If the tri-average measure is used, and the PLM test repeated, the influence of test movement habituation was minimized and no significant systematic changes were found between visit 2–1 and 3–1. These results imply that the tri-average ought to be used to minimize the effects of PLM test movement habituation.

Table I. *Test-retest reliability of the patients (n = 12), and the controls (n = 12) before intervention. Posturo-Locomotion-Manual – test measures: movement time, postural phase, locomotion phase and movement phase and simultaneity index comparing method "all 10"and "3 fastest" (tri-average)*

	Visit 1 Mean (SD) Median (range)	Diff visit 2–1 Mean (SD) Median (range)	Diff visit 3–1 Mean (SD) Median (range)	LOA lower–upper CI visit 2–1	LOA lower–upper CI visit 3–1	Intra-ind SD[a] visit 2–1	Intra-ind SD[a] visit 3–1
Patients (n = 12)							
MT – all 10	2.23 (0.64)	−0.22 (0.54)	−0.36 (0.63)	−1.287–0.837	−1.599–0.884	0.400	0.498
	2.00 (1.52, 3.51)	−0.13 (−1.81, 0.32)	−0.21 (−2.16, 0.32)				
MT – 3 fastest	2.00 (0.55)	−0.09 (0.45)	−0.20 (0.55)	−0.972–0.790	−1.285–0.880	0.311	0.400
	1.75 (1.47, 2.96)	−0.03 (−1.41, 0.46)	−0.01 (−1.67, 0.47)				
P phase – all 10	0.95 (0.2)	−0.03 (0.17)	−0.05 (0.20)	−0.363–0.312	−0.444–0.335	0.118	0.140
	0.87 (0.71, 1.42)	−0.01 (−0.50, 0.18)	−0.00 (−0.60, 0.21)				
P phase – 3 fastest	0.92 (0.21)	−0.04 (0.15)	−0.03 (0.18)	−0.338–0.258	−0.385–0.329	0.107	0.125
	0.85 (0.69, 1.39)	−0.02 (−0.42, 0.14)	0.02 (−0.55, 0.12)				
L phase – all 10	1.43 (0.33)	−0.11 (0.34)	−0.09 (0.39)	−0.771–0.547	−0.855–0.676	0.241	0.272
	1.31 (1.01, 2.20)	−0.10 (−1.00, 0.35)	−0.14 (−1.04, 0.53)				
L phase – 3 fastest	1.30 (0.30)	−0.04 (0.34)	0.00 (0.35)	−0.694–0.623	−0.686–0.691	0.229	0.238
	1.20 (0.98, 1.91)	−0.03 (−0.84, 0.51)	−0.00 (−0.81, 0.57)				
M phase – all 10	1.29 (0.38)	−0.04 (0.39)	−0.20 (0.37)	−0.798–0.722	−0.916–0.518	0.264	0.285
	1.23 (0.64, 1.98)	−0.01 (−0.93, 0.69)	−0.14 (−1.16, 0.22)				
M phase – 3 fastest	1.16 (0.33)	0.06 (0.48)	−0.15 (0.34)	−0.884–1.001	−0.816–0.525	0.328	0.254
	1.11 (0.68, 1.77)	0.07 (−0.88, 1.21)	−0.06 (−1.01, 0.25)				
SI – all 10	2.09 (0.13)	−0.05 (0.07)	−0.12 (0.12)	−0.086–0.183	−0.110–0.344	0.058	0.114
	2.07 (1.88, 2.34)	−0.05 (−0.06, 0.20)	−0.10 (−0.03, 0.41)				
SI – 3 fastest	2.14 (0.14)	−0.02 (0.12)	−0.11 (0.15)	−0.228–0.258	−0.177–0.395	0.085	0.125
	2.13 (1.95, 2.39)	−0.00 (−0.14, 0.27)	−0.09 (−0.05, 0.40)				
Controls (n = 12)							
MT – all 10	1.68 (0.31)	−0.15 (0.20)	−0.20 (0.20)	−0.552–0.248	−0.598–0.191	0.175	0.198
	1.65 (1.29, 2.31)	−0.15 (−0.47, 0.18)	−0.23 (−0.47, 0.16)				
MT – 3 fastest	1.55 (0.30)	−0.07 (0.12)	−0.11 (0.14)	−0.310–0.178	−0.384–0.171	0.096	0.122
	1.48 (1.26, 2.18)	−0.05 (−0.24, 0.14)	−0.12 (−0.36, 0.13)				
P phase – all 10	0.80 (0.09)	−0.07 (0.07)	−0.05 (0.10)	−0.211–0.066	−0.256–0.149	0.070	0.080
	0.78 (0.7, 1.01)	−0.08 (−0.20, 0.06)	−0.06 (−0.25, 0.16)				
P phase – 3 fastest	0.81 (0.14)	−0.08 (0.14)	−0.07 (0.11)	−0.345–0.192	−0.288–0.156	0.107	0.090
	0.78 (0.64, 1.17)	−0.08 (−0.42, 0.10)	−0.06 (−0.35, 0.06)				
L phase – all 10	1.23 (0.22)	−0.07 (0.16)	−0.09 (0.15)	−0.390–0.253	−0.393–0.212	0.121	0.123
	1.16 (0.85, 1.64)	−0.05 (−0.42, 0.15)	−0.07 (−0.44, 0.13)				
L phase – 3 fastest	1.18 (0.22)	−0.04 (0.12)	−0.05 (0.10)	−0.286–0.196	−0.243–0.134	0.089	0.076
	1.13 (0.80, 1.60)	−0.03 (−0.32, 0.12)	−0.03 (−0.30, 0.08)				
M phase – all 10	0.99 (0.23)	−0.06 (0.15)	−0.11 (0.15)	−0.356–0.245	−0.399–0.183	0.111	0.126
	0.95 (0.73, 1.51)	−0.10 (−0.23, 0.24)	−0.15 (−0.29, 0.18)				
M phase – 3 fastest	0.92 (0.21)	−0.01 (0.10)	−0.05 (0.12)	−0.207–0.181	−0.293–0.187	0.068	0.091
	0.84 (0.72, 1.40)	−0.01 (−0.18, 0.20)	−0.09 (−0.22, 0.16)				
SI – all 10	2.23 (0.11)	−0.03 (0.12)	−0.06 (0.14)	−0.210–0.263	−0.210–0.337	0.084	0.105
	2.23 (2.01, 2.41)	−0.00 (−0.15, 0.24)	−0.08 (−0.19, 0.24)				
SI – 3 fastest	2.30 (0.12)	−0.02 (0.14)	−0.02 (0.14)	−0.287–0.247	−0.264–0.296	0.093	0.097
	2.3 (2.04, 2.47)	−0.01 (−0.26, 0.20)	−0.06 (−0.26, 0.22)				

