Journal of Biomechanics 82 (2019) 1–19

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Review

Effect of age and sex on lumbar lordosis and the range of motion. A systematic review and meta-analysis

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ARTICLE INFO

Article history:
Accepted 12 November 2018

Keywords:
Lumbar lordosis
Range of motion
Asymptomatic
Low back pain
Functional analysis
Kinematics

ABSTRACT

Lumbar lordosis (LL) and the range of motion (RoM) are important physiological measurements when initiating any diagnosis and treatment plan for patients with low back pain. Numerous studies reported differences in LL and the RoM due to age and sex. However, these findings remain contradictory. A systematic review and meta-analysis were performed to synthesize mean values and the differences in LL and the RoM because of age and sex. The quality assessment tool for quantitative studies was applied to assess the methodological quality of the studies included.

We identified 2372 papers through electronic (2309) and physical (63) searches. We assessed 218 full-text studies reporting measurements of LL or the RoM. In total, 65 studies were included, and a normative database for LL and the RoM is provided as supplementary material. Among these, 11 were included in the meta-analysis. LL and the RoM displayed non-monotonic variations with significant age and sex differences. Young females showed a significantly greater LL and the range of extension (RoE), whereas young males exhibited a greater range of flexion (RoF). Sex differences in the range of lateral bending (RoLB) were small but were significant for the axial rotation (RoAR). For the RoF, RoE and RoLB, differences because of age were significant among most of the age groups in both sexes, whereas for the RoAR, differences were significant only between the 20s vs the 30s-40s (males) and 40s vs 50s (females).

Significant differences because of age/sex were identified. However, the age-dependent reduction in LL and the RoM was non-monotonic and differed in both sexes. These findings will help to better distinguish between functional deficits caused by spinal disorders and natural factors/conditions related to age and sex.

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https://doi.org/10.1016/j.jbiomech.2018.11.022
0021-9290/

1. Introduction

Assessment of lumbar lordosis (LL) and the range of motion (RoM) is the basis of physical examination related to low back pain. These mechano-morphological parameters are essential predictors of lumbar pathologies (Kim et al., 2015; C.S. Lee et al., 2014), abnormal spine mechanics (Lee et al., 2015; S. Lee et al., 2014), and possibly of low back pain. For elimination of low back pain and return to perform daily functions, treatment strategies may require lordosis correction (Roussouly et al., 2005) and restoration of the "normal" RoM. The initial standard examination normally requires kinematic assessment in flexion, extension, lateral bending or axial rotation. The evaluation of these measurements requires normative data of LL and the RoM as reference for a correct prognosis and treatment plan (Foster et al., 2018).

LL and the RoM have been measured for more than five decades. However, the reported measurements in the existing literature show considerable differences because of several factors. In a normal population, age and sex caused temporal and spatial variation in LL (Damasceno et al., 2006; González-Sánchez et al., 2014; Kobayashi et al., 2004; Koumantakis et al., 2016; Krejčí and Gallo, 2016; Milne and Lauder, 1974; Norton et al., 2004; Parkinson et al., 2013; Vialle et al., 2005; Youdas et al., 1996; Zhu et al., 2014) and the RoM (Burton and Tillotson, 1988; Consmüller et al., 2012; Dopf et al., 1994; Dreischarf et al., 2016; Fitzgerald, 1983; Goldberg and Chiarello, 2001; Hindle et al., 1990; Ignasiak et al., 2017; Kasukawa et al., 2017; Kienbacher et al., 2015; Kuo et al., 2009; Moll and Wright, 1971; Pries et al., 2015; Sung and Kim, 2011; Uluçam and Cigali, 2009), whereas other studies did not find any significant differences in LL (Boulay et al., 2006; Endo et al., 2012; Janssen et al., 2009; Jean, 2014; Lee et al., 2011; Mehta et al., 2016; Singh et al., 2010; Tüzün et al., 1999) or RoM (Wong et al., 2004) due to age or sex. This poses a major difficulty for clinicians in defining what is a normal LL or RoM for different age groups and sex to be able to differentiate what is dysfunctional spinal motion. An evidence-based understanding of these differences because of age and sex is necessary, which implies a collective analysis of the published data. Previously, a systematic review and meta-analysis was conducted to understand the differences in the lumbar RoM because of aging (Intolo et al., 2009). However, the analysis was based on limited available datasets and the influence of age and sex on LL was not considered.

In vivo studies reporting LL or RoM measurements used radiological (e.g., x-rays and computed tomography) or non-radiological devices (e.g., inclinometer, rotometer, goniometer, flexicurve, inertial, electromagnetic and 3-dimensional motion capture). Recently, several studies reported measurements based on non-radiological techniques, because for radiological imaging methods there are concerns regarding excess cancer risks (Lin, 2010). The data reported is valuable to identify and evaluate the differences in an asymptomatic population and to generate the representative values of LL and the RoM related to age and sex.

Therefore, in this systematic review, we aimed to identify differences between radiological and non-radiological measurements of LL, summarize the reported *in vivo* measurements of LL and the RoM in asymptomatic adults of different sex and age groups, to create a normative database of LL and of the range of flexion (RoF), extension (RoE), lateral bending (RoLB) and axial rotation (RoAR) and to determine the influence of age and sex by meta-analysis.

2. Methods

The systematic review conducted in this study is in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) statement (Liberati et al., 2009; Moher et al., 2009).

2.1. Literature search and inclusion criteria

Search criteria with keywords, including spine, lumbar, range of motion, kinematic, flexibility, movement, motion, rhythm, mobility, flexion, extension, lateral bending and axial rotation, were used with logical operators (AND, OR) to search the electronic databases of (1) PubMed (National Library of Medicine and National Institute of Health, USA), (2) Web of Science (Clarivate Analytics, USA) and (3) EMBASE (Elsevier, NLD). The search was performed for papers from 1960 to March 2018 that were written in English. Complete search strings that were used are presented in Appendix A. Additional papers were physically searched through bibliographies that were absent from the electronic search.

The following inclusion criteria were used:

Systematic review

(1) Measurements were performed on asymptomatic subjects without a current or previous history of spinal disorders or low back pain.
(2) Subjects were ≥18yrs.
(3) Reported LL or RoM measurements for males and females.
(4) Reported the influence of age or sex as a primary or secondary objective.
(5) Measured an active RoM (subject controlled) either in flexion, extension, lateral bending or axial rotation.
(6) Initial position or reference posture for measurements of RoM was standing; because LL and the RoM can vary significantly in other positions (E.S. Lee et al., 2014; Salem et al., 2015).
(7) For radiological studies, in addition to the reference posture of standing, the lateral recumbent position was also considered to evaluate and discuss the differences between radiological and non-radiological measurements.

Meta-analysis

(8) Non-radiological studies were considered.
(9) Subjects were grouped in the age bands of 20–29, 30–39, 40–49, 50–59 and 60–69.

(10) Studies that did not classify the decade wise age groups were still included when the mean age and standard deviation of the subjects were within the range of the defined age groups. It is possible that these data include individuals with ages outside the age range and therefore, some of the age groups may not be completely exclusive.

2.2. Methodological assessment

Initially, two authors (RA and FP) independently assessed and selected studies that reported measurements of LL or the RoM. These papers were further scrutinized in detail by one of the authors (RA) to ensure that they met the criteria for selection. Final inclusion of any paper in the study was with the mutual consensus of all the authors (RA, FP, SR and HR). Any publication lacking details regarding the number of subjects, sex or age was not considered in the meta-analysis. Furthermore, one author (RA) performed the quality assessment of the included studies using the Public Health Practice Project (https://merst.ca/ephpp/), developed by the Effective Public Health Practice 2003, Canada (Jackson and Waters, 2005).

2.3. Data extraction and management

The data were managed in the Microsoft Excel® software, where the extracted data, including the number of subjects, sex, body height, weight, body mass index, type of measuring device, number of lumbar levels, the mean values, standard deviations of LL and the RoM were tabulated. Further, for decade wise age groups, the mean values and the standard deviations for LL, the RoF, RoE, left and right RoLB and left and right RoAR were summarized for male and female subjects (Appendix B).

