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Multi-segment spine and hip kinematics in asymptomatic individuals during standardized return from forward bending versus functional box lifting

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ABSTRACT

Clinically, sagittal spinal mobility is objectively assessed by forward bending range of motion (ROM) tests such as the modified-Schober test (m-Schober test). However, evidence comparing ROM during forward bending and daily activities is limited. In this study, a kinematic model including six spinal regions, pelvic/sacral and femur segment was used to characterize associations between m-Schober test and return from forward bending (RFB), and between RFB and lifting. No significant correlations were found between m-Schober test and lumbar ROM during RFB. Furthermore, we found significantly smaller ROM in all spinal regions during lifting compared to RFB, except in the upper thoracic spine, lumbosacral (L5/S1) and hip joints. However, we observed moderate to very strong correlations between the two movements tasks for all lumbar regions. Furthermore, cross-correlation between L5/S1 and lower lumbar spine regions showed no segmental redundancy of L5. These results suggest that an m-Schober test provides insufficient insight into lumbar mobility and that multi-segmental spine measurements should be introduced clinically. Furthermore, this study has demonstrated that RFB can be used as a reference for lumbar regions during lifting, with use of the current multi-segmental spine model and that the inclusion of L5/S1 provides more detailed information on lumbar kinematics.

1. Introduction

Assessment of spinal and hip mobility is part of good clinical practice when evaluating spinal impairments during intake and intervention follow-up (Dankaerts et al., 2006). Clinicians routinely evaluate impairments of spinal mobility by measuring spinal range of motion (ROM) with commonly available and easy to use instruments such as the tape measure method. The Modified-Schober Test (m-Schober test) is regarded as a radiographically validated tape measure method and is commonly used by practitioners to measure lumbar mobility in maximal forward bending of the trunk despite its shortcomings discussed below (Reynolds, 1975; Williams et al., 1993; Wright, 1983).

Current measuring standards for lumbar spine mobility used in clinical practice have limitations in several aspects. Firstly, many clinical studies using more advanced motion capture devices demonstrated a complicated interaction between lumbar and hip kinematics during sagittal movements. This is generally described as the lumbar-hip complex (Dankaerts et al., 2006; Shum et al., 2005; Tully et al., 2005; Williams et al., 2013; Wong and Lee, 2004). Besides that, the spine naturally behaves as multiple spinal regions with distinct movement patterns during both clinical and functional tasks (Alqhtani et al., 2016, 2015, Christe et al., 2017, 2016; Dankaerts et al., 2006; Gombatto et al., 2017; Leardini et al., 2011; Parkinson et al., 2013). Therefore, tools such as the m-Schober test, while simple and easy to use, do not take into account the multiple spinal segments and hip motion. As a consequence these measurements might provide insufficient detail as a diagnostic tool for disorders of the lumbar-hip complex (Alqhtani et al., 2015). Secondly, albeit multiple spinal regions have different movement patterns during standardized clinical tasks and functional activities of daily living (ADLs) such as lifting, the relationship between spinal mobility during these clinical tasks and ADL is not well understood (Alqhtani et al., 2015; Ogata et al., 2018), and is unlikely to be fully revealed using single segment spine measurements such as the m-Schober test.

Lifting an object from the floor is a common functional task, which can involve increased loading of both the spine and hips. As a

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consequence, analysing this task has recently received considerable attention in clinical biomechanics and ergonomics (Alqhtani et al., 2016, 2015; Gombatto et al., 2017; Ogata et al., 2018). As mentioned above, sagittal spinal ROM is predominantly tested with a simple standardized forward bending task (e.g. m-Schober test) in clinical practice. Nevertheless, tests analysing more complex functional tasks that resemble ADLs are often lacking. This is a matter of concern, as there is only limited evidence linking spinal ROM during a standard forward bending task with ROM during ADLs.

Alqhtani et al. (2015) did not find correlations between spinal ROM during standard forward bending and the functional task of lifting a box, except for ROM in the lower lumbar spine (LLs). Consequently, they suggested that clinicians should not extrapolate clinical findings of ROM during forward bending to other functional sagittal tasks (Alqhtani et al., 2015). Additionally, the return from forward bending (RFB) phase may provide a more clinically relevant measure than the downward phase, given its similarity to the extension phase of lifting or sit-to-stand (against gravity). However, if spinal ROM during RFB shows to be different from lifting or other common sagittal functional tasks, the use of RFB as a reference for all sagittal ADLs is only possible if there is a high between-task correlation. Otherwise, this may lead to erroneous clinical judgement of spinal movement deficits.

Most of the above-mentioned multi-segmental spine studies defined the LLs as the angle between the sacrum and the third lumbar vertebra (L3) (Alqhtani et al., 2016, 2015; Dankaerts et al., 2006; Leardini et al., 2011; Parkinson et al., 2013). This may dissolve important information about the lumbosacral joint (L5/S1) mobility. The fifth lumbar vertebrae (L5) is the lowest and most mobile lumbar vertebrae, and is facing the highest compression and shearing forces during movements such as forward bending and lifting (Hamill and Knutzen, 2009; Iyer et al., 2010). It could therefore be interesting to investigate if a separate L5 segment in addition to the LLs and sacral segment can add relevant information about the lumbosacral (L5/S1) movement. However, the addition of a new segment could also be redundant if the movement pattern of the added segment (and regional/joint angle between segments) highly correlates with the pattern of an adjacent segment, also known as spatiotemporal similarity. Schinkel-Ivy and Drake (2015) used multiple clusters of markers (CM) on the thoracic spine to test thoracic movement during elementary tasks. They stated that adjacent thoracic CMs whose angular time-series showed a strong spatiotemporal similarity (cross-correlation) were considered to be redundant (i.e. one of the clusters could be eliminated) (Ryan and Bruno, 2017; Schinkel-Ivy and Drake, 2015). The need to add an L5 segment should therefore also be tested for segmental redundancy. Additionally, the inclusion of multiple thoracic segments could provide interesting insights into possible adaptations or links between mobility in thoracic and lumbar regions while performing forward bending and lifting. Therefore, the current study focussed on differences and correlations in multi-segment spine kinematics between a standardized clinical task and a functional task with a model that separates the lumbosacral joint from the LLs region.