[a] Measurement error = $1.96\sqrt{2} \times$ intra-individual standard deviation (SD).
LOA = limits of agreement; PLM = Posturo-Locomotion-Manual; MT = movement time; P = postural; L = locomotion; M = movement; SI = simultaneity index; CI = confidence interval.

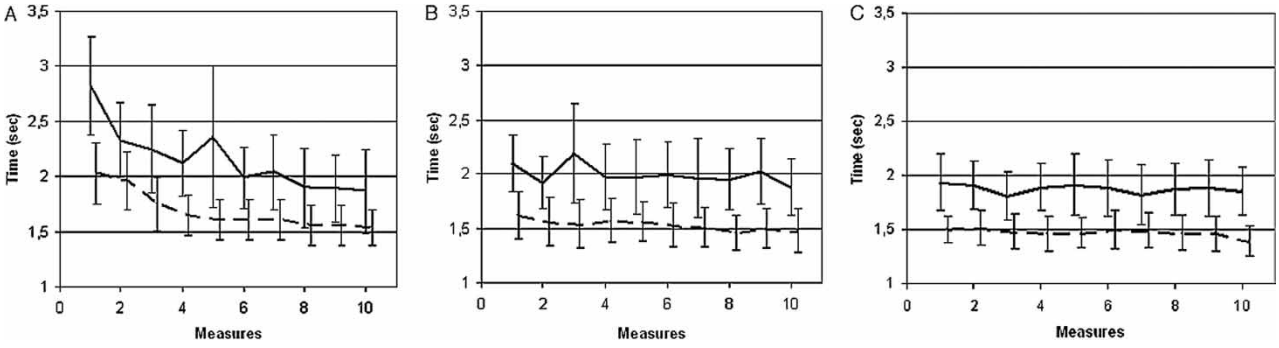

Fig. 4. (A) Comparison of mean values for movement time at (A) visit 1, (B) visit 2 and (C) visit 3 for each of the 10 measures that the software (PLM program) automatically calculated, for the group of patients (—) ($n=12$) and the group of healthy controls (--) ($n=12$). Error bars represent 95% confidence intervals.