2.4. Data synthesis and meta-analysis

The mean values and 95% confidence interval (CI) of LL, the RoF, RoE, RoLB and RoAR were calculated for both sexes and different age groups (20–29, 30–39, 40–49, 50–59 and 60–69 years). The random-effects model was used in Comprehensive Meta-Analysis software (Version 3.0) to calculate the mean values for single groups either for males or females (without a control group). Furthermore, age groups were defined as subgroups to calculate the mean values and 95% CI.

To calculate the age and sex differences for LL and the RoM, studies were pooled for both sexes and different age groups. Mean values, standard deviations and sample sizes were pooled using Review Manager software (RevMan, Version 5.3. Copenhagen: The Nordic Centre, The Cochrane Collaboration, 2014). The meta-analysis was performed using the random-effects model for considering heterogeneity (inconsistency) among studies because of different study designs, methods of measurement and subjects from different populations.

Statistical heterogeneity was evaluated based on the inconsistency (I^2) index that provides an estimated percentage of the total variation across the studies that were included. The scale of heterogeneity was considered, whereby <25% indicates low, 25–75% medium and >75% high heterogeneity (Higgins JPT GSe., 2011). Mean pooled differences and 95% CIs in LL and the RoM between different age and sex groups were presented as statistically significant when $p < 0.05$ as calculated by the Z-test.

3. Results

3.1. Search procedure

The electronic search with the selected criteria retrieved 788 (PubMed), 641 (Web of Science) and 880 (Embase) publications, while 63 studies were found by physical search, giving a total of 2372 articles (Fig. 1). Following title and abstract screening and the removal of the duplicates in the three databases, 2154 papers were excluded. The remaining 218 full-text papers were screened for eligibility and 153 were excluded. Among these, 66 papers did not report age or sex differences, 53 investigated only males or females, 10 studies had missing data, 7 studied symptomatic subjects, 6 studies did not report data in reference to standing posture, 3 studies reported measurements on children, 3 used lumbar models or cadavers, 2 studies reported measurements in units other than degrees, 2 investigated passive RoM and 1 study had duplicate data. Finally, 65 studies were included in the review. These studies were conducted in Europe (30), Americas (15), Asia (12), Australia (4) and Africa (4). Among these, 11 non-radiological studies were considered in the meta-analysis, whereas 54 studies (X-ray measurements (21), different range of age groups (20), did not separate results for sex (4), linear units (3), lumbar levels (L1-L4, T8-S1 and C7-L5/S1) other than T12/L1-S or L1-S (3), lumbar kyphosis (1), standard deviation missing (2)) were not considered.

3.2. Characteristics and quality of studies

The characteristics of the included studies are presented in Table 1. The total number of participants in these studies were 18,585 with 9882 males and 8703 females, the sample size range from 18 (González-Sánchez et al., 2014) to 3020 (Batti'e et al., 1987). Here, 34 studies reported on LL, 23 the RoM and 8 on both parameters. In 62 studies, the initial or neutral posture of subjects was standing (upright, erect or relaxed) and lateral incumbent in 2 studies. Twenty-one studies used X-rays, 43 studies used non-radiological devices and 1 study used both to measure LL or RoM. Different non-radiological devices were used: flexicurve (6), Epionics (4), Fastrak/3 Space Isotrak (6), Spinal Mouse (2), goniometer (3), inclinometer (5), CA 6000 Spine Motion Analyzer (4), measuring tape (3), spinometer (1), accelerometer (1), DTP system (1), ARCON system (1), motion capture (3), Metrecom (1), smart phone (2), Zebris (1), stadiometer (1), B-200 Isostation (1) and spondylometer (1). The quality assessment results of the studies included are presented in Table 2. Sixteen studies were assessed as "strong", 48 as "moderate" and 1 as "weak" for representing the target population, whereas study design of most studies was "moderate" (58). The studies selected for meta-analysis were cross-sectional cohort studies with a moderate study design quality. Heterogeneity (I^2) of the studies considered in the meta-analysis were in the range from 0 to 96%.

3.3. Differences between radiological and non-radiological devices

The differences in LL between ten radiological (Amonoo-Kuofi, 1992; Fernand and Fox, 1985; Gelb et al., 1995; Hammerberg and Wood, 2003; Iyer et al., 2016; Korovessis et al., 1999, 1998; Oyakhire and Udoaka, 2017; Rajnics et al., 2001; Stagnara et al., 1982) and four non-radiological studies (Dreischarf et al., 2014; Lang-Tapia et al., 2011; Youdas et al., 2006, 1996) are presented

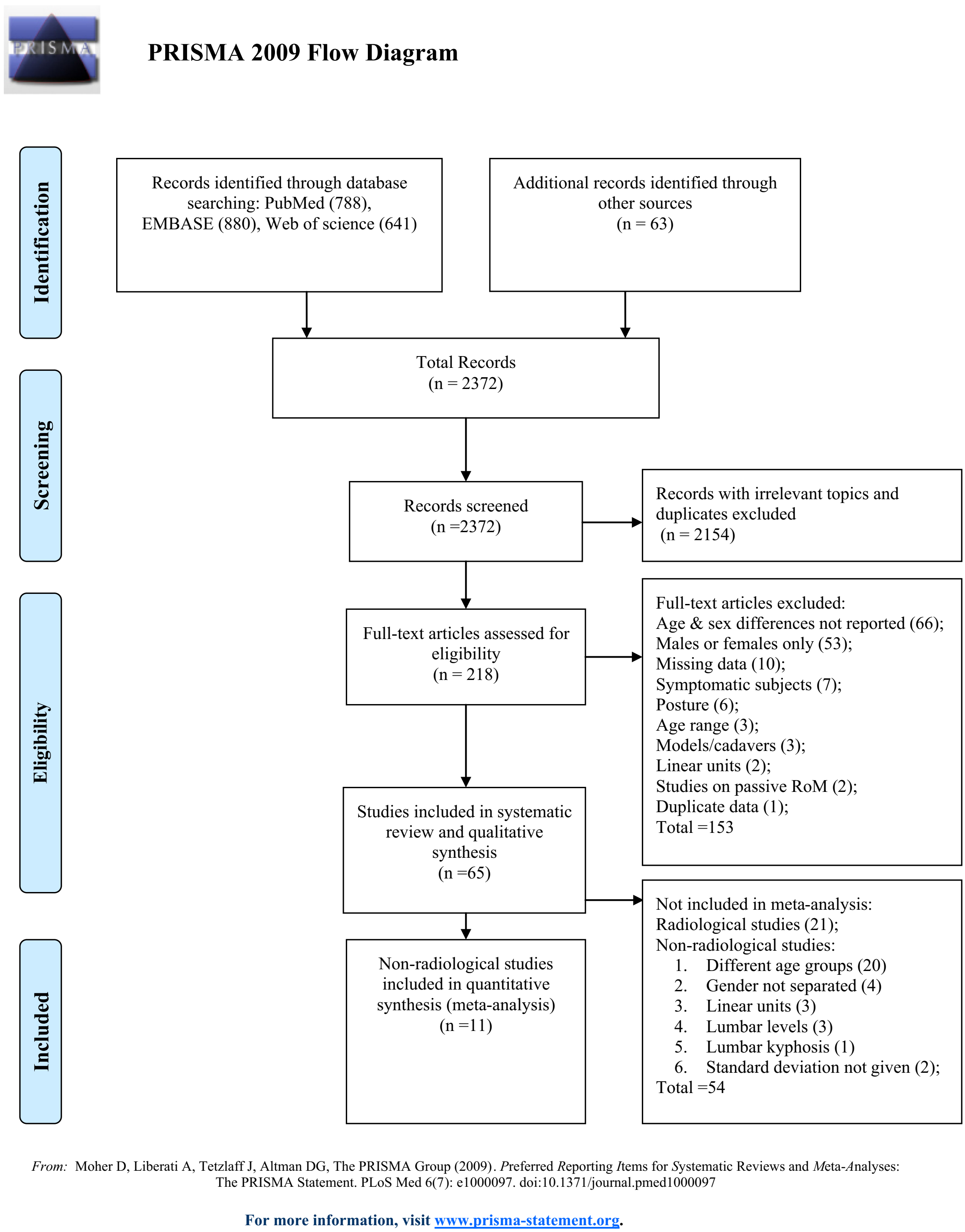

Fig. 1. PRISMA flow chart for the literature search and selection.

in Fig. 2. Measurements for LL in standing and lateral recumbent are given for different lumbar levels (T12-S1/S2, L1-S1, L2-L5/S and L1-L5). Among these measurements, for standing, differences between radiological (Korovessis et al., 1998) and non-radiological measurements (Lang-Tapia et al., 2011) were large for T12–S1/S2 lumbar segment (57.9°) for both sexes. Also, within radiological studies, it can be observed that LL for L1-S1 measured during standing (Iyer et al., 2016) was comparatively larger (14°) than the LL for L2-L5/S in lateral recumbent position (Fernand and Fox, 1985) for males and females.

