ORIGINAL REPORT

RELIABILITY AND VALIDITY OF A KINEMATIC SPINE MODEL DURING ACTIVE TRUNK MOVEMENT IN HEALTHY SUBJECTS AND PATIENTS WITH CHRONIC NON-SPECIFIC LOW BACK PAIN

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Objective: **To develop a standardized, reliable, valid spine model of active trunk movements that accurately discriminates kinematic patterns of patients with chronic non-specific low back pain from those of healthy subjects.**
Design: **Comparative cohort study.**
Subjects: **Healthy subjects ($n=25$) and patients with chronic non-specific low back pain ($n=25$) aged 30–65 years.**
Methods: **Subjects performed 7 trunk movements from a seated position at non-imposed speed during 2 sessions. Nine markers on bony landmarks measured range of motion and speed of 5 spinal segments, recorded by 8 optoelectronic cameras.**
Results: **Both groups showed good–excellent reliability in all movements for range of motion and speed of all spinal segments (intraclass correlation (ICC), 0.70–0.96; standard error of measurement, expressed as a percentage, 19.4–3.3%). The minimal detectable change in the patient group was 16.7–53.7%. Range of motion and speed in all spinal segments for trunk flexion, rotation, and flexion with rotation differed significantly between groups ($p<0.001$), with large/very large effect sizes (Cohen's $d=1.2$–2). Binary logistic regression yielded sensitivies/specificities of 92%/84% for range of motion and 92%/80% for speed.**
Conclusion: **Kinematic variables are valid, reliable measures and can be used clinically to diagnose chronic non-specific low back pain, manage treatment, and as quantitative outcome measures for clinical trial interventions.**

INTRODUCTION

Back disorders are the most frequently reported musculoskeletal problems, and back pain is the third most common bodily symptom, after headache and fatigue (1, 2). Approximately 60–80% of people in Western societies experience low back pain (LBP) at some stage of life (1, 3). In France, the annual prevalence of LBP is estimated to be 55% in individuals aged 30–64 years, and 55% of individuals with LBP consult a physiotherapist or other healthcare professional (4–6). In the USA, LBP is the second most frequent reason for consultation among physiotherapists and work absenteeism (3, 7). Thus, LBP is a considerable public health problem, particularly with regard to work absenteeism and large healthcare costs (3, 8, 9).

Specific LBP, which represents less than 7% of all LBP, may be due to a serious spinal pathology (e.g. spinal tumour or infection), rheumatological disease, or true nerve root pain. However, no definitive diagnosis is possible in 80% of cases of LBP. This non-specific LBP (NS-LBP) is caused by mechanical disturbance of the musculoskeletal structures or back function, or by degenerative changes in the vertebral column (1, 2, 4). Approximately 10% of acute NS-LBP becomes chronic (>3 months) NS-LBP, which affects 7% of the US population (1–5, 8).

Traditionally, classification of LBP has been based on anatomopathology, and diagnosis on clinical examination, X-ray, and/or magnetic resonance imaging findings. However, medical imaging findings are correlated with symptoms in only 15% of patients with LBP (10); for example, imaging detects signs of herniated discs in 25% of asymptomatic subjects. Only an estimated 10–20% of LBP diagnoses are accurate and able to identify the origin of the disorder (11).

Perhaps due to this diagnostic inaccuracy and the lack of a sub-classification system for this heterogeneous disorder, the best care for NS-LBP remains controversial and its management varies considerably among medical disciplines. The classification of NS-LBP into homogenous subgroups is likely to increase treatment efficacy (12, 13), but anatomopathological classifications may not effectively guide targeted treatment choices for patients with chronic NS-LBP. Instead, clinical examination findings may be more useful for the identification of subgroups of patients with NS-LBP and the management of specific treatment strategies (14, 15).

In clinical practice, NS-LBP is commonly classified by examining active trunk movements in various directions (14–17). For example, the valid and reliable movement impairment classification system (MICS) proposed by O'Sullivan (17) is based on impairment related to symptoms and mechanical

factors (e.g. pain, asymmetry, misalignment, loss of range of motion (ROM), patterns of coordination) observed during a standardized examination of trunk motions in various planes (single or combined) (14–18). With this system, classification is based on the direction(s) of movements and alignments that appear to increase a subject's NS-LBP symptoms and influence the quality of movement; such assessment may also be achieved with clinical tools (e.g. goniometer) or complemented with instrumented tools (e.g. electrogoniometer, electromagnetic or optoelectronic systems) (15, 19, 20).