Spontaneous variations in PLM test performance

Variability in PLM test performance in patients with CLBP between the 3 visits at the first test session is reflected by the IISD. IISD for the group of patients with CLBP was always greater than that of the group of healthy controls. This was found for the differences between visit 1 and visit 3, just as between visit 1 and visit 2 regardless of approach to the 10 computer-generated measures, and for all the time related aspects (MT, P, L, M phases) (Table I).

For the patient group, the lowest mean found out of any of 3 consecutive measures (the tri-average) had the lowest IISD, when comparing several different approaches to the 10 computer-generated measures and can be considered the most precise and reliable measure (Table I).

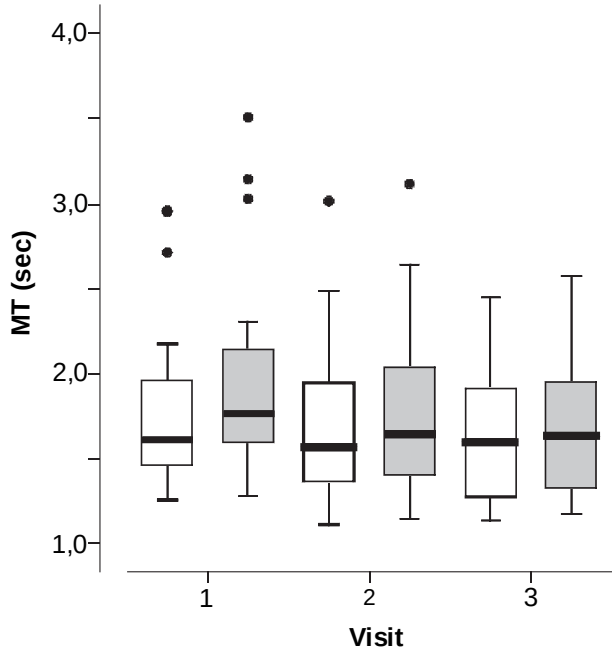

Fig. 5. Comparison of movement time (MT) for all subjects ($n=24$) when using the mean of all 10 measures (filled boxes) and the tri-average (open boxes) that the Posturo-Locomotion-Manual program generated at visits 1, 2 and 3. Outliers are defined as $>1.5\times$ IQR (interquartile range).

When comparing MT at visit 1 with MT at visit 3 (at test session 1), using the tri-average, the CI for the change for the group of healthy controls is small. The upper limit is +0.2 seconds and the lower limit is −0.4 seconds. For the group of patients, the same CI is +0.9 seconds −1.3 seconds. This indicates that in the group of patients with CLBP the PLM test performance varies more between visits at the first test session (before the SML intervention) than in the group of healthy controls (Table I).

The fact that the variation of the PLM test performance between visits at test session 1, is substantially smaller for the group of healthy controls than for the group of patients, is also reflected both by limits of agreement and by IISD (Table I).

After the SML intervention the variability of the PLM test performance, as reflected by changes from immediately post-intervention to 1-year post intervention, was reduced. The CI for the change between these measurements is now small. The IISD also indicates that the stability between measurements has increased after the SML intervention and became just as high for the group of patients with CLBP as for the group of healthy controls (Table II) (25).

Group differences in PLM test performance

When comparing the PLM test performance of the group of patients with CLBP with the group of healthy controls at the 3 visits of test session 1, using the tri-average, statistically significant differences were found. The performance of the healthy control group was better than the performance of the group of patients with CLBP in all aspects of the PLM test movement except in the L phase. The differences are displayed in Table III.

Directly after the SML intervention, the group of patients with CLBP had improved their PLM test performance so there were no longer any significant differences between the groups in any of the PLM test aspects. The results were retained and 10–12 months after the completion of the intervention there was no differences between the groups as the patients with CLBP now moved significantly faster than before intervention (25).