3.4. Lumbar lordosis (LL)

The results from two studies (Dreischarf et al., 2014; Youdas et al., 2006) were pooled to calculate the means and 95% CI as well as the differences between both sexes and age groups of the 20s, 30s, 40s and 50+ (Table 3).

3.4.1. Sex difference in LL

The calculated mean values of LL for males and females (Fig. 3a) generally show that females have greater LL in the age groups of

Table 1
Characteristics of the included studies.

No	Author	Country	n sex	Age Mean (SD) or Range	Device	Posture	Lumbar levels	Gender separated	LL/RoM	Result
Radiological studies										
1.	Oyakhire and Udoaka (2017)	Nigeria	75M 45F	18–22 23–27 28–32 33–37 38–42 43+	X-ray	-	L1-S	N	LL in sagittal plane	Significant difference due to age.
2.	Iyer et al. (2016)	USA	37M 78F	21–30 31–40 41–50 51–60 61–70 >71	X-ray	Standing	L1-S1	Y	LL in sagittal plane	Significant decrease in LL due to age. Significant difference in LL due to sexes.
3.	Jean (2014)	Belgium	36M 53F	19–40 40–60 60+	X-ray	Standing	L-S1	N	LL in sagittal plane	No significant difference in LL due to age.
4.	Zhu et al. (2014)	China	104M 156F	20–56	X-ray	Standing	L1-S1	Y	LL in sagittal plane	Significant difference in LL due to sexes.
5.	Endo et al. (2012)	Japan	25M 25F	31.5 (7.4)	X-ray	Standing	L1-L5	Y	LL in sagittal plane	No significant difference in LL due to sexes.
6.	Lee et al. (2011)	Republic of Korea	54M 32F	19–39	X-ray	Standing	T12-S1	Y	LL in sagittal plane	No significant difference in LL due to sexes.
7.	Janssen et al. (2009)	The Netherlands	30M 30F	20–49	X-ray	Standing	L1-S1	Y	LL in sagittal plane	No significant difference in LL due to sexes.
8.	Damasceno et al. (2006)	Brazil	143M 207F	18–50	X-ray	Standing	L1-L5 L1-S1	Y	LL in sagittal plane	Significant difference in LL due to sexes and age.
9.	Boulay et al. (2006)	France	78M 71F	19–50	X-ray	Standing	T/L-S	N	LL in sagittal plane	No significant difference in LL due to sexes.
10.	Vialle et al. (2005)	France	190M 110F	20–70	X-ray	Standing	L1-L5	Y	LL in sagittal plane	Significant difference in LL due to sexes.
11.	Kobayashi et al. (2004)	Japan	29M 71F	50–84	X-ray	Standing	L1-L5	N	LL in sagittal plane	LL decrease with age.
12.	Wong et al. (2004)	Hong Kong	50M 50F	21–30 31–40 41–50 51+	X-ray Electrogoniometer Fluoroscopy	Standing	L1-S1	Y	RoM in sagittal plane	No significant difference in RoM due to sexes. Significant difference in RoM due to age.
13.	Hammerberg and Wood (2003)	USA	26M 24F	70–85	X-ray	Standing	L1-S1	Y	LL in sagittal plane	No significant correlation between age and LL.
14.	Vaz et al. (2002)	France	54M 46F	23–45	X-ray	Standing	Selection of segments vary in lumbar region	N	LL in sagittal plane	No significant difference in LL due to sexes.
15.	Rajnics et al. (2001)	Hungary	15M 15F	30–39	X-ray	Standing	L1-L5	Y	LL in sagittal plane	No significant difference in LL due to sexes.
16.	Korovessis et al. (1999)	Greece	60M 60F	20–29 30–39 40–49 50–59 60–69 70–79	X-ray	Standing	T12-S1	N	LL in sagittal plane	No significant difference in LL due to sexes.
17.	Tüzün et al. (1999)	Turkey	8M 42F	20–63	X-ray	Standing	L1-S	Y	LL in sagittal plane	No significant difference in LL due to sexes. Strong correlation between age and LL.
18.	Korovessis et al. (1998)	Greece	38M 61F	20–29 30–39	X-ray	Standing	T12-S1, L1-L5	N	LL in sagittal plane	No significant difference in LL due to sexes

(*continued on next page*)

Table 1 (*continued*)

No	Author	Country	n sex	Age Mean (SD) or Range	Device	Posture	Lumbar levels	Gender separated	LL/RoM	Result
				40–49 50–59 60–69 70–79						No significant correlation between age and LL.
19.	Gelb et al. (1995)	USA	46M 54F	40–49 50–59 60–69 70+	X-ray	Standing	T12-S1	Y	LL in sagittal plane	Strong correlation between loss of lordosis and increasing age. No significant sex differences in LL.
20.	Amonoo-Kuofi (1992)	Saudia Arabia	250M 235F	10–19.9 20–29.9 30–39.9 40–49.9 50+	X-ray	Lateral incumbent	L1-L5	Y	LL in sagittal plane	Significant difference in LL due to sex. Significant difference in LL due to age.
21.	Fernand and Fox (1985)	USA	380M 487F	17–29 30–39 40–49 50+	X-ray	Lateral incumbent	L2-S, L2-L5	Y	LL in sagittal plane	Significant difference in LL due to sexes.
22.	Stagnara et al. (1982)	France	75M 62F	20–29	X-ray	Standing	T/L-S	Y	LL in sagittal plane	No difference in average LL due to sexes.
Non-radiological studies										
23.	Ignasiak et al. (2017)	Switzerland	16M 26F	20–35 65–80	VICON MX, Oxford Metrics Group, Oxford, UK	Standing	L1-S	N	RoM in sagittal plane	Significant difference in RoM due to age.
24.	Kasukawa et al. (2017)	Japan	252M 320F	50s 60s 70s 80s	SpineMouse, Idiag, Volkerswill, Switzerland	Standing	L1-S1	Y	LL and RoM in sagittal plane	Significant difference in LL and RoM due to age in females.
25.	Mehta et al. (2016)	India	120M 80F	23–45	Flexible curve	Standing	T12-S2	Y	LL in sagittal plane	No significant difference due to sexes in IT professionals.
26.	Krejčí and Gallo (2016)	Czech Republic	440M 580F	19.1–29.7 19.3–29.7	DTP-3 system, Palacký University Olomouc, Olomouc, Czech Republic	Standing	T/L-L5	Y	LL in sagittal plane	Significant difference due to sexes.
27.	Koumantakis et al. (2016)	Greece	83M 100F	26.1 (10.4)	iHandy level smartphone application	Standing	T12/L1-S1/S2	Y	LL in sagittal plane	Significant difference due to sexes.
28.	Dreischarf et al. (2016)	Germany	93M 115F	20–35 35–50 >50	Epionics SPINE system, Epionics, Medical GmbH, Potsdam, Germany	Standing	T12/L1-S	Y	LL and RoM in sagittal plane	Significant difference in LL due to aging. Significant difference in RoM due to sexes.
29.	Pries et al. (2015)	Germany	134M 175F	20–35 36–50 >50	Epionics SPINE system, Epionics, Medical GmbH, Potsdam, Germany	Standing	T12/L1-S	Y	LL and RoM in sagittal plane	Significant effects of age on LL and RoM.
30.	Dreischarf et al. (2014)[a]	Germany	139M 184F	20–29 30–39 40–49 >50	Epionics SPINE system, Epionics, Medical GmbH, Potsdam, Germany	Standing	T12/L1-S	Y	LL and RoM in sagittal plane	Significant difference in RoM and LL due to age. Significant difference in RoM and LL due to sexes.
31.	Kienbacher et al. (2015)	Austria	24M 25F	18–40 60–90	Triaxial accelerometric sensors (Model Trigno, DelSys Inc®, Boston, MA, USA	Standing	T4-L5	Y	RoM in sagittal plane	Significant difference in RoM due to age.
32.	González-Sánchez et al. (2014)	Australia	9M 9F	<40	Fastrak, Polhemus Navigation; Colchester, VT, USA	Standing	L1-L5	Y	LL in sagittal plane.	Significant difference in LL due to sexes.
33.	Parkinson et al. (2013)	Australia	16M 13F	31 (13)	Fastrak, Polhemus Navigation; Colchester, VT, USA	Standing	T12-L3 L3-S2	Y	RoM in sagittal plane	Significant differences in upper and lower RoM due to sexes.