This study had several aims. The first aim was to investigate the correlation between m-Schober test and lumbar ROM during forward bending using the multi-segment spine model. The second aim was to explore spinal ROM differences and relationship between a standardized RFB task and a functional box lifting task. The third aim was to explore whether or not a separate L5 is segmentally redundant.

We hypothesized that there would be no significant correlations between lumbar forward bending ROM and m-Schober test, since we have stated that the m-Schober test is too generic as a diagnostic tool for spinal mobility in the lumbar-hip complex. Next, we hypothesized significantly smaller spinal and hip ROM during box lifting compared to RFB, but significant positive correlations ($r > 0.6$) in ROM between these tasks (Kottner et al., 2011). Furthermore, we hypothesized that the inclusion of a separate L5 segment provides relevant kinematic detail and is not segmentally redundant ($r < 0.6$).

2. Methods

2.1. Participants

A priori sample size calculations, based upon a previous study by Alqhtani et al. (2015) which investigated ROM differences and correlations and correlations between flexion, lifting and other tasks in the upper lumbar spine (ULs) and LLs (Alqhtani et al., 2015), resulted in a required sample size of 18 subjects ($\eta^2 = 0.85$; $\alpha = 0.05$; $\beta = 0.10$) (G*Power 3.1, Kiel, Germany). In the current study, 18 healthy individuals were included (11 males, 7 females). Mean and standard deviation (SD) for age, weight and height were 45.8 ± 14.8 years, 74.0 ± 14.5 kg and 1.76 ± 9.5 m respectively. Potential participants were recruited by convenience sampling, word-of-mouth advertising within the faculty of Movement and Rehabilitation Sciences of KU Leuven and in personal social media network of involved researchers. Subjects had to be free of any physical injury two months prior to the measurements, must have had no history of subacute or chronic back pain (>6 weeks) or spine related injuries/diseases, no past health condition affecting the neuromuscular system and no visual aberrations in posture or gait (no asymmetry, pelvic drop, scoliosis or limping) based on an evaluation by the assessor (SS). The study protocol was approved by the Medical Ethical Committee of the University Hospitals Leuven (S58067). All participants signed informed consent prior to testing in accordance with the Declaration of Helsinki.

2.2. Instrumentation and marker placement

Three-dimensional motion analysis was performed by means of 10 infrared Vicon MX motion capture cameras with sampling rate of 100 Hz and Vicon Nexus 2.4 software (Vicon Motion Systems, Oxford, UK). A full body plug-in-gait (PiG) marker-set was adapted with the addition of CMs on the second, sixth and tenth thoracic spinal process (T2, T6, T10), and on the first, third and fifth lumbar spinal process (L1, L3, L5), each CM containing three sticks with reflective markers

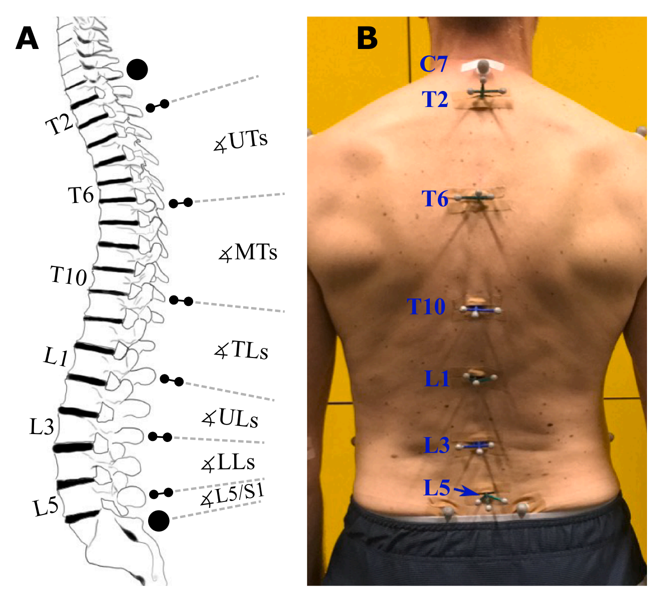

Fig. 1. (A) Sagittal plane: model illustration of spinal cluster markers (CMs; Ø 8 mm) on spinal processes of T2, T6, T10, L1, L3 and L5, and normal markers (Ø 14 mm) on the posterior superior iliac spine, both left and right side. ∡UTs: Upper Thoracic spine angle between T2 and T6, ∡MTs: Mid Thoracic spine angle between T6 and T10, ∡TLs: Thoracolumbar spine angle between T10 and L1, ∡ULs: Upper Lumbar spine angle between L1 and L3, ∡LLs: Lower Lumbar spine angle between L3 and L5, and ∡L5/S1: lumbosacral joint angle between L5 and sacral bone. (B) Frontal plane: representation of the in vivo spinal marker placement onto a human subject.