Manual therapy (MT) and active rehabilitation (AR) appear to be promising approaches to the treatment of NS-LBP subgroups, and considerable evidence has suggested the presence of movement impairments in patients with NS-LBP (13–18, 21–23). Kinematic analyses of trunk movements are potentially useful outcome measures for the quantification of specific kinematic patterns (15, 19, 20, 24–26) to assess the efficacy of a multidimensional therapeutic approach including MT and AR. Nevertheless, these findings require confirmation by independent data-sets to raise the overall level of evidence before they can be validated and used to aid in diagnosis or as an outcome measure for specific rehabilitation therapies in clinical trials (20). Several back kinematic tools have been used previously (15, 19, 20, 24–26), but few have been used in combination with optoelectronic camera systems, which can measure kinematic patterns with high accuracy (15). Furthermore, previous studies (19, 20, 24–26) have focused on the low back area, and kinematic assessments of the full spine during various active trunk motions from a seated position in chronic NS-LBP has not been validated with instrumented measures.

Using an optoelectronic camera system, we sought to develop a standardized and reliable spine model of active trunk movements including 5 spinal segments that would be sufficiently accurate to discriminate kinematic patterns of patients with chronic NS-LBP from those of healthy subjects. Inspired by clinical classification systems for NS-LBP (e.g. MICS), we included 7 trunk motion tasks performed from a seated position, which reduces the influence of hip motion (27, 28), pelvic asymmetry (29, 30), and hamstring contracture (28, 30, 31), and better targets the movements of the lower spine (28, 32). To determine the quality of our kinematic spine model, we aimed: (*i*) to evaluate the intra-examiner reliability of active trunk motion measurements in healthy subjects and those with chronic NS-LBP, (*ii*) to study the responsiveness of the model, and (*iii*) to determine the sensitivity and specificity of ROM and speed (SPEED) measurements during active trunk movement.

METHODS

Subjects

The cohort comprised 25 healthy subjects aged 30–60 years and 25 subjects with chronic NS-LBP aged 30–65 years. Anthropometric data are shown in Table I.

The chronic NS-LBP group included men and women recruited from Saint-Luc University Hospital (Brussels, Belgium) with chronic (≥ 12 weeks) NS-LBP with or without pain radiating into the thigh, but not extending below the knee.

Table I. *Baseline characteristics of healthy subjects and those with chronic non-specific low back pain (NS-LBP)*

	Healthy ($n=25$)	Chronic NS-LBP ($n=25$)
M/F, n	10/15	12/13
Age, years, mean (SD)	40 (11)	42 (9)
BMI, kg/m², mean (SD	23.3 (2.5)	25.2 (3.2)
VAS T_0, mean (SD)	–	2.4 (1.7)
VAS T_1, mean (SD)	–	2.5 (1.5) NS

M: male; F: female; BMI: body mass index; VAS: 10-point visual analogue scale pain score during the first (T_0) and second (T_1) sessions; NS: non-significant difference between T^0 and T^1 (paired *t*-test, $p=0.44$; intra-class correlation coefficient=0.85).

These NS-LBP patients had several (≥2/7) directions of impairment during clinical examination of active trunk movements in a seated position.

Healthy subjects were recruited on a voluntary basis and had no incidence of NS-LBP in the 6 months before the experiment. The ethics committee of the University of Louvain approved the study protocol and informed consent was obtained from subjects prior to testing.

Protocol and materials

The protocol included 7 trunk motion tasks that involved the whole spine and were performed at a non-imposed speed. Eight infrared cameras (ELITE-BTS, Milan, Italy) registered the 3-dimensional positions of 9 reflective markers placed on bony landmarks. Each subject performed each of the 7 tasks 15 times per session (10 trials were recorded) in 2 sessions approximately 1 week apart. From the positions of the markers, customized software calculated the ROM and SPEED of each spinal segment for each subject and each trial. The mean and standard deviation (SD) of 10 trials were calculated for each variable.

All trunk movements were executed from a seated position on a stool; the height of the stool was adjusted for each subject to create a 120° angle between the thigh and trunk, thereby maintaining normal physiological curvature in the starting position. From this position, subjects performed the 7 tasks successively (in the same way as during clinical examination) described below (see "Tasks and instructions" section, below).

Placement of markers. The following standardized marker locations were used: 5 markers were placed on the spinous processes of S2, L3, T12, T7, and C7; two markers were placed on the right and left anterosuperior iliac spines; and two markers were placed on the right and left acromioclavicular (Ac) joints. An experienced manual therapist placed the markers to maximize palpatory accuracy. To further reduce the approximate nature of bony landmark palpation, the distances between markers on each subject were (*i*) measured from C7, which served as a reference due to its readily located spinous process (most prominent in head flexion); (*ii*) recorded; and (*iii*) reported from the first to the second session.

Kinematic spine model. A spine model including the pelvic and shoulder girdles was elaborated (Fig. 1A, B). The spine and shoulder were divided into 6 segments: upper thoracic spine (UTS: C7–T7), lower thoracic spine (LTS: T7–T12), Upper lumbar spine (ULS: T12–L3), lower lumbar spine (LLS: L3–S2), total lumbar spine (TLS: T12–S2), and shoulder segment (SS: AcRight–AcLeft). Each segment was considered to be rigid and homogenous and was delimited by proximal and distal markers (Fig. 1). This modelling procedure is similar to those of Larivière et al. (33) and Gombatto et al. (15).