34.	Prushansky et al. (2013)[a]	Israel	15M 13F	25.6 (2.4) 25.3 (1.8)	1. 3D US pointer posture system, Zebris GmbH, Isny, Germany 2. Digital stadiometer	Standing	T12-S	Y	LL in sagittal plane	Significant sex differences in LL during relaxed standing.
35.	Consmüller et al. (2012)	Germany	198M 231F	20–35 36–50 51–75	Epionics SPINE system, Epionics, Medical GmbH, Potsdam, Germany	Standing	C7-S1	Y	LL and RoM in sagittal plane	Significant difference due to age. Significant difference due to sexes.
36.	Egwu et al. (2012)[a]	Nigeria	267M 235F	<20 20–25 26–30 30–47	Dual Inclinometer	Standing	T12-S1	Y	RoM in sagittal and coronal plane	Significant difference due to age. Significant difference due to sexes.
37.	Lang-Tapia et al. (2011)	Spain	362M 297F	20–29 30–39 40–49 ≥50	Spinal Mouse, Idiag, Volkerswill, Switzerland	Standing	T12-S1	Y	LL in sagittal plane	Significant differences due to sexes.
38.	Saidu et al. (2011)[a]	Nigeria	69M 66F	20–29 30–39 40–49 50–59 60–69 >70	Goniometer	Standing	(a) Forward flexion with Schober's technique (b) Goniometric axis placed at sacrum	Y	RoM in sagittal, coronal and transverse plane	Significant difference in RoM due to age.
39.	Sung and Kim (2011)	South Korea	16M 28F	21–72	3D motion capture (Motion Analysis Corporation; Santa Rosa, California) Tracked digital video recording, EVA 5.20	Standing	L1-L5	Y	RoM in sagittal, coronal and transverse plane	Significant differences in RoM due to sexes.
40.	Singh et al. (2010)	UK	20M 32F	27.96 (5.24) 72.11 (5.90)	Fastrak, Polhemus Navigation; Colchester, VT, USA	Standing	L1-L5	N	LL in sagittal plane	No significant difference in LL due to age.
41.	Kuo et al. (2009)	Australia	17M 29F	17–27 60–83	PEAK Motus System, PEAK Performance Technologies Inc., Englewood, Colorado, USA	Standing	L1-S1	N	RoM in sagittal plane	Significant difference in RoM due to age.
42.	Uluçam and Cigali (2009)	Turkey	50M 50F	18–22	Zebris® CMS 70P, CA 6000 Spine Motion Analysis, Germany	Standing	L1-S1	Y	RoM in sagittal, coronal and transverse plane	Significant difference in RoM due to sexes.
43.	Youdas et al. (2006)[a]	USA	119M 116F	20–29 30–39 40–49 50–59 60–69 70–79	Flexible curve, Acu-Arc Adjustable Curve, Hoyle Products Inc., Filmore, CA, USA	Standing	T12-S2	Y	LL in sagittal plane	Significant difference in LL due to age. Significant difference in LL due to sexes.
44.	Troke et al. (2005)[a]	UK	209M 196F	<20 20–25 25–30 30–35 35–40 40–45 45–50 50–55 55–60 60–65 65–70 70–75 75–80 80–85 85–90	CA6000 Spine Motion Analyser, Orthopedic Systems Inc., CA, USA	Standing	T12-S2	Y	RoM in sagittal, coronal and transverse plane	Significant difference in RoM due to age.
45.	Norton et al. (2004)	USA	27M 33F	19–73	Metrecom Skeletal Analysis System	Standing	T12/L1-S2	Y	LL in sagittal plane	Significant difference in LL due to sexes.
46.	Goldberg and Chiarello (2001)	USA	11M 29F	70.5 (5.3)	Goniometer	Standing	L1-S2	Y	LL and RoM in sagittal, coronal and transverse plane	Significant difference in LL and RoM due to sexes.

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Table 1 (*continued*)

No	Author	Country	n sex	Age Mean (SD) or Range	Device	Posture	Lumbar levels	Gender separated	LL/RoM	Result
47.	Nourbakhsh et al. (2001)	Iran	210M 210F	20–34 35–49 50–65	Flexicurve	Standing	–	Y	LL in sagittal plane	Significant difference in LL due to age and sexes.
48.	Van Herp et al. (2000)[a]	UK	50M 50F	20–29 30–39 40–49 50–59 >60	3 Space Isotrak, Polhemus Navigation; Colchester, VT, USA	Standing	T12-S1	Y	RoM in sagittal, coronal and transverse plane	Significant difference due to age. Significant difference due to sexes.
49.	Youdas et al. (1996)	USA	45M 45F	40–49 50–59 60–69	Flexicurve	Standing	T12-S2	Y	LL in sagittal plane	Age and sexes influence LL.
50.	McGregor et al. (1995)[a]	UK	103M 100F	20–29 30–39 40–49 50–59 60–70	CA6000 Spine Motion Analyser, Orthopedic Systems Inc., CA, USA	Standing	T12/L1-posterior superior iliac spine	Y	RoM in sagittal, coronal and transverse plane	Significant difference due to age. Significant difference due to sexes.
51.	Hasten et al. (1995)[a]	USA	16M 17F	18–33	ARCON system Dual inclinometer	Standing	T12-S	Y	RoM in sagittal, coronal and transverse plane	Significant differences in RoM due to sexes.
52.	Dopf et al. (1994)	USA	60M 60F	20–35	CA6000 Spine Motion Analyser, Orthopedic Systems Inc., CA, USA	Standing	T12-S2	N	RoM in sagittal, coronal and transverse plane	Significant difference in RoM due to sexes.
53.	Russell et al. (1993)[a]	Australia	135M 118F	20–29 30–39 40–49 50–59 60–69	3 space isotrak, Polhemus Navigation; Colchester, VT, USA	Standing	L1-S	Y	RoM in sagittal, coronal and transverse plane	Significant difference due to age. Significant difference due o sexes.
54.	Gomez et al. (1991)	Canada	85M 83F	<30 30–39 40–49 ≥50	Isostation-B-200 dynamometer, Isotechnologies, Carrboro, North Carolina	Standing	Trunk	N	RoM in Sagittal plane	Significant difference in RoM due to age and sex.
55.	Hindle et al. (1990)	UK	40M 40F	20–29 30–39 40–49 >50	3Space Isotrak, Polhemus Navigation; Colchester, VT, USA	Standing	L1-L4	Y	Primary and coupled motions. RoM in sagittal, coronal and transverse planes	Significant difference due to age. Significant difference due to sexes.
56.	Bridger et al. (1989)[a]	South Africa	25M 25F	28.4 (10.8) 22.4 (5.2)	Inclinometer	Standing	T12/L1-L5/S1	Y	LL in sagittal plane	No significant difference in lumbar lordosis due to sexes.
57.	Burton and Tillotson (1988)	UK	242M 268F	10–12 16–34 35–54 54+	Flexicurve	Standing	T12-S2	Y	RoM	Significant difference due to age. Significant difference due to sexes.
58.	Batti'e et al. (1987)	USA	2350M 670F	20–29 30–39 40–49 50–59 60+	Modified Schober method	Standing	Three Marks; at lumbo-sacrum (LS), 5 cm below and 10 cm above LS	Y	RoM in sagittal and frontal plane	Significant difference in RoM due to sexes. Significant difference in RoM due to age.
59.	Keeley et al. (1986)	USA	15M 16F	Average 28–42	Dual inclinometer	Standing	T12/L1-S	Y	RoM in sagittal plane	No significant difference in RoM due to sexes.
60.	Fitzgerald (1983)	USA	168M 4F	20–29 30–39 40–49 50–59 60–69	Shöber method Goniometer	Standing	Two points on lumbar spine.	N	RoM in sagittal and coronal plane	Significant Differences in RoM due to age.