(Fig. 1). Spinal CM models have previously shown to be reproducible (Needham et al., 2015; Seerden et al., 2016) and is further supported by currently unpublished data from a reproducibility study by our research group, which showed high test-retest repeated-measures reliability (Intra-class correlation coefficients between 0.62 and 0.96) and good agreement (standard error of measurement < 2.1°; average SD < 2°) (Seerden et al., 2019). The origin of each CM was defined by the congregation point of its three sticks with markers. Rotation around the X, Y and Z axes correspond to three-dimensional (3D) angular movement in the sagittal, frontal and transversal plane respectively. The following relative (3D) angular kinematics between adjacent spinal CMs were calculated with use of the XYZ Cardan-rotation sequence from previous research (Seerden et al., 2019, 2016): Upper Thoracic (UTs; between T2-T6), Mid Thoracic (MTs; between T6-T10), Thoracolumbar (TLs; between T10-L1), Upper Lumbar (ULs; between L1-L3), Lower Lumbar (LLs; between L3-L5) and Lumbosacral (L5/S1; between L5 and pelvic segment) based on previous literature (Leardini et al., 2011; Needham et al., 2015; Schinkel-Ivy and Drake, 2015; Seerden et al., 2016). Hip joints were defined according to the standard Vicon PiG model between the femur and pelvic segments. The trunk angle, defined in the PiG model as the angle between the thorax and pelvic segments, was also calculated. Positive 3D angles represented flexion, and both bending and axial rotation to the right side. Negative angles represented extension, and bending and rotation to the left side.

2.3. Procedures

A standing static calibration trial was performed before all movements. The alignment between adjoining spinal segments was defined by 0° during standing static calibration. Each subject's kinematics during the movements were expressed relative to their standing static calibration trial. Range of motion was analysed for a return from forward bending task and a sagittal box lifting task (Fig. 2). Each task was executed five consecutive times. The first trial was only used for familiarisation with the movement. The following four trials were used for analysis. For the forward bending and return task, participants were instructed to bend the trunk forward as far as possible (flexion phase) and return to standing position (returning phase), while keeping the knees extended and the feet flat on the floor during the whole movement. Individuals with very large trunk flexion were instructed to abduct the arms while reaching maximal forward bending, to prevent floor contact with the hands. Angular kinematics and ROM were analysed from full forward bending position (0%) until standing straight (100%) again (Fig. 2A, Fig. 3), also known as RFB. For the box lifting task, participants were instructed to freely pick up a transparent box with a fixed weight of six kilograms from the floor, starting from a standing position, with both feet constantly in full contact with the floor. The box was centred in front of the subjects' toes at 15 cm distance. Angular kinematics and ROM were analysed from box lift-off (0%) to standing straight while holding the box passively in front of the hips (100%) (Fig. 2B, Fig. 3). Calculated start and ending point for both RFB and box lifting: 0% indicated by the start of vertical acceleration of the C7 marker, 100% as the stop of horizontal deceleration of C7: threshold = 0.1 m/s^2 for > 5 frames).

After all motion capture measurements, an m-Schober test for forward bending ROM was performed as described in previous literature (Wright, 1983). While the subject was standing up straight, the midpoint of the lumbosacral junction between left and right Posterior Superior Iliac Spine (PSIS) was marked, as well as 5 cm below and 10 cm above the mid PSIS line using a tape measure. Subsequently, the subject was asked to bend the trunk forward with straight legs. Instructions were completely similar to those of the forward bending and return task during motion capture analysis. At maximum forward bending, the distance between the upper and lower mark was measured again. The m-Schober test outcome is the length difference between maximal forward bending and standing straight (maximal forward bending lumbosacral length (cm) – 15 cm of standing straight). The m-Schober test was implemented in this study because this test is also used in clinical practice by the co-authors (division of rheumatology, University Hospitals Leuven).

2.4. Data processing

A full body Vicon PiG kinematic model was constructed with the addition of six spinal segments based on the previously described CMs'. Main outcome parameters were relative ROM of the six spinal regions and of the hips. The relative trunk angle (as defined by the PiG model) was also calculated to show potential importance of a detailed multi-segmental spine model compared to a one-segment trunk analysis. Furthermore, to examine the speed of the movements, the average trunk angular velocity during RFB and box lifting was calculated for each participant. Percentage of box lifting over RFB ROM was

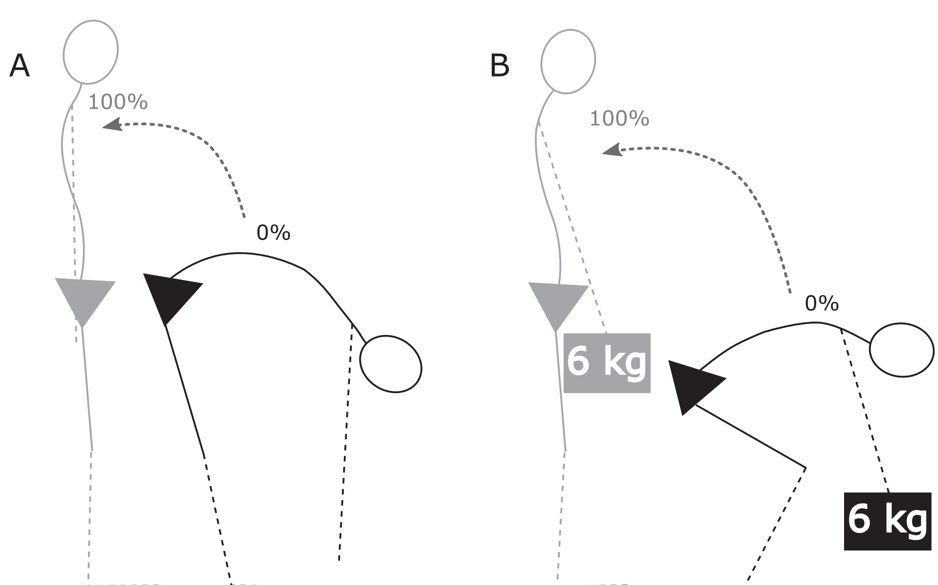

Fig. 2. (A) return from forward bending; (B) box lifting with 6 kg weight. The dashed arrows in both A and B indicate the movement direction (0% is maximal forward bending in A and box lift-off in B, 100% is standing up straight in both A and B).