Tasks and instructions. Subjects were asked to follow 4 rules during all tasks: (*i*) begin and end each movement in a seated position with physiologically normal curvature; (*ii*) aim to move at a non-imposed (spontaneous) speed and to the greatest possible extent; (*iii*) maintain contact between the ischial tuberosities and the stool; (*iv*) and adhere
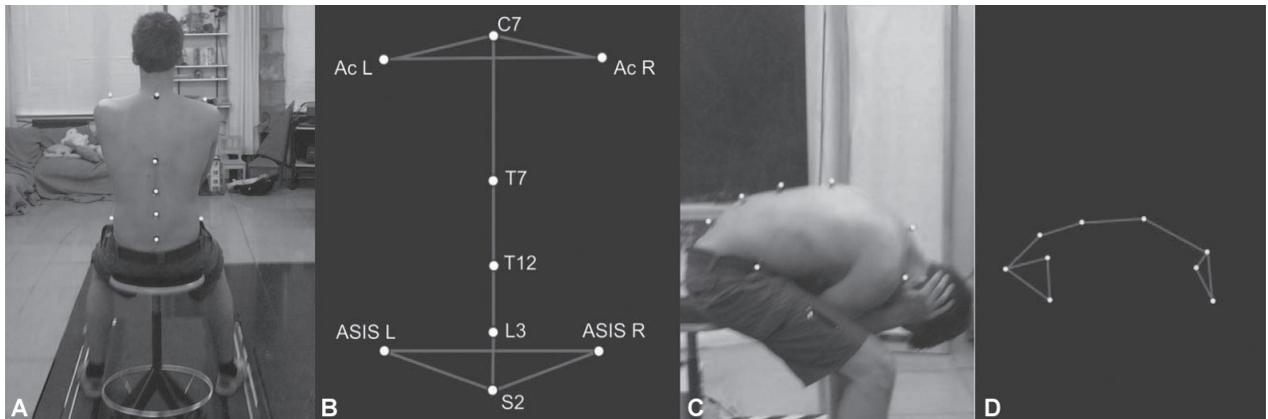
Fig. 1. Flexion task from a seated position (A, B) to the end of the range of motion (C, D). (A, B) Photograph and schematic illustration of marker placement on a seated subject. The shoulder and pelvic girdles are represented by two triangles, where the pelvis is delimited by S2 and the anterosuperior iliac spines (ASISs), and the shoulders are delimited by C7 and the acromioclavicular (Ac) joints.

strictly to the plane of motion specified by each task. Each movement was repeated 15 times and recorded after the fifth movement (*n* = 10 trials). Subjects were given the following instructions for each task:

- *Anterior trunk flexion.* Subjects positioned themselves with hands on the ears and elbows forward, and then flexed the trunk as far as possible in the sagittal plane (Fig. 1A, C, D).
- *Lateral trunk side-bending (left and right).* Subjects crossed the arms on the chest and then inclined the trunk in the frontal plane.
- *Rotation (left and right).* Subjects crossed the arms on the chest and rotated the head and shoulders as far as possible to one side, while respecting the transverse plane.
- *Anterior trunk flexion with left and right rotation (rotated pelvis).* Subjects sat with the pelvis rotated 30º to the left or right, and then performed the anterior trunk flexion task from that position.

Data analysis

Mean ROM and SPEED were calculated for each spinal segment and set of 10 trials per task per subject. Mean ROM (º) corresponded to the range of angular displacement of each spinal segment during 10 trials. In each photographic frame (200 Hertz), angular displacement in the sagittal (YZ) and frontal (XZ) planes was calculated from the vertical axis (Z) located on the proximal marker of each segment, as follows:

$$\Theta_{YZ} = \tan^{-1} \frac{Y_p - Y_d}{Z_p - Z_d} \text{ and } \Theta_{XZ} = \tan^{-1} \frac{X_p - X_d}{Z_p - Z_d}$$

and angular displacement in the transverse plane (XY) was calculated from the horizontal axis (Y) located on the proximal marker of each segment, as follows:

$$\Theta_{XY} = \tan^{-1} \frac{X_p - X_d}{Y_p - Y_d}$$

In these equations, X, Y, and Z are the lateral, horizontal, and vertical coordinates, respectively; *p* is the proximal segment marker; and *d* is the distal marker. Fig. 2 illustrates the calculation of angular displacement in a single frame during lateral side-bending.

Mean SPEED (º/s) was calculated as the mean of the amplitude between the maximal and minimal peak SPEEDs of each trial. Speed was calculated from the finite derivative of the angular displacement.