61.	Sugahara et al. (1981)	Japan	1071M 1243F	20–29 30–39 40–49 50–59 ≥60	Spinometer	Standing	T8-S1	Y	LL and RoM in sagittal plane	Decrease in RoM and LL due to age.
62.	Milne and Lauder (1974)	UK	413M 406F	20–24 25–29 30–34 35–39 40–44 45–49 50–54 55–59 60–64 65–69 70–74 75–79 ≥80	Flexicurve	Standing	C7-L5/S1	Y	LL curve depth variable in sagittal plane	LL decreases with age.
63.	Sturrock et al. (1973)	UK	142M 142F	15–24 25–34 35–44 45–54 55–64 65–74 75+	Spondylometer	Standing	Thoraco-lumbar	Y	RoM	Significant differences in RoM due to sexes. Significant difference in RoM due to age.
64.	Moll and Wright (1971)	UK	119M 118F	15–24 25–34 35–44 45–54 55–64 65–74 >75	Distraction method	Standing	T-S	Y	RoM in sagittal and coronal plane	Significant decrease in RoM due to age. Significant difference in RoM due to sexes.
65.	Loebl (1967)	UK	84M 92F	15–20 21–30 31–40 41–50 51–60 61–70 70+	Inclinometer	Standing	Thoraco-lumbar	Y	LL and RoM in sagittal plane	RoM decreases with age.

n: Number of subjects; LL: lumbar lordosis; RoM: range of motion; M: Males; F: Females; Y: Yes; N: No; a: Studies included in meta-analysis.

Table 2
Quality assessment of the included studies.

Study	Selection Bias	Study design	Confounders	Blinding	Data collection methods	Withdrawls and drop-outs	Measurement integrity	Analysis		
								Sample size calculation	Significant difference	Appropriate statistic
1. Oyakhire and Udoaka (2017)	M	M	W	W	S	W	Y	Y	Y	Y
2. Iyer et al. (2016)	M	M	W	W	S	S	Y	Y	Y	Y
3. Jean (2014)	M	M	W	W	S	W	Y	Y	N	Y
4. Zhu et al. (2014)	S	M	W	W	S	W	Y	Y	Y	Y
5. Endo et al. (2012)	M	M	W	W	S	W	Y	Y	N	Y
6. Lee et al. (2011)	M	M	W	W	S	W	Y	Y	N	Y
7. Janssen et al. (2009)	M	M	W	W	S	W	Y	Y	N	Y
8. Damasceno et al. (2006)	M	M	W	W	S	W	Y	Y	Y	Y
9. Boulay et al. (2006)	M	M	W	W	S	W	Y	Y	N	Y
10. Vialle et al. (2005)	M	M	W	W	S	W	Y	Y	Y	Y
11. Kobayashi et al. (2004)	M	M	W	W	S	W	Y	Y	Y	Y
12. Wong et al. (2004)	M	M	W	W	S	W	Y	Y	Y	Y
13. Hammerberg and Wood (2003)	M	M	W	W	S	W	Y	Y	N	Y
14. Vaz et al. (2002)	M	M	W	W	S	M	Y	Y	N	Y
15. Rajnics et al. (2001)	M	M	W	W	S	W	Y	Y	N	Y
16. Korovessis et al. (1999)	M	M	W	W	S	W	Y	Y	N	Y
17. Tüzün et al. (1999)	M	M	W	W	S	W	Y	Y	N	Y
18. Korovessis et al. (1998)	M	M	W	W	S	W	Y	Y	N	Y
19. Gelb et al. (1995)	M	M	W	W	S	W	Y	Y	Y	Y
20. Amonoo-Kuofi (1992)	M	M	W	W	S	W	Y	Y	Y	Y
21. Fernand and Fox (1985)	S	S	W	W	S	W	Y	Y	Y	Y
22. Stagnara et al. (1982)	M	M	W	W	S	W	Y	Y	N	Y
23. Ignasiak et al. (2017)	M	M	W	W	S	W	Y	Y	Y	Y
24. Kasukawa et al. (2017)	M	M	W	W	M	W	Y	Y	Y	Y
25. Mehta et al. (2016)	S	M	W	W	W	W	Y	Y	N	Y
26. Krejčí and Gallo (2016)	M	M	W	W	S	S	Y	Y	Y	Y
27. Koumantakis et al. (2016)	M	M	W	W	S	W	Y	Y	Y	Y
28. Dreischarf et al. (2016)	M	M	W	W	S	S	Y	Y	Y	Y
29. Pries et al. (2015)	M	M	W	W	S	S	Y	Y	Y	Y
30. Dreischarf et al. (2014)[a]	M	M	W	W	S	S	Y	Y	Y	Y
31. Kienbacher et al. (2015)	S	M	W	W	S	W	Y	Y	Y	Y
32. González-Sánchez et al. (2014)	M	M	S	W	S	W	Y	Y	Y	Y
33. Parkinson et al. (2013)	S	M	W	W	S	W	Y	Y	Y	Y
34. Prushansky et al. (2013)[a]	M	M	S	W	S	W	Y	Y	Y	Y
35. Consmüller et al. (2012)	M	M	W	W	S	W	Y	Y	Y	Y
36. Egwu et al. (2012)[a]	M	M	W	W	M	W	Y	Y	Y	Y
37. Lang-Tapia et al. (2011)	S	M	M	W	M	W	Y	Y	Y	Y
38. Saidu et al. (2011)[a]	M	M	W	W	M	W	Y	Y	Y	Y
39. Sung and Kim (2011)	M	M	M	W	S	M	Y	Y	Y	Y
40. Singh et al. (2010)	M	M	W	W	S	W	Y	Y	N	Y
41. Kuo et al. (2009)	M	M	W	W	S	W	Y	Y	Y	Y
42. Uluçam and Cigali (2009)	M	M	W	W	M	W	Y	Y	Y	Y
43. Youdas et al. (2006)[a]	S	S	M	W	S	W	Y	Y	Y	Y
44. Troke et al. (2005)[a]	S	S	W	W	S	W	Y	Y	Y	Y
45. Norton et al. (2004)	S	M	W	W	S	S	Y	Y	Y	Y
46. Goldberg and Chiarello (2001)	S	M	W	W	S	W	Y	Y	Y	Y
47. Nourbakhsh et al. (2001)	M	M	M	W	S	W	Y	Y	Y	Y
48. Van Herp et al. (2000)[a]	M	M	W	W	S	W	Y	Y	Y	Y
49. Youdas et al. (1996)	S	S	M	W	S	W	Y	Y	Y	Y
50. McGregor et al. (1995)[a]	S	M	W	W	S	W	Y	Y	Y	Y
51. Hasten et al. (1995)[a]	M	M	W	W	S	W	Y	Y	Y	Y
52. Dopf et al. (1994)	M	M	W	W	S	W	Y	Y	Y	Y
53. Russell et al. (1993)[a]	M	M	M	W	M	W	Y	Y	Y	Y
54. Gomez et al. (1991)	M	M	M	W	S	W	Y	Y	Y	Y
55. Hindle et al. (1990)	W	M	W	W	S	W	Y	Y	Y	Y
56. Bridger et al. (1989)[a]	M	M	W	W	M	W	Y	Y	N	Y
57. Burton and Tillotson (1988)	S	M	W	W	S	W	Y	Y	Y	Y
58. Batti'e et al. (1987)	M	W	W	W	S	W	Y	Y	Y	Y
59. Keeley et al. (1986)	S	S	M	M	S	W	Y	Y	N	Y
60. Fitzgerald (1983)	M	M	W	W	S	W	Y	Y	Y	Y
61. Sugahara et al. (1981)	S	M	M	W	W	W	Y	Y	Y	Y
62. Milne and Lauder (1974)	S	S	M	W	S	W	Y	Y	Y	Y
63. Sturrock et al. (1973)	M	M	M	W	S	W	Y	Y	Y	Y
64. Moll and Wright (1971)	M	M	W	M	S	W	Y	Y	Y	Y
65. Loebl (1967)	M	M	W	W	S	W	Y	Y	Y	N

Selection bias – Are the selected participants likely to be representative of the target population? Study design – Was the study design method appropriate? Confounders – Were there significant differences between groups prior to the intervention? Blinding – Were the study participants or examiners aware of the research question? Data collection methods – Was reliability or validity been reported? Withdraws and drop-outs – Were withdrawals and drop-outs reported? Measurement Integrity – Did all participants undergo the consistent measurement? Statistical Analysis – were the statistical methods appropriate for the study design?
a: Studies included for Meta-analysis. S: Strong; M: Moderate; W: Weak; Y: Yes; N: No.