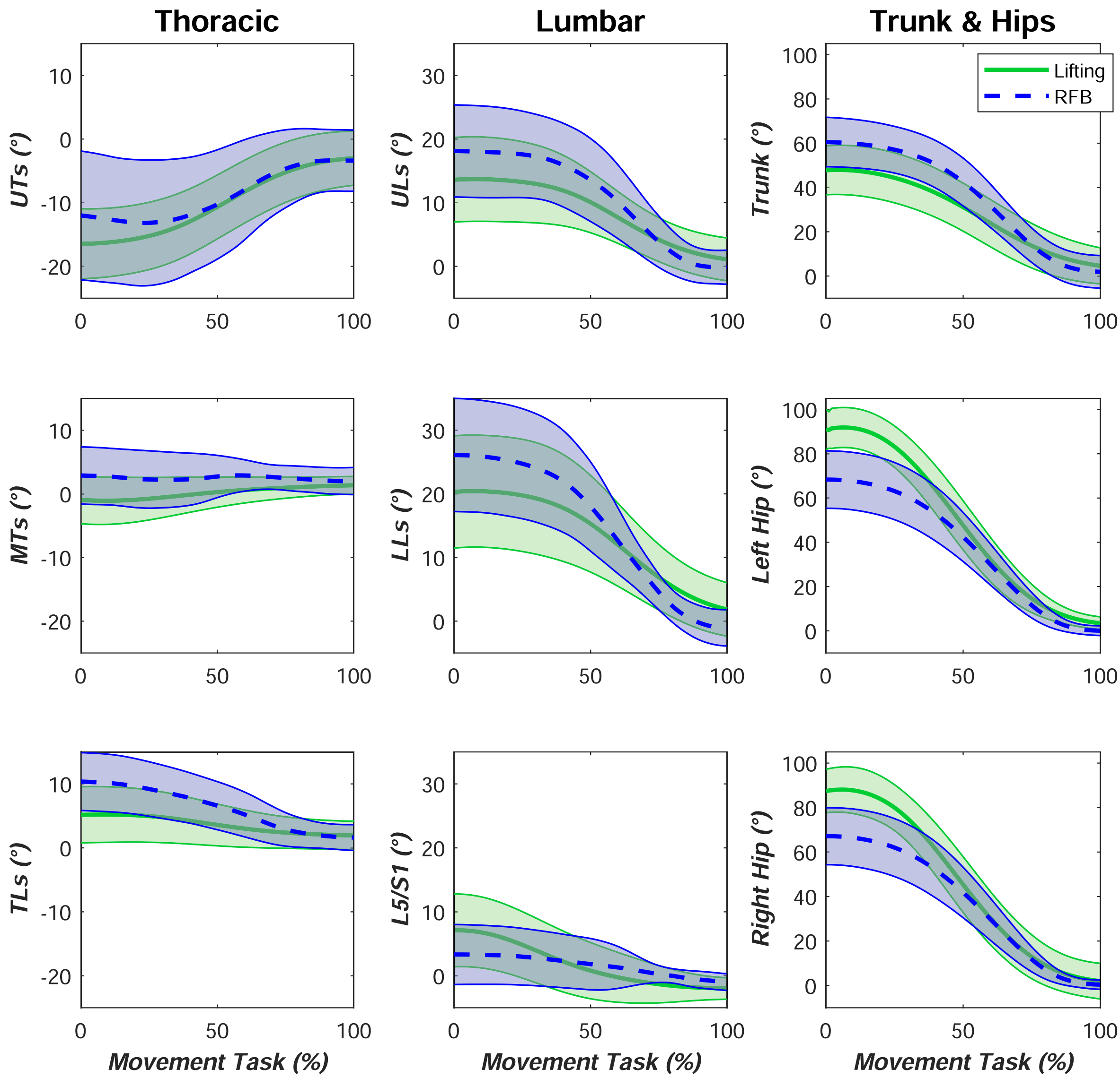

Fig 3. Group mean angles (flexion is positive, extension is negative) and standard deviation over normalized time during box lifting (green/solid) and return from forward bending (RFB; blue/dashed) in the upper thoracic spine (UTs), mid thoracic spine (MTs), thoracolumbar spine (TLs) [left]; upper lumbar spine (ULs), lower lumbar spine (LLs), L5/S1 [middle], total trunk and both hips [right] in the sagittal plane (0% is maximal forward bending/box lift-off, 100% is standing up straight). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

calculated as the average of each individual subject's percentage. Maximal lumbar spine flexion ROM was compared between data based on a) the m-Schober test and b) the lumbar kinematics from the motion capture analysis. The latter total lumbar ROM angle was calculated with a single lumbar angle from L1 to the pelvic segment (named combined lumbar ROM). All motion capture data was filtered with a fourth-order (zero-lag) low pass Butterworth filter with a cut-off frequency of 2 Hz, since the movements were executed in a slow and controlled manner (Needham et al., 2016). Filtering and post-processing was done in Matlab R2017b (Mathworks Inc., Natick, US).

2.5. Statistical analyses

Correlations between the m-Schober test and combined lumbar ROM during RFB, and between m-Schober test and PiG Trunk ROM were investigated with Spearman's Rank-order correlation coefficients using SPSS v20 (IBM Corporation, Armonk, USA), because a Shapiro-Wilk test for normality showed no normal distribution of the m-Schober test outcomes in this population.