Table II. *Stability of measurements after intervention and one year after intervention*

Patients (n = 12)

	Mean difference	LOA lower–upper CI	Intra-ind SD[a]	IISD ×2.77	*p*-value Wilcoxon signed-rank test
MT – 3 fastest	−0.010	−0.265–0.245	0.089	0.245	0.985
P phase – 3 fastest	−0.017	−0.166–0.130	0.053	0.146	0.450
L phase – 3 fastest	−0.006	−0.250–0.238	0.084	0.234	0.954
M phase – 3 fastest	0.044	−0.146–0.235	0.073	0.202	0.211
↑SI – 3 fastest	0.023	−0.141–0.188	0.059	0.164	0.457

Controls (n = 12)

	Mean difference	LOA lower–upper CI	Intra–ind SD[a]	IISD ×2.77	*p*-value Wilcoxon signed-rank test
MT – 3 fastest	−0.002	−0.216–0.213	0.074	0.205	0.924
P phase – 3 fastest	0.004	−0.092–0.100	0.033	0.092	0.749
L phase – 3 fastest	0.001	−0.138–0.140	0.048	0.133	0.982
M phase – 3 fastest	0.013	−0.124–0.150	0.048	0.134	0.392
SI – 3 fastest	0.017	−0.168–0.202	0.065	0.065	0.780

[a] Measurement error = $1.96\sqrt{2} \times$ intra-individual SD.
LOA = limits of agreement; MT = movement time; P = postural; L = locomotion; M = movement; SI = simultaneity index; intra-ind = intra-individual, IISD = intra individual standard deviation.

At test session 1 the IISD was lower for the SI than for MT, P, L and M phases. The fact that SI varied little between the 3 first visits in both groups shows that even though the speed of the PLM test performance varied, the integration of the different movement phases to a smooth whole-body movement was stable (Table I).

Directly after the SML intervention the group of patients with CLBP had improved their ability to integrate the P, L and M phases and there were no longer any significant differences between the groups in SI. This result was retained 12 months after the SML intervention (25).

DISCUSSION

Persons with CLBP, similarly to persons with Parkinson's disease, are forced to perform the PLM test action in separate movement phases as they can not integrate the action into a smooth whole-body movement. The PLM test thus reflects crucial aspects of low back function as it measures how quickly and how well a subject can integrate postural changes with locomotion and a targeted arm movement that requires rotation along the spinal axis.

Change seen during repeated testing is an inherent problem with all measurements of movement capacity, as repeated execution of a motor act produces changes in behaviour. The effects of practice are increased speed of performance and increased accuracy (28). These changes are results of neural adaptive learning processes (29, 30). Therefore exact repetitions of motions are not possible and the value of the variability measure is never zero. In this study one objective was to clarify to what extent the changes seen with repeated PLM test performances were due to PLM test movement habituation or to spontaneous variations in PLM test performance.

The observation that only minor systematic differences existed between visit 1 and visit 2 at test session one in any of

Table III. *Posturo-Locomotion-Manual test results comparing the group of patients with chronic low back pain (n = 12) and the group of back healthy controls (n = 12) before intervention, using the tri-average measure of movement time, postural phase, locomotion phase, movement phase and simultaneity index*

	Patients (*n* = 12)	Controls (*n* = 12)	
	Mean (SD) Median (range)	Mean (SD) Median (range)	Test between groups, *p*-value
MT, mean visit 1–3, 3 fastest	1.90 (0.40) 1.84 (1.35, 2.81)	1.49 (0.28) 1.38 (1.20, 2.06)	0.009*
P phase, mean visit 1–3, 3 fastest	0.90 (0.15) 0.86 (0.64, 1.10)	0.76 (0.08) 0.73 (0.67, 0.91)	0.010*
L phase, mean visit 1–3, 3 fastest	1.29 (0.23) 1.30 (0.96, 1.79)	1.15 (0.21) 1.11 (0.78, 1.52)	0.18
M phase, mean visit 1–3, 3 fastest	1.13 (0.21) 1.15 (0.80, 1.47)	0.90 (0.19) 0.82 (0.70, 1.31)	0.009*
SI, mean visit 1–3, 3 fastest	2.18 (0.12) 2.15 (2.02, 2.37)	2.30 (0.11) 2.30 (2.08, 2.51)	0.035*

*Statistically significant differences between groups $p < 0.05$.
MT = movement time; P = postural; L = locomotion; M = movement; SI = simultaneity index.

the PLM phases is interesting, since none of the 24 subjects had ever performed the PLM test before. It indicates that the PLM test task is naturally well known and patient-friendly in that it requires little training and the test can be performed by a fully dressed subject and without any restriction of movements.