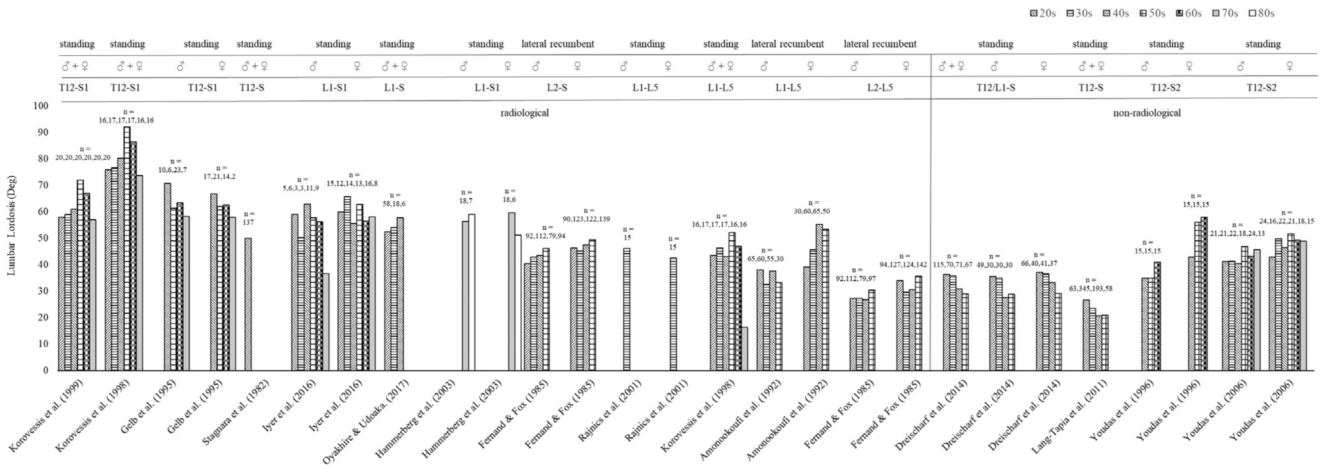

Fig. 2. Differences in lumbar lordosis (LL) between radiological and non-radiological measurements. Lumbar levels: T12-S1/S2, L1-S1, L2-L5/S and L1-L5. n: number of subjects in each age group.

20s to 50+, with the meta-analysis further confirming an overall greater LL in females ($p < 0.05$) (Fig. 3b). Females displayed significantly greater LL ($p < 0.05$) in the age groups of 40s and 50+. However, no significant sex difference ($p > 0.05$) was evident in the youngest groups of 20s and 30s. To further evaluate the outcome for young subjects, a new age group was considered by combining the first two decades of 20s and 30s to allow the inclusion of more studies. Four studies (Bridger et al., 1989; Dreischarf et al., 2014; Prushansky et al., 2013; Youdas et al., 2006) were pooled to calculate the sex differences in the age group of 20–39 years. Here, the calculated sex difference was significant ($p < 0.05$), with LL being greater in young females than males (Fig. 8).

3.4.2. Age difference in LL

The calculated mean values showed a non-monotonic change in males and females between different age groups (Fig. 3a). Males showed only a minor decrease in LL from the 20s to 30s, but a notable decrease to the 40s. However, LL increased from the 40s to 50+ in males. The meta-analysis results showed that the effect of age in males was significant ($p < 0.05$) between the age groups of 40s and 50+ (Fig. 3c). In females, LL increased from the 20s to 30s, but then decreased to the 40s. Furthermore, a minor increase was observed from the 40s to 50+. LL decreased significantly from the 30s to 40s in females ($p < 0.05$, Fig. 3d).

3.5. Range of Motion (RoM)

For the RoF, the results from five studies (Dreischarf et al., 2014; McGregor et al., 1995; Russell et al., 1993; Troke et al., 2005; Van Herp et al., 2000) and for the RoE six studies (Dreischarf et al., 2014; McGregor et al., 1995; Russell et al., 1993; Saidu et al., 2011; Troke et al., 2005; Van Herp et al., 2000) were pooled to calculate the mean and 95% CI and the differences because of age and sex. In addition, the results from four studies (McGregor et al., 1995; Saidu et al., 2011; Troke et al., 2005; Van Herp et al., 2000) were pooled for the RoLB and from three studies (McGregor et al., 1995; Troke et al., 2005; Van Herp et al., 2000) for the RoAR. The mean and 95% CI differences between sex and different age groups were calculated (Table 3, Figs. 4–7).

3.5.1. Sex difference in the RoM

The mean RoF was greater in males for all age groups, which was significant in the 20s age group (Fig. 4a-b). The overall sex differences in the RoF was also significant ($p < 0.05$). To further evaluate the outcome, first two age groups (20s and 30s) were combined. Here, seven studies (Dreischarf et al., 2014; Egwu et al., 2012; Hasten et al., 1995; McGregor et al., 1995; Russell et al., 1993; Troke et al., 2005; Van Herp et al., 2000) were pooled and found that males displayed significantly greater RoF than females (Fig. 8).

The mean RoE was generally greater for females in all age groups (Fig. 5a). However, the overall sex difference found was not significant ($p > 0.05$) nor was it in any individual decade age group (Fig. 5b). To further investigate the sex effect, the two youngest groups (20s and 30s) were combined. Here, eight studies (Dreischarf et al., 2014; Egwu et al., 2012; Hasten et al., 1995; McGregor et al., 1995; Russell et al., 1993; Saidu et al., 2011; Troke et al., 2005; Van Herp et al., 2000) were pooled and the RoE in females was found non-significantly greater than in males ($p < 0.05$, Fig. 8).

The mean left and right RoLB were similar between sexes (Fig. 6-a-b) and the sex-based differences were nonsignificant ($p > 0.05$) for all age groups (Fig. 6c-d). The pattern of these sex differences was similar in the left and right RoLB. Comparable results were obtained for the age group of 20–39 years. Here, six studies (Egwu et al., 2012; Hasten et al., 1995; McGregor et al., 1995; Saidu et al., 2011; Troke et al., 2005; Van Herp et al., 2000) were pooled, however, no significant effect was found (Fig. 8).

The mean left, and right RoAR demonstrated greater axial rotation in young females (Fig. 7a). However, this difference became minimal from the 50s. The overall sex-differences were significant and in the age groups of 40s (left) and 50s (right) (Fig. 7c-d). For the age group of 20–39 yrs, three studies (McGregor et al., 1995; Troke et al., 2005; Van Herp et al., 2000) were pooled and no significant differences were found (Fig. 8).