A Shapiro-Wilk test for normality showed normal distribution and a Levene's test showed homogeneity of all spinal ROMs during both movement tasks. Therefore, significance of difference between spinal ROM during box lifting versus RFB was determined with a paired samples *t*-test. Next, Pearson product-moment correlation coefficients were calculated to determine the correlations in ROM between the two movements, in each of the six spinal regions and hips using SPSS v20 (IBM Corporation, Armonk, USA). A two-tailed paired-samples *t*-test was conducted for average trunk speed between RFB and box lifting task, to investigate whether or not the two movements are performed at different speeds.

The spatiotemporal similarity between the L5/S1 and LLs angle time-series was assessed to investigate whether or not the inclusion of a separate L5 segment shows segmental redundancy (Ryan and Bruno, 2017; Schinkel-Ivy and Drake, 2015). This was done with a cross-correlation analysis at the zero time-lag point (R_0) for the RFB task as described by Ryan and Bruno (2017), using the *crosscorr* function with a customized script written in Matlab v. R2017b (Mathworks Inc., Natick, US). This analysis was done for all RFB trials of all participants to calculate the individuals' R_0 means and R_0 SD. The overall R_0, R_0 SD (inter-subject variability) and averageSD (intra-subject variability:

Table 1
Spearman's correlations between modified-Schober test (cm) and forward bending ROM of ULs, LLs, L5/S1, combined lumbar and trunk angles (°).

	ROM ± SD	Spearman's rho			
				r	p value
MST (cm)	6.0 ± 1.4	MST vs.			
combined Lumbar (°)	53.3 ± 10.3		Combined Lumbar	0.05	0.42
ULs (°)	21.1 ± 7.0		ULs	0.10	0.68
LLs (°)	25.8 ± 5.4		LLs	0.26	0.33
L5/S1 (°)	8.2 ± 3.4		L5/S1	0.09	0.73
PiG Trunk (°)	60.3 ± 8.0		PiG Trunk	0.63	0.01 *

ULs: upper lumbar spine, LLs: lower lumbar spine, L5/S1: lumbosacral joint, PiG: Plug-in-Gait, ROM: Range of Motion, SD: Standard Deviation, combined lumbar is all participants ULs, LLs and L5/S1 ROM combined, significant values (p value ≤ 0.05) are marked with an asterisk (*).

average of all individuals R_0 SD) where subsequently calculated across all participants. All Pearson correlation coefficients as well as all segmental redundancy cross-correlation outcomes were interpreted following the standards: very weak (0.00–0.19), weak (0.20–0.39), moderate (0.40–0.59), strong (0.60–0.79), and very strong (0.80–1.00) (Kottner et al., 2011; Ryan and Bruno, 2017). Decisive statistical significance was set at $p < 0.05$ (two-sided) level for all tests.

3. Results

A Shapiro-Wilk test for normality showed no normal distribution of the m-Schober test outcomes in this population ($p = 0.021$). Mean (±SD) and Spearman's Rank-order correlations of m-Schober test versus ULs, LLs, and L5/S1 ROM, combined lumbar ROM, and versus trunk ROM are displayed in Table 1. A strong correlation was only observed between m-Schober test and trunk ROM ($r = 0.63$). No significant correlation was found between m-Schober test and any lumbar region ROM, nor the combined lumbar ROM during forward bending.

A Shapiro-Wilk test for normality showed normal distribution of all spinal ROMs during both movement tasks ($p \geq 0.059$). Mean (±SD) spinal and hip ROM during box lifting and RFB are presented in Table 2. Mean (±SD) angles time series for both movement tasks are depicted in Fig. 3. Paired samples *t*-test outcomes showed that ROM in box lifting was significantly smaller compared to RFB, for MTs, TLs, ULs and LLs regions and for the total trunk. However significantly larger ROM occurred in the box lifting task compared to RFB for the UTs, L5/S1 and hips (Table 2).

Significant moderate to very strong correlations were found between box lifting and RFB for TLs, ULs, LLs, L5/S1 and total trunk ROM ($r = 0.56 – 0.81$, $p < 0.05$). No significant correlations were shown for the hips, UTs and MTs ROM ($p > 0.05$, Table 2). No differences were observed in average trunk speed during RFB (24.4 ± 10.1°/s) and box lifting (27.1 ± 6.4°/s) ($p = 0.21$).

Cross-correlation at the zero time-lag point between the L5/S1 and LLs angle time series during RFB showed large inter-subject variability with individuals' R_0 ranging from −0.95 to 0.99. Small intra-subject variability showed with an averageSD of 0.09. Group mean R_0 showed a moderate correlation ($R_0 = 0.51$) with a very large standard deviation (R_0 SD ± 0.68).

4. Discussion

Despite a strong positive correlation between the m-Schober test and trunk ROM during forward bending, no significant correlations were observed between the m-Schober test and ROM of any lumbar region. Furthermore, ROMs in all spinal regions and the hips were significantly different between RFB and box lifting. However, ROM in the lumbar regions were correlated between these tasks. Cross-correlation between L5/S1 and the lower lumbar spine time-series angles showed that the addition of an L5 segment and L5/S1 joint is not segmentally redundant.

The first aim of this study was to investigate the relationship between a clinical m-Schober test versus multiple lumbar regions ROM, and versus trunk ROM of forward bending. The current results showed a strong correlation of m-Schober test with the PiG trunk ROM during RFB. Despite the strong correlation between m-Schober test and PiG trunk ROM, no relationship was found with any lumbar region, nor with the combined lumbar ROM (Table 1). This indicated that m-Schober test does not reflect actual lumbar kinematics and is too general to determine good clinical reasoning (Miller et al., 1992). For objective quantification of the spinal-hip complex, a more detailed measurement may be recommended for clinical evaluations.