Statistical analysis

Reliability (Table II). To assess reliability, subjects were invited for a second session approximately 1 week (6.3 ± 1.5 days) after the first session. To minimize bias in the kinematic variables due to a significant change in pain score, each patient was asked before the second session

whether he/she remained in a state of pain similar to that at the time of the first session. The visual analogue scale (VAS) was also used to assess back pain in patients with chronic NS-LBP before each session (Table I); paired *t*-tests and intraclass correlation coefficients (ICCs) were used to confirm that VAS scores did not differ significantly between sessions (*p* = 0.44, ICC = 0.85). Each subject was evaluated by the same examiner during both sessions. Reliability assessments were performed according to a method described by Wagner et al. (34) using the ICC and the standard error of the measurement (SEM).

ICCs indicated variations in the population sample within and between patients (34). ICC consistency parameters were calculated in a 2-way mixed model using the SPSS software (version 16.0 for Windows; SPSS Inc., Chicago, IL, USA). According to Shrout & Fleiss (35), an ICC > 0.75 indicates excellent reliability, ICC of 0.40–0.75 indicates fair to good reliability, and ICC < 0.40 indicates poor reliability.

SEMs estimated non-systematic variance (34), including natural fluctuation in a single patient's kinematic patterns and the potential non-reproducibility of the optoelectronic system. As a measure of within-subject variability among repeated trials, the SEM expressed
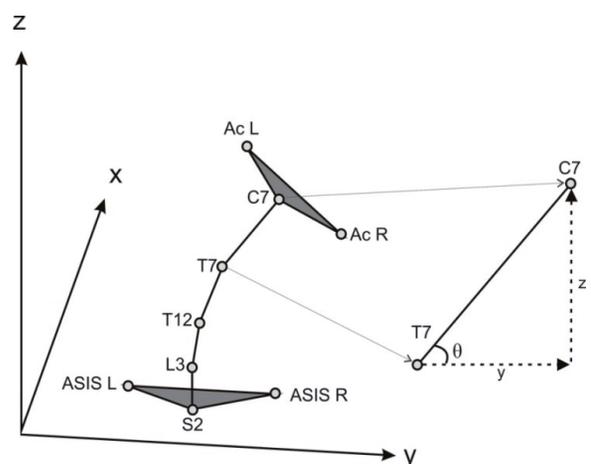

Fig. 2. Illustration of angle calculation for the lateral side-bending task. Side-bending is performed in the sagittal plane, and the angular displacement of each segment is calculated from the vertical (Z) and horizontal (Y) axes. A close-up image of angular displacement in the upper thoracic segment (C7–T7) is presented in the right-hand part of the figure. ASIS: anterosuperior iliac spines; Ac: acromioclavicular; L: left; R: right.

Table II. *Reliability and responsiveness results of trunk movement tasks*

Trunk task	Healthy (*n*=25)			Chronic NS-LBP (*n*=25)		
	ICC	SEM%	MDC%	ICC	SEM%	MDC%
Flexion						
ROM						
LLS	0.91	5.9	16.6	0.87	12.8	35.4
ULS	0.91	4.8	13.4	0.87	10.6	29.5
TLS	0.90	4.5	12.5	0.86	9.6	26.7
LTS	0.89	3.9	10.9	0.92	7.1	19.9
UTS	0.89	4.1	11.4	0.90	7.3	20.4
SPEED						
LLS	0.93	8.8	24.4	0.82	16.9	46.9
ULS	0.94	7.1	19.6	0.84	13.2	36.7
TLS	0.94	6.3	17.5	0.89	10.1	27.9
Lateral side-bending	L/R	L/R	L/R	L/R	L/R	L/R
ROM						
LLS	0.86/0.96	11.5/13.7	32.1/38	0.92/0.81	13.7/19.4	38.1/53.7
ULS	0.90/0.85	7.6/9.1	21.2/25.1	0.94/0.96	9.8/6.1	27.3/16.7
TLS	0.91/0.87	6.8/7.1	18.8/19.8	0.93/0.93	9.5/8.4	26.4/23.3
LTS	0.80/0.70	6.3/5.8	17.5/16.3	0.94/0.95	6.2/4.3	17.3/11.8
UTS	0.76/0.60	6.4/6.5	17.8/18.1	0.85/0.90	7.5/5.9	20.8/16.3
SPEED						
LLS	0.77/0.75	15.6/19.4	43.4/53.8	0.90/0.77	15.3/18.8	42.5/46.4
ULS	0.84/0.70	9.4/16.9	26.1/46.8	0.91/0.85	11.7/9.9	32.6/27.3
TLS	0.87/0.72	8.2/15.1	22.8/46.6	0.90/0.86	12.1/10.3	33.4/28.4
Rotation	L/R	L/R	L/R	L/R	L/R	L/R
ROM						
SS	0.70/0.96	6.5/4.7	18.1/12.9	0.81/0.87	11.8/9.2	32.8/25.4
Flexion with rotation	L/R	L/R	L/R	L/R	L/R	L/R
ROM						
LLS	0.82/0.92	8.4/9.7	23.3/27.1	0.93/0.91	10.4/11.9	29.1/33.2
ULS	0.85/0.90	6.4/8.4	17.9/23.3	0.93/0.92	9.5/11.3	26.4/31.3
TLS	0.86/0.88	5.4/7.1	15.2/19.7	0.93/0.92	8.6/11.3	23.9/31.3
LTS	0.85/0.89	4.1/5.1	11.6/14.2	0.93/0.94	8.1/6.9	22.4/19.1
UTS	0.88/0.93	3.3/3.8	9.3/10.4	0.92/0.81	7.8/14.4	21.7/39.9
SPEED						
LLS	0.85/0.87	13.8/12.5	38.3/34.6	0.92/0.87	10.8/14.8	29.9/40.9
ULS	0.82/0.85	12.9/11.1	35.8/30.7	0.90/0.75	10.1/14.1	27.7/39.2
TLS	0.78/0.84	12.6/10.8	34.9/29.9	0.89/0.75	9.8/7.5	27.2/20.8