3.5.2. Age difference in the RoM

Overall, a non-monotonic but significant decrease in RoF with age was observed in both sexes ($p < 0.05$). The decreasing patterns of RoF in both sexes were different (Fig. 4c–d). In males, there was a significant decrease in the RoF for the 20s vs. 40s–60s, 30s vs. 60s, 40s vs. 60s and 50s vs. 60s age groups ($p < 0.05$). In females, the RoF decreased considerably for the 20s vs. 60s and 30s vs. 40s–60s age groups ($p < 0.05$). For RoE, a monotonic pattern of decrease with age was evident in both sexes. There were significant differences between almost all the age groups ($p < 0.05$, Fig. 5c–d). The decrease in the RoLB was considerable between almost all the age groups in both sexes (Fig. 6e–h). The differences between age groups for the left and right RoAR were non-significant between most of the age groups, whereas, changes observed with age in both sexes were not similar (Fig. 7e–h). For example, in males, only

Table 3
Mean and 95% CI differences (°) in lumbar lordosis (LL) and the range of motion (RoM) in three primary planes because of age and sex.

Age Group	LL		Sagittal				Coronal				Axial			
			RoF		RoE		RoLB-L		RoLB-R		RoAR-L		RoAR-R	
	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value
20s	−1.66 ± 2.47	0.19	**5.49 ± 4.57**	**0.02**	−2.15 ± 4.8	0.38	1.59 ± 2.34	0.18	0.54 ± 0.76	0.16	−1.16 ± 3.83	0.55	−1.69 ± 4.10	0.42
30s	−4.95 ± 6.66	0.14	1.36 ± 2.21	0.23	−1.53 ± 2.42	0.21	−0.07 ± 0.92	0.89	0.11 ± 0.92	0.81	−3.61 ± 6.46	0.27	−3.77 ± 5.01	0.14
40s	**−5.83 ± 3.4**	**0.0008**	2.43 ± 6.53	0.46	−2.71 ± 3.37	0.11	−0.47 ± 1.78	0.60	−0.46 ± 1.49	0.55	**−2.89 ± 2.62**	**0.03**	−1.25 ± 1.61	0.13
50s, 50+	**−3.80 ± 3.5**	**0.03**	4.23 ± 5.21	0.11	−0.52 ± 3.64	0.78	1.01 ± 1.85	0.29	0.9 ± 1.5	0.24	−0.19 ± 3.20	0.91	**−1.74 ± 1.53**	**0.03**
60s	**–**	–	1.57 ± 3.22	0.34	−0.61 ± 2.39	0.62	−1.65 ± 3.04	0.29	−1.2 ± 1.59	0.14	−0.84 ± 2.11	0.44	−1.04 ± 2.76	0.46
Overall effect	**−3.77 ± 1.8**	**<0.0001**	**2.96 ± 2**	**0.004**	−1.54 ± 1.68	0.07	0.16 ± 1.08	0.77	0.19 ± 0.48	0.45	**−1.52 ± 1.36**	**<0.03**	**−1.50 ± 1.15**	**<0.01**

Females

Age Group		LL		Sagittal				Coronal				Axial			
				RoF		RoE		RoLB-L		RoLB-R		RoAR-L		RoAR-R	
Group 1	Group 2	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value
20s	30s	−2.95 ± 7.14	0.42	−2.16 ± 2.8	0.13	2.29 ± 3.56	0.21	−0.64 ± 1.84	0.49	0.59 ± 0.98	0.24	0.65 ± 1.22	0.30	0.23 ± 1.30	0.73
	40s	0.49 ± 7.12	0.89	1.84 ± 2.26	0.11	**5.77 ± 2.95**	**0.0001**	**2.84 ± 1.39**	**<0.0001**	**4.02 ± 1.45**	**<0.00001**	0.29 ± 2.34	0.81	1.87 ± 4.38	0.40
	50s, 50+	−2.29 ± 10.92	0.68	3.23 ± 7.86	0.42	**8.41 ± 3.53**	**<0.00001**	**4.61 ± 1.33**	**<0.00001**	**5.57 ± 2.13**	**<0.00001**	1.21 ± 1.24	0.06	1.95 ± 4.11	0.35
	60s	**–**	**–**	**9.11 ± 4.36**	**<0.0001**	**12.65 ± 2.69**	**<0.00001**	**6.7 ± 1.81**	**<0.00001**	**7.92 ± 1.48**	**<0.00001**	1.81 ± 4.06	0.38	2.80 ± 6.91	0.43
30s	40s	**3.3 ± 2.67**	**0.02**	**4.35 ± 3.1**	**0.006**	**3.53 ± 1.83**	**0.0002**	**3.37 ± 1.54**	**<0.0001**	**3.17 ± 1.86**	**0.0009**	−0.11 ± 2.79	0.94	−0.35 ± 1.80	0.71
	50s	2.27 ± 5.96	0.46	**6.21 ± 3.93**	**0.002**	**6.82 ± 1.35**	**<0.00001**	**4.96 ± 2.26**	**<0.0001**	**4.41 ± 3.17**	**0.006**	0.76 ± 1.74	0.40	0.02 ± 2.48	0.99
	60s	**–**	**–**	**11.56 ± 2.74**	**<0.00001**	**11.17 ± 4.52**	**<0.00001**	**7.02 ± 3.39**	**<0.0001**	**7.1 ± 2.13**	**<0.00001**	1.40 ± 4.50	0.54	1.21 ± 5.45	0.66
40s	50s	−0.9 ± 6.12	0.77	2.36 ± 7.64	0.55	**3.27 ± 2.17**	**0.003**	1.69 ± 1.74	0.06	**1.7 ± 1.72**	**0.05**	**1.73 ± 1.40**	**0.02**	−0.07 ± 1.52	0.93
	60s	–	–	3.69 ± 6.72	0.28	**7.89 ± 4.81**	**0.001**	**3.76 ± 2.33**	**0.002**	**3.69 ± 1.66**	**0.0001**	0.43 ± 1.49	0.57	−0.45 ± 2.68	0.74
50s	60s	–	–	2.5 ± 3.14	0.12	**4.55 ± 3.05**	**0.004**	**2.4 ± 1.64**	**0.004**	**1.96 ± 1.66**	**0.02**	**−1.40 ± 1.31**	**0.04**	−0.56 ± 2.35	0.64
Overall effect		−0.07 ± 2.64	0.96	**4.1 ± 1.73**	**<0.00001**	**6.65 ± 1.56**	**<0.00001**	**3.56 ± 1.17**	**<0.00001**	**3.95 ± 0.99**	**<0.00001**	0.34 ± 0.61	0.28	0.27 ± 0.81	0.52

Males

Age Group		LL		Sagittal				Coronal				Axial			
				RoF		RoE		RoLB-L		RoLB-R		RoAR-L		RoAR-R	
Group 1	Group 2	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value	Mean ± 95%CI	*p*-Value
20s	30s	0.31 ± 3.12	0.84	2.05 ± 2.67	0.13	**3.32 ± 0.96**	**<0.00001**	**1.03 ± 0.71**	**0.005**	**0.98 ± 0.66**	**0.004**	0.78 ± 1.08	0.16	**2.88 ± 2.80**	**0.04**
	40s	4.53 ± 6.95	0.20	**5.27 ± 3.43**	**0.003**	**6.94 ± 2.03**	**<0.00001**	**4.68 ± 2.69**	**0.0006**	**5.11 ± 1.98**	**<0.00001**	**1.63 ± 1.45**	**0.03**	1.74 ± 2.17	0.12
	50s, 50+	−0.22 ± 7.17	0.95	**5.93 ± 4.48**	**0.009**	**8.34 ± 2.48**	**<0.00001**	**5.12 ± 2.81**	**0.0004**	**5.55 ± 2.12**	**<0.00001**	0.38 ± 2.75	0.79	**1.85 ± 1.23**	**0.003**
	60s	**–**	**–**	**13.8 ± 6.72**	**<0.0001**	**13.1 ± 3.41**	**<0.00001**	**9.44 ± 1.76**	**<0.00001**	**9.27 ± 1.31**	**<0.00001**	1.10 ± 1.48	0.15	0.99 ± 2.67	0.47
30s	40s	4.1 ± 6.27	0.2	3.16 ± 3.48	0.08	**4.75 ± 1.12**	**<0.00001**	**3.36 ± 3.13**	**0.04**	**3.83 ± 2.18**	**0.0006**	0.78 ± 1.37	0.26	−0.61 ± 1.55	0.44
	50s	−0.51 ± 6.33	0.87	2.68 ± 5.57	0.35	**6.59 ± 1.27**	**<0.00001**	**3.82 ± 3.19**	**0.02**	**4.19 ± 2.31**	**0.0004**	−0.38 ± 1.64	0.65	−0.91 ± 2.43	0.46
	60s	**–**	**–**	**10.94 ± 5.49**	**<0.0001**	**10.84 ± 2.48**	**<0.00001**	**8.37 ± 2.08**	**<0.00001**	**8.31 ± 1.28**	**<0.00001**	0.30 ± 1.38	0.67	−1.73 ± 2.88	0.24
40s	50s	**−3.43 ± 3.04**	**0.03**	0.57 ± 6.03	0.85	**2 ± 1.29**	**0.002**	0.44 ± 1.19	0.46	0.52 ± 1.12	0.36	−1.16 ± 1.54	0.14	0.18 ± 1.59	0.82
	60s	**–**	**–**	**8.9 ± 4.15**	**<0.0001**	**6.73 ± 1.78**	**<0.00001**	**4.41 ± 1.4**	**<0.00001**	**4.23 ± 1.65**	**<0.00001**	−0.45 ± 1.65	0.59	−0.46 ± 1.84	0.62
50s	60s	**–**	**–**	**8.21 ± 5.44**	**0.003**	**4.42 ± 2.64**	**0.001**	**3.99 ± 1.45**	**<0.00001**	**4.11 ± 2.13**	**<0.0002**	0.59 ± 1.54	0.46	−0.87 ± 2.13	0.42
Overall effect		0.39 ± 2.39	0.75	**5.85 ± 1.78**	**<0.00001**	**6.15 ± 1.21**	**<0.00001**	**4.51 ± 1.07**	**<0.00001**	**4.6 ± 1.01**	**<0.00001**	**0.43 ± 0.44**	**<0.05**	0.38 ± 0.64	0.24