The second aim was to study the differences in ROM of six spinal regions and the hip between a RFB task, commonly used in clinical

Table 2
Range of Motion, % of box lift compared to return from forward bending (RFB) task, Paired samples T-test significant differences, and Pearson product-moment correlation coefficients between both tasks for each spinal region and hips.

		ROM ± SD	Box lift/RFB	Paired samples T-test	Pearson's r		Correlation confidence interval	
		(°)	(%)	p value	*r*	p value	LB	UB
UTs	*Box lift*	−14.2 ± 4.2	144.3	< 0.01*	0.43	0.08	−0.03	0.74
	RFB	−10.8 ± 4.0						
MTs	*Box lift*	3.5 ± 2.0	34.6	< 0.01*	0.45	0.06	0.00	0.75
	RFB	2.0 ± 6.1						
TLs	*Box lift*	4.2 ± 3.0	44.5	< 0.01*	0.57	0.01*	0.15	0.81
	RFB	9.8 ± 3.9						
ULs	*Box lift*	12.9 ± 5.9	60.7	< 0.01*	0.81	< 0.01*	0.57	0.93
	RFB	21.1 ± 7.0						
LLs	*Box lift*	15.5 ± 3.8	60.2	< 0.01*	0.80	< 0.01*	0.52	0.93
	RFB	25.8 ± 5.4						
L5/S1	*Box lift*	10.2 ± 4.2	131.0	0.03*	0.56	0.02*	0.14	0.81
	RFB	8.2 ± 3.4						
Trunk	*Box lift*	43.2 ± 9.2	71.6	< 0.01*	0.70	< 0.01*	0.35	0.87
	RFB	60.3 ± 8.0						
Hips	*Box lift*	88.0 ± 10.2	117.0	0.01*	0.14	0.59	−0.33	0.60
	RFB	77.5 ± 13.5						

UTs: upper thoracic spine, MTs: mid thoracic spine, TLs: thoracolumbar spine, ULs: upper lumbar spine, LLs: lower lumbar spine, L5/S1: lumbosacral joint, ROM: Range of Motion, SD: Standard Deviation, Pearson r: Pearson product-moment correlation coefficients, LB: lower bound of the 95% confidence interval, UB: upper bound of the 95% confidence interval, significant values (p ≤ 0.05) are marked with an asterisk (*).

practice to assess spinal movement abnormalities, and a functional box lifting task. A significantly smaller ROM was observed in box lifting for all spinal regions except for UTs, hip joints and L5/S1, where a larger ROM occurred (Table 2). The larger L5/S1 ROM during box lifting demonstrates that the ROM is not fully measured with a forward bending task. This was likely due to the anatomical advantage to create more pelvic tilt when the knees are flexed during box lifting, compared to the passive insufficiency of the hip extensors during forward bending with extended knees. In contrast, a previous study showed no significant differences between lifting and forward bending tasks in ULs and LLs kinematics (Alqhtani et al., 2015). This contrast could have multiple reasons. The current study defined the spinal segmental angles slightly different compared to the previous studies (Alqhtani et al., 2016, 2015). Especially separating L5/S1 from the LLs could have led to significant differences in the lumbar spine in the current study, indicating the importance of separating the sacrum and L5 segment in a multi-segment lumbar spine model. The previous research also used a lower lifting weight (3 kg versus 6 kg in current study) (Alqhtani et al., 2015; Williams et al., 2013). The lower weight induces less loading on the spine, which could provoke a more stooped spinal flexion and less flexion of the lower extremities during lifting. Additionally, the participant group consisted of relatively young males (mean ± SD = 29.4 ± 6.5 years) and it was suggested that future research should extend the analysis to females and a broader age group (Alqhtani et al., 2015), as was done in the current study.

The third aim of this study was to explore the relationship between RFB and functional box lifting in spine and hips, to determine if RFB is a good representation of spinal and hip ROM during lifting. Correlations between the two tasks were very high in ULs and LLs, and moderate in the TLs region and L5/S1 joint which implied that RFB could be relevant as a reference for sagittal movement in the lumbar spine regions during lifting, despite the observed differences between the two tasks. For instance, a person with little ROM in the lumbar regions during RFB, will most likely also have little lumbar ROM while lifting a box. However, especially when involving the 95% confidence interval of the Pearson correlation coefficients, it is noteworthy that the lower bound of TLs and L5/S1 (0.15 and 0.14 respectively) are very low, while the lower bound of ULs and LLs (0.57 and 0.52 respectively) are close to the hypothesized correlation cut-off point of 0.6. This signifies that, even though there are significant differences in spinal mobility between the two motion tasks, they are still highly correlated in the ULs and LLs regions, and we cautiously state that TLs and L5/S1 are moderately correlated. Contrary to previous research, which did find a moderate relationship between the two tasks for the hips (Alqhtani et al., 2015), the current study found (very) weak and insignificant correlations between box lifting and RFB for UTs, MTs and the hips, especially when considering the lower bound of the 95% CI (-0.03, 0.00 and −0.39 respectively). As an explanation of this contradiction, the prior study showed smaller ROM in the hips during both lifting and forward bending (63.2° and 53.2° respectively) compared to the current study (88.0° and 77.5° respectively). Smaller ROM in combination with less external weight (3 kg) in the younger and exclusively male population of the referred study may have resulted in more uniform hip kinematics profiles during box lifting. Therefore, the latter results are not fully comparable with the results of the current study. The way of lifting (freestyle, stoop or squat) is highly individual (Pavlova et al., 2018; Riley et al., 2015). Therefore, we intended to let the participants mimic their real-life lifting performance closely, by only limiting task instructions through standardisation of the box and feet position, and thus preserving the full-body freedom of movement as much as possible. Unfortunately, the study by Alqhtani et al. (2015) did not include a comprehensive description of task instructions. Thus, it remains difficult to explain the present differences between the studies.