At visit 1 the patients with CLBP, as well as the healthy controls, improved the velocity of their performance during the iterated recordings (Fig. 4A). However, the change in patients was greater than that of the healthy controls, indicating that the patients with CLBP needed a few more trials than the healthy controls to reach optimal velocity. At visits 2 and 3 the PLM test performance was stable in both groups. This indicates that most subjects approached optimal velocity at the end of visit 1 (Fig. 4B, C).

Statistical analyses of intra-individual changes demonstrated that MT was somewhat lower at visit 2 and 3 compared with visit 1 (at test session 1). This difference was most obvious for the group of patients when approach "all 10" was used. This result makes sense, since the patients with CLBP probably reach their maximal capacity after a few PLM trials and thereafter their ability gets impaired, whereas the healthy controls reach their maximal ability quite quickly and can continue on the same level for some time.

The fact that the changes in MT in both groups were small and seen mainly during the first visit of test session 1 indicates that these changes in both groups were an effect of PLM test movement habituation. After the first visit at test session 1, the PLM test performances were stable in both groups.

It is not possible to use descriptive statistics to define acceptable limits of agreement, as it depends upon the clinical circumstances (26). This study shows that we can expect PLM test performance in patients to vary more between 2 test occasions, compared with the performance of a healthy subject.

The tri-average had the lowest IISD and can be considered the most precise and reliable measure. Therefore this approach should always be used for each of the 5 aspects (MT, P, L, M phases and SI). For the healthy control group, IISD was negligibly small with either approach.

Practising, in the narrow sense of repeated procedures, will make the performance of an action less variable, but it does not influence a subject's habitual way of moving. In this study a second objective was to investigate whether intervention in the form of SML could change the efficiency of the PLM test performance for the better, measured by MT and the integration of the different movement phases to a smoother whole-body movement (higher SI).

MT reflects the efficiency with which a person performs the PLM task. Efficient behaviour has to do with skill and requires the ability to perform an action with speed, accuracy, economy and resourcefulness (13, 31). SI reflects how well the nervous system integrates the P, L and M phases into a single smooth movement. After the SML intervention MT and SI of the PLM test performance of the group of patients with CLBP had increased significantly and the improvements were retained after one year (25). The fact that statistically significant differences in MT, P and M phases and SI were found between the patient group and the back healthy control group shows that the PLM test has construct validity. It can detect differences in the way patients with CLBP and healthy persons perform the task (Tables I and III). Moreover, this also implies that the PLM test is sensitive to changes in performance as it could capture the more efficient behaviour that the patients with CLBP had learned and retained.

The precision of the PLM test, as reflected by changes from post-intervention to one year post-intervention, measured by LOA and IISD, demonstrated that the PLM test is not only sensitive to changes in performance but also to changes in variability between test occasions and/or as a result of an intervention. In this case, the group of patients had significantly improved their movement capacity after the SML intervention and the improvements were retained after one year (25, 29). The higher precision of the PLM test performance after intervention strengthens the evidence that the patients with CLBP had learned and retained a more efficient behaviour (Table II).

The PLM test was developed for assessment of the movement capacity of patients with Parkinson's disease based on knowledge of disease specific impairments in the central nervous system (2–4). To perform the PLM test the subject has to carry out postural changes, locomotion and a targeted arm movement. The performance of the PLM test thus involves the whole body and can objectively capture significant behavioural aspects, not only in CLBP patients but also in patients with many other disorders that limit gait and upper limb function, e.g. patients with hip-, knee-, neck- or shoulder disabilities.

Intentional activities are performed at a certain time in a certain environment. The performance of a physical task is dependent on the coordination of multiple "functional units", and the way in which individuals perform activities of their daily life, varies considerably (32, 33). This implies that evaluations of movement capacity should be done without fixed ideas as to how the task is best performed. In this respect the PLM test is adequate.

As the PLM test procedure only requires a small test area and no more than one camera, it can be assumed that the PLM test provides the demanded possibility to evaluate the ability to perform a common activity of daily life in an objective and quantitative manner.

In conclusion, the PLM test can precisely quantify dynamic performance in freely moving patients with CLBP from the perspective of the 5 aspects of the PLM test movement; MT, the inherent movement phases P, L and M and the degree by which the 3 movement phases are integrated into a single smooth body movement (simultaneity index). Effects of test movement habituation can be reduced if the PLM test is repeated several times and the tri-average is used as a measure. Thus the PLM test is a useful clinical tool to quantify the performance of a common daily task in freely moving patients with CLBP.

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