Note: For sex differences, If mean difference < 0°, it represents males have a smaller LL or RoM than females; if mean difference > 0°, it represents males have a larger LL or RoM than females; For age differences in males and females, If mean difference < 0°, it represents age group 1 has smaller LL or RoM than group 2; if mean difference > 0°, it represents group 1 has larger LL or RoM than group 2; RoF – Range of Flexion, RoE – Range of Extension (RoE), RoLB – Range of Lateral Bending, RoAR – Range of Axial Rotation, L – Left, R – Right; For LL, 50+ age group ranges 50–69 yrs.

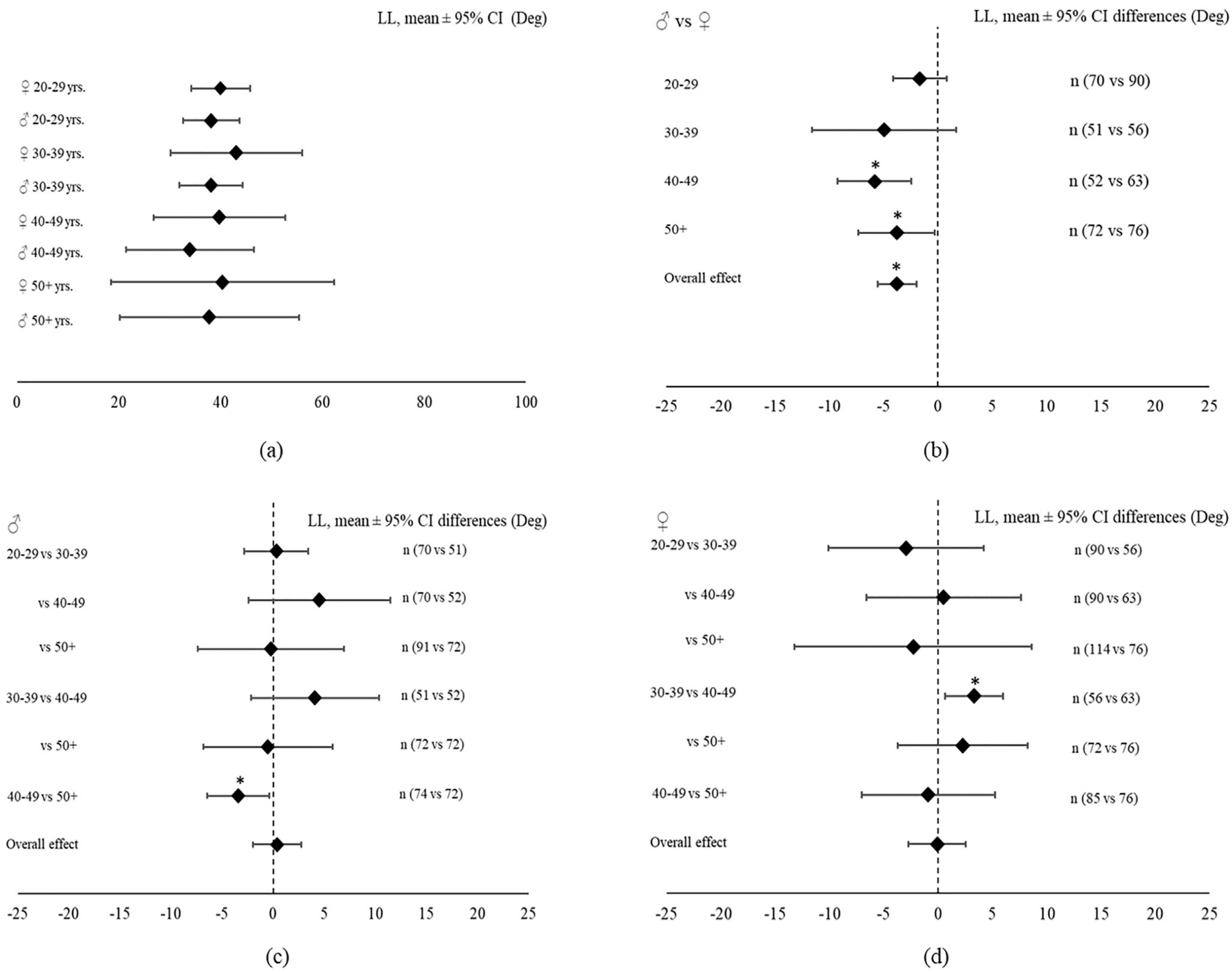

Fig. 3. Lumbar lordosis (LL). Two studies included for meta-analysis (Dreischarf et al., 2014; Youdas et al., 2006). (a) Mean and 95% confidence interval (CI) for males and females of different age groups. (b) Mean and 95% CI differences between males and females. (c) Mean and 95% CI differences in males because of age. (d) Mean and 95% CI differences in females because of age. For sex differences, if means difference < 0°, it represents males have a smaller LL than females; For age differences in males and females, if means difference < 0°, it represents age group 1 has smaller LL than age group 2.

a significant decrease existed from the 20s to 30 and then shows non-significant increase from 30 to 60s (Fig. 7f). In females, an overall decrease in the RoAR with age was apparent from 20s to 60s but found significant only in 40s vs 50s on the left side.

4. Discussion

The current systematic review and meta-analysis aimed to obtain the related literature and to substantiate the influence of age and sex on LL and the RoM in asymptomatic adults. Based on the collected data, the mean values, difference in mean values and confidence intervals for LL and the RoF, RoE, RoLB and RoAR were calculated. The quantitative statistical analysis demonstrated significant differences because of age and sex. While the young population in both sexes had a greater LL and RoM, aging significantly reduced the lordotic angle and the range of mobility in older subjects.

It is evident from the literature that females have greater LL (Dreischarf et al., 2014; Hay et al., 2015; Youdas et al., 2006), possibly because of a greater sacral slope than males (Koumantakis et al., 2016). In the present study, two studies (Dreischarf et al., 2014; Youdas et al., 2006) were pooled to calculate the mean values for LL and the differences due to age and sex. Although the results support significant sex differences and a non-monotonic decrease in LL with age, essentially, more data is required to further strengthen and elaborate the age-related finding. Both studies reported significant sex differences, with females having greater LL. However, the variation in LL with age reported in both studies were not similar. Dreischarf et al. (2014) showed a decrease in LL, consistent with the fact that the intervertebral disc flattens, particularly in