The last aim of the study was to test whether or not the inclusion of a separate L5/S1 joint would be redundant. The current results of the R_0 between L5/S1 and LLs angle during RFB, showed that segmental redundancy was not applicable and that the L5/S1 angle provides extra information about lower lumbar spine movement. Therefore, the inclusion of a separate L5/S1 joint to provide scientifically relevant information was supported.

In addition to the main findings of the study, we encountered some interesting results in the thoracic regions. Although the ROM in the thoracic regions were significantly different, we noticed an extension pattern in UTs during both movement tasks for all subjects (Table 2; Fig. 3). This could be explained by backwards tilting of the head, neck and upper thorax. While reaching maximal forward bending, all participants lifted their head backwards to maintain a single focus point on the floor to prevent an upside-down view and preserve balance. Abducting the arms to prevent floor contact could also have provoked an extension of the upper thoracic region. While reaching for the box just before lifting, all participants were visually focussing on the box, which explained an extension of the neck and UTs at box lift-off compared to standing up straight. Besides that, some participants possibly prepared themselves for receiving the external weight by retraction of the shoulders. Subsequently, a large variability between individuals in the MTs was observed during RFB. The majority of participants showed a flexion pattern, while few individuals with larger trunk ROM showed an extension pattern in the MTs, presumably related to the extension pattern of UTs. This MTs variability resulted in a smaller average ROM with a large SD (Table 2; Fig. 3). Unfortunately, since there are no prior studies that included multiple thoracic regions in lifting studies, the current thoracic results could not be compared and the used model should be reproduced in future studies.

Despite its novel findings, some limitations of this study should be acknowledged. First, this study was performed on a group with a large variability in age. Correlations between movement tasks could differ between age groups. The large SDs of the spinal kinematics, which in turn widened the 95% Confidence Interval (CI) bounds as well. Unfortunately, the group was not large enough to stratify age groups. Although we have shown these correlations already in a small healthy population, it would be interesting to see if reproducing these analyses with a larger sample size will increase the correlations, especially in the spinal regions with only moderate correlations. Besides that, while lumbar ROM showed to be well correlated between RFB and box lifting movements, it is not known if any alternations in lumbar kinematics due to pain or pathology with box lifting will be reflected during RFB ROM or vice versa. Thus, it would also be interesting to focus future research on differences and correlations of multi-segmental spine kinematics between standardised spinal mobility tasks and ADLs in people with CLBP. Furthermore, a comparison of the latter analyses between a group of people with CLBP and asymptomatic individuals would help to create a better understanding of adaptations in movement behaviour in people with CLBP.

5. Conclusion

In asymptomatic individuals, measuring spinal ROM with a general m-Schober test appears inadequate to assess spinal and hip kinematics. Return from forward bending and box lifting showed different kinematics in all spinal regions and hips, and require opposite spinal-hip contributions between movements. Although RFB and lifting differ significantly in spinal and hip kinematics, they were highly correlated in ULs and LLs and moderately correlated in TLs and L5/S1. This clearly demonstrates that the amount of ROM in the lumbar regions during RFB indicates the amount of ROM during sagittal functional lifting movements. These findings have confirmed that RFB can be used as a reference for the lumbar regions during lifting in asymptomatic individuals. Furthermore, including a separate L5/S1 joint in the spinal kinematic model adds relevant and more detailed lumbar kinematic information compared to previous studies.

Declaration of competing Interest

No conflicts of interest exist.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jelekin.2019.102352.

References

Alqhtani, R.S., Jones, M.D., Theobald, P.S., Williams, J.M., 2016. Investigating the contribution of the upper and lower lumbar spine, relative to hip motion, in everyday tasks. Man. Ther. 21, 268–273. https://doi.org/10.1016/j.math.2015.09.014.

Alqhtani, R.S., Jones, M.D., Theobald, P.S., Williams, J.M., 2015. Correlation of lumbar-hip kinematics between trunk flexion and other functional tasks. J. Manipulative Physiol. Ther. 38, 442–447. https://doi.org/10.1016/j.jmpt.2015.05.001.

Christe, G., Kade, F., Jolles, B.M., Favre, J., 2017. Chronic low back pain patients walk with locally altered spinal kinematics. J. Biomech. 60, 211–218. https://doi.org/10.1016/j.jbiomech.2017.06.042.

Christe, G., Redhead, L., Legrand, T., Jolles, B.M., Favre, J., 2016. Multi-segment analysis of spinal kinematics during sit-to-stand in patients with chronic low back pain. J. Biomech. 49, 2060–2067. https://doi.org/10.1016/j.jbiomech.2016.05.015.

Dankaerts, Wim, O'Sullivan, Peter, Burnett, Angus, Straker, Leon, 2006. Differences in sitting postures are associated with nonspecific chronic low back pain disorders when patients are subclassified. Spine (Phila. Pa. 1976) 31 (6), 698–704. https://doi.org/10.1097/01.brs.0000202532.76925.d2.

Gombatto, S.P., D'Arpa, N., Landerholm, S., Mateo, C., O'Connor, R., Tokunaga, J., Tuttle, L.J., 2017. Differences in kinematics of the lumbar spine and lower extremities between people with and without low back pain during the down phase of a pick up task, an observational study. Musculoskelet. Sci. Pract. 28, 25–31. https://doi.org/10.1016/j.msksp.2016.12.017.

Hamill, J., Knutzen, K.M., 2009. Biomechanical basis of human movement, 3rd. ed. Lippincott Williams & Wilkins, Philadelphia, US.