NS-LBP: non-specific low back pain; ROM: range of motion (in degrees); SPEED: velocity (in degrees/s); LLS: lower lumbar spine (S2–L3); ULS: upper lumbar spine (L3–T12); TLS: total lumbar spine (S2–T12); LTS: lower thoracic spine (T12–T7); UTS: upper thoracic spine (T7–C7); SS: shoulder segment (acromioclavicular Left– acromioclavicular Right); ICC: intraclass correlation coefficient; SEM%: standard error of measurement, expressed as a percentage; MDC%: minimal detectable change, expressed as a percentage; L/R: left and right.

the measurement error in the same units as those of the original measurement. SEM was calculated as:

$$SEM = SD_x \sqrt{(1-R_x)}$$

where SD is the standard deviation for all observations, *x* represents sessions 1 and 2, and R is the test-retest reliability coefficient (ICC) for sessions 1 and 2.

Measurement error was also expressed as the SEM%, the within-subject SD as a percentage of the mean, which was defined as:

$$SEM\% = \frac{SEM}{mean} \times 100$$

where mean is the mean of all observations in sessions 1 and 2. The SEM% indicates measurement error independent of the unit of measurement, and represents the limit for the smallest change indicating real improvement for a subject group (34).

Responsiveness. This parameter indicated sensitivity to a change in outcome measures and was assessed from the SEM using the minimal detectable change (MDC). MDC_{95} represented the change in variables falling outside of the measurement error and the magnitude of change necessary to exceed the measurement error of two repeated sessions (T_0

and T_1) at a specified confidence interval (CI) of 95%:

$$MDC_{95} = 1.96 \times \sqrt{2} \times SEM$$

where 1.96 is the 2-sided table *z* value for the 95% CI and √2, is used to account for variance in the two measurement sessions (34).

The MDC was made independent of the unit of measurement by expressing it as a percentage (MDC%), which was defined as:

$$MDC\% = \frac{MDC95}{mean}$$

where mean is the mean of all observations for a task in sessions 1 and 2. The MDC% thus represents the smallest real change in a single individual (34).

Comparison between groups (Table III). Student's *t*-tests were used to compare the overall means of ROM and SPEED for each spinal segment variable (*n*=42) between groups. The effect size with the standardized mean of difference (SMD) was calculated to compare the magnitude of the difference between populations:

$$SMD = \frac{mean\ A - mean\ B}{mean\ SD}$$

Table III. *Healthy controls vs. NS-CLBP*

Trunk task	Healthy (n=25) Mean (SD)	Chromic NS-LBP (n=25) Mean (SD)	SMD Effect size	β	Standard error	Constant
Flexion						
ROM						
LLS	73.1 (15.8)	53.8 (16.3)***	1.2			
ULS	81.9 (15.9)	60.9 (16.8)***	1.3			
TLS	92.2 (14.9)	69.4 (16.8)***	1.4			
LTS[a]	110.4 (14.1)	85.4 (20.4)***	1.4	−0.074	0.039	Step 1: 7.05
UTS	122.4 (15.2)	100.1 (22.0)***	1.2			
SPEED						
LLS	120.7 (42.4)	88.1 (32.1)**	0.9			
ULS	139.6 (40.9)	101.1 (31.8)***	1.1			
TLS	159.3 (40.8)	117.6 (34.3)***	1.1			
Rotation (left)						
ROM						
SS	57.6 (10.2)	50.6 (12.1)*	0.6			
Rotation (right)						
ROM						
SS[a]	65.6 (10.4)	50.6 (12.6)***	1.3	−0.111	0.045	Step 2: 12.34
Flexion with rotation (left)						
ROM						
LLS	61.2 (13.3)	39.6 (15.7)***	1.5			
ULS	71.6 (13.1)	47.4 (17.3)***	1.5			
TLS[a]	82.6 (12.8)	55.8 (18.4)***	1.7	−0.059	0.034	Step 3: 17.77
LTS	98.2 (11.8)	70.3 (21.2)***	1.7			
UTS	108.7 (10.5)	82.9 (22.5)***	1.5			
SPEED						
LLS	96.9 (32.9)	63.5 (23.1)***	1.2			
ULS	115.6 (32.7)	77.8 (22.7)***	1.3			
TLS	134.9 (33.3)	94.1 (25.7)***	1.4			
Flexion with rotation (right)						
ROM						
LLS	61.1 (14.8)	39.4 (18.8)***	1.3			
ULS	71.7 (14.3)	46.9 (20.6)***	1.4			
TLS	81.9 (13.9)	54.7 (22.8)***	1.5			
LTS	98.5 (11.6)	69.9 (25.1)***	1.6			
UTS	110.8 (10.4)	85.8 (30.9) ***	1.2			
SPEED						
LLS	98.1 (37.2)	60.2 (28.1)***	1.2			
ULS	116.4 (38.5)	66.1 (20.6)***	1.7			
TLS[b]	135.4 (40.3)	76.1 (18.2)***	2	−0.063	0.018	Step1: 6.19

*p<0.05; **p<0.005; ***p<0.001. [a]Most discriminant ROM variables; [b]most discriminant SPEED variable.

SMD: standardized mean of difference (Cohen's d); NS-LBP: non-specific low back pain; ROM: range of motion (in degrees); SPEED: velocity (in degrees/s); LLS: lower lumbar spine (S2–L3); ULS: upper lumbar spine (L3–T12); TLS: total lumbar spine (S2–T12); LTS: lower thoracic spine (T12–T7); UTS: upper thoracic spine (T7–C7); SS: shoulder segment (acromioclavicular Left–acromioclavicular Right).

where mean A is the mean of the healthy group, mean B is the mean of the chronic NS-LBP group, and mean SD is the mean of SDs A and B.

We calculated an index enabling better discrimination between groups using binary logistic regression analyses (stepwise forward likelihood ratio in SPSS). These analyses were applied only to variables found to differ significantly by Student's t-tests (n=26). These variables were assigned as independent variables, and group membership (0=healthy, 1=chronic NS-LBP) was the dependent variable. Before regression analyses were performed, the variance inflation factor (VIF) was estimated for each of the 26 selected variables, in order to remove variables with strong correlation (VIF > 10); 17 variables were finally selected and included in the logistic regression (36).

Sensitivity and specificity. These parameters were determined by constructing receiver operating characteristic curves (MedCalc software, version 11.5, Mariakerke, Belgium) from each subject's logit scores

(LSs) of ROM and SPEED, to identify the most discriminant variables from the binary logistic regression. The greatest Youden index (Y=sensitivity + specificity – 1) was chosen as a decision criterion for the most appropriate cut-off LSs for ROM and SPEED (37).

The generalizability of our results to people not tested in the experiment was assessed using the probability (α=0.05) equation based on the LSs with any new subject (p>0.5=affected by chronic NS-LBP; Table IV).

RESULTS

Overall, ROM and SPEED variables showed good to excellent reliability and responsiveness for all tasks and spinal segments in healthy subjects (ICC=0.60–0.96, SEM%=3.3–19.4%, MDC%=9.3–53.8%) and subjects with chronic NS-LBP

Table IV. *Sensitivity and specificity of logit scores for range of motion (ROM) and speed (SPEED)*

Logit score	Sensitivity/ specificity %	Cut-off value	Area under ROC curve Mean [95% CI]	Standard error	*p*-value	Probability (α=0.05)
LS ROM=17.77–(0.074×LTS°)–(0.11×SS°)–(0.059×TLS°)	92/84	–0.6507	0.95 [0.85–0.99]	0.028	<0.0001	$P = \dfrac{e^{LS\ rom}}{1+e^{LS\ rom}}$
LS SPEED=6.19–(0.063×TLS°/s)	92/80	–0.3544	0.90 [0.77–0.96]	0.050	<0.0001	$P = \dfrac{e^{LS\ speed}}{1+e^{LS\ speed}}$

p>0.5 indicates patient affected by chronic non-specific low back pain.
ROC: receiver operating characteristic; CI: confidence interval; LS ROM: logit score for range of motion; LTS°: lower thoracic spine ROM in flexion; SS°: shoulder segment ROM in right rotation; TLS°: total lumbar spine ROM in flexion with left rotation; LS SPEED: logit score for speed; TLS°/s: total lumbar spine speed in flexion with right rotation.

(ICC=0.77–0.96, SEM%=4.3–19.4%, MDC%=11.8–53.7%; Table II).

ROM and SPEED variables showed a highly significant difference ($p<0.001$) between healthy subjects and those with chronic NS-LBP in all spinal segments during anterior flexion (Table III). The SMDs for this task showed very large effect sizes (0.9–1.4). The ROM variable for the SS showed a significant difference between groups ($p<0.05$, SMD=0.6) for left trunk rotation and a highly significant difference ($p<0.001$, SMD=1.3) for right trunk rotation. Both variables showed highly significant ($p<0.001$) differences between groups and large effect sizes (SMD=1.2–2) in all spinal segments for trunk flexion with rotation (Fig. 3). For the lateral side-bending task, most ROM and SPEED variables in all spinal segments were not normally distributed and did not differ significantly between groups ($p>0.05$).

Binary logistic regression analyses indicated that the most discriminant variables were ROM in the LTS segment during flexion (LTS°), SS during right rotation (SS°), and the TLS segment during flexion with left rotation (TLS°); and SPEED in the TLS segment during flexion with right rotation (TLS°/s; Table III, Fig. 4).

LSs for ROM showed a sensitivity of 92% and a specificity of 84%, with a cut-off value of –0.65; LSs for SPEED showed a sensitivity of 92% and specificity of 80%, with a cut-off value of –0.35 (Table IV).

DISCUSSION

Our kinematic spine model and trunk movement protocol demonstrated good to excellent reliability and validity for the use of ROM and SPEED measurements to identify patients with chronic NS-LBP (15, 20, 24–31). Previous studies (20, 24–29, 31) have assessed primarily the lumbar spine segment during unidirectional trunk movement in a standing position. In the present study, decreased ROM and SPEED were observed for all tasks (7 directions) in all spinal segments only in the chronic NS-LBP group; these findings may reflect localized disorders of the lumbar spine. Only left and right lateral trunk side-bending failed to reach the statistical power of 0.8 for the majority of variables, or displayed non-normal distribution or non-significant differences between groups. Thus, although this task showed reliability and was found previously to discriminate between healthy subjects and those with LBP (28), we believe that it should not be used to identify subjects with chronic NS-LBP; for the purpose of simplification, it was removed from Table III.

Marras et al. (20, 24) described speed and acceleration from a standing position, but not ROM, as sensitive variables to dis-
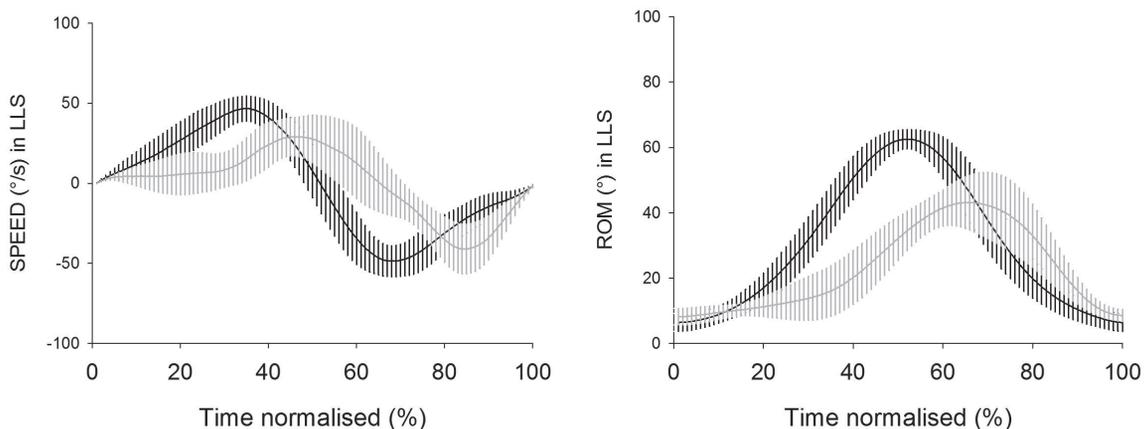

Fig. 3. Typical curves for speed in °/s and range of motion (ROM) in ° as function of normalized time in % during trunk flexion with rotation ($n=10$ trials) in the lower lumbar spine segment. Grey=mean curve of patient with chronic non-specific low back pain; black=mean curve of a healthy subject. Vertical bars expressed the standard deviation of 10 trials.
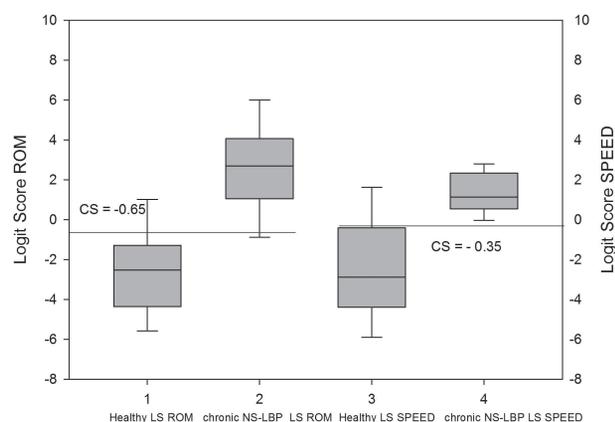
Fig. 4. Boxplots of logit scores for range of motion (ROM) and speed in healthy subjects and those with chronic non-specific low back pain (chronic NS-LBP). CS: cut-off score.

tinguish chronic LBP. Compared with those of healthy subjects, the kinematic variables of patients with LBP showed a specific "motion signature" during active trunk movements, which revealed the musculoskeletal status of the spine with a very good sensitivity and specificity (20, 24). We obtained similar findings for the LSs of SPEED, but also found the LSs of ROM to be very sensitive, probably due to the seated reference position and the use of LSs from the binary logistic regression.

Larivière et al. (33) observed increased mobility in the thoracic spine during trunk flexion in patients with chronic LBP, which they interpreted as compensation for the loss of flexibility in the lumbar spine. In contrast, our results demonstrated significant stiffness (reduced ROM) in the thoracic spine in the chronic NS-LBP group compared with healthy subjects. This discrepancy may be explained by methodological differences between studies; the previous trial (33) used a standing position, which probably stimulated compensation in the thoracic spine when subjects attempted to touch the floor during flexion (28, 30, 31). Moreover, the natural reduction in hamstring flexibility with age may have limited lumbar spine mobility during forward flexion from a standing position (31).

The tasks used in our protocol were chosen on the basis of biomechanical (38–40) and classification system evidences for NS-LBP (14–18). For example, anterior flexion increases the load on vertebral discs and may cause back pain due to the enhancement of neural compression. Moreover, the posterior fibres of the annulus and posterior ligaments are thought to provide resistance (38). Side-bending of the trunk decreases ROM in subjects with LBP generated by painful hernia and/or facet joints (15, 26, 28, 39). Rotations are focused on the thoracolumbar hinge because of the very small biomechanical motion of the lumbar spine during such motion (39). Anterior trunk flexion with pelvic rotation increases the pelvic constraint due to the inferior and superior iliolumbar ligaments, leading to lumbar stiffness, especially in the LLS, and thus reduced ROM (40).

Our kinematic protocol initially included a trunk extension task because such movement increases the load on the facet joints in degenerative vertebrae (39) and is used in the MICS for NS-LBP

(14–18). However, our preliminary study found that trunk extension from a seated position showed poor reliability (ICC=0.25–0.60), and subjects perceived this task to be difficult or dangerous. Therefore, this task was deleted from our protocol.

Preliminary analysis also revealed poor reliability (ICC <0.40, SEM% >20%) for the variables in all spinal segments for the performance of anterior trunk flexion at an imposed speed (following a metronome rhythm), as compared with performance at a non-imposed speed. Moreover, several previous studies (20, 24–31) have proven the reproducibility of non-imposed speed during trunk movements; our protocol thus used a non-imposed speed.

The ROM and SPEED variables during trunk movement tasks demonstrated good to excellent reliability (ICC ≥0.7, SEM% ≤15%), and LSs provided the best discrimination between populations. These logit indices may be helpful as quantitative kinematic outcome measures to support the diagnosis any patient with chronic NS-LBP or to evaluate improvement in future clinical trials.

Our results provide additional insight into the future use of kinematic spine motion models to aid the classification of NS-LBP subgroups. These models can also improve the targeting of specific treatments (e.g. MT, AR) adapted to movement impairments and motor control, as well as measure therapeutic effects with the MDC and/or LS in clinical practice for a single patient, or with the SEM and/or LS in clinical studies for a sample of patients.

The LSs for sensitivity and specificity and the results of probability equations indicate the generalizability of our results to people not tested in these trials (Table IV). Nevertheless, these findings should be interpreted cautiously because of the small sample size in this study. Therefore, future trials using our spine model should have increased sample sizes and integrated SPEED variables for the thoracic spine to improve LSs.

In conclusion, the quantitative analysis of kinematic motion patterns in subgroups of patients with chronic NS-LBP during trunk movements in different directions is of major importance because it can help clinicians to identify motion patterns that may contribute to chronic NS-LBP disorders and target interventions according to the quality of movement. The kinematic spine model and standardized protocol including 7 trunk motion tasks demonstrated good to excellent reliability. However, only 4 tasks were selected for inclusion in the final protocol. The LSs of ROM and SPEED variables may be used as quantitative outcome measures to aid in the diagnosis and assessment of patients with chronic NS-LBP before and after physical therapy (e.g. MT) in clinical practice and research. To our knowledge, such analyses have not been used in randomized clinical trials assessing the efficacy of physical therapies in NS-LBP subgroups.

ACKNOWLEDGEMENTS

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