Iyer, S., Christiansen, B.A., Roberts, B.J., Valentine, M.J., Manoharan, R.K., Bouxsein, M.L., 2010. A biomechanical model for estimating loads on thoracic and lumbar vertebrae. Clin. Biomech. 25, 853–858. https://doi.org/10.1016/j.clinbiomech.2010.06.010.

Kottner, J., Audigé, L., Brorson, S., Donner, A., Gajewski, B.J., Hróbjartsson, A., Roberts, C., Shoukri, M., Streiner, D.L., 2011. Guidelines for reporting reliability and agreement studies (GRRAS) were proposed. J. Clin. Epidemiol. 64, 96–106. https://doi.org/10.1016/j.jclinepi.2010.03.002.

Leardini, A., Biagi, F., Merlo, A., Belvedere, C., Benedetti, M.G., 2011. Multi-segment trunk kinematics during locomotion and elementary exercises. Clin. Biomech. 26, 562–571. https://doi.org/10.1016/j.clinbiomech.2011.01.015.

Miller, S.A., Mayer, T., Cox, R., Gatchel, R.J., 1992. Reliability problems associated with the modified schober technique for true lumbar flexion measurement. Spine (Phila. Pa. 1976). https://doi.org/10.1097/00007632-199203000-00017.

Needham, R., Naemi, R., Healy, A., Chockalingam, N., 2015. Multi-segment kinematic model to assess three-dimensional movement of the spine and back during gait. Prosthet. Orthot. Int. https://doi.org/10.1177/0309364615579319.

Needham, R., Stebbins, J., Chockalingam, N., 2016. Three-dimensional kinematics of the lumbar spine during gait using marker-based systems: a systematic review. J. Med. Eng. Technol. 40, 172–185. https://doi.org/10.3109/03091902.2016.1154616.

Ogata, Y., Anan, M., Takahashi, M., Takeda, T., Tanimoto, K., Sawada, T., Shinkoda, K., 2018. Relationships between trunk movement patterns during lifting tasks compared with unloaded extension from a flexed posture. J. Manipulative Physiol. Ther. 41, 189–198. https://doi.org/10.1016/j.jmpt.2017.09.007.

Parkinson, S., Campbell, A., Dankaerts, W., Burnett, A., O'Sullivan, P., 2013. Upper and lower lumbar segments move differently during sit-to-stand. Man. Ther. 18, 390–394. https://doi.org/10.1016/j.math.2013.02.001.

Pavlova, A.V., Meakin, J.R., Cooper, K., Barr, R.J., Aspden, R.M., 2018. Variation in lifting kinematics related to individual intrinsic lumbar curvature: An investigation in healthy adults. BMJ Open Sport Exerc. Med. 4. https://doi.org/10.1136/bmjsem-2018-000374.

Reynolds, P.M.G., 1975. Measurement of spinal mobility: A comparison of three methods. Rheumatology. https://doi.org/10.1093/rheumatology/14.3.180.

Riley, A.E., Craig, T.D., Sharma, N.K., Billinger, S.A., Wilson, S.E., 2015. Novice lifters exhibit a more kyphotic lifting posture than experienced lifters in straight-leg lifting. J. Biomech. 48, 1693–1699. https://doi.org/10.1016/j.jbiomech.2015.05.022.

Ryan, N., Bruno, P., 2017. Analysis of 3D multi-segment lumbar spine motion during gait and prone hip extension. J. Electromyogr. Kinesiol. 33, 111–117. https://doi.org/10.1016/j.jelekin.2017.02.005.

Schinkel-Ivy, A., Drake, J.D.M., 2015. Which motion segments are required to sufficiently characterize the kinematic behavior of the trunk? J. Electromyogr. Kinesiol. 25, 239–246. https://doi.org/10.1016/j.jelekin.2014.12.008.

Seerden, S., Dankaerts, W., Swinnen, T., De Vlam, K., Westhovens, R., Vanwanseele, B., 2019. Test-retest reliability and waveform agreement of a multi-segmental kinematic model to analyse three-dimensional lumbar spine movement. Manuscript submitted for publication.

Seerden, S., Dankaerts, W., Vanwanseele, B., 2016. Reliability of a multi-segmental kinematic model to analyse 3D movement in the lumbar spine. Gait Posture 49, 53. https://doi.org/10.1016/j.gaitpost.2016.07.117.

Shum, G.L.K., Crosbie, J., Lee, R.Y.W., 2005. Effect of low back pain on the kinematics and joint coordination of the lumbar spine and hip during sit-to-stand and stand-to-sit. Spine (Phila. Pa. 1976) 30, 1998–2004. https://doi.org/10.1097/01.brs.0000176195.16128.27.

Tully, E.A., Fotoohabadi, M.R., Galea, M.P., 2005. Sagittal spine and lower limb movement during sit-to-stand in healthy young subjects. Gait Posture 22, 338–345. https://doi.org/10.1016/j.gaitpost.2004.11.007.

Williams, J.M., Haq, I., Lee, R.Y., 2013. A novel approach to the clinical evaluation of differential kinematics of the lumbar spine. Man. Ther. 18, 130–135. https://doi.org/10.1016/j.math.2012.08.003.

Williams, R., Binkley, J., Bloch, R., Goldsmith, C.H., Minuk, T., 1993. Reliability of the modified-modified Schober and double inclinometer methods for measuring lumbar flexion and extension. Phys. Ther. https://doi.org/10.1093/ptj/73.1.26.

Wong, T.K.T., Lee, R.Y.W., 2004. Effects of low back pain on the relationship between the movements of the lumbar spine and hip. Hum. Mov. Sci. 23, 21–34. https://doi.org/10.1016/j.humov.2004.03.004.

Wright, V., 1983. The measurement of back movement. Rheumatology 22, 193–196. https://doi.org/10.1093/rheumatology/22.4.193-a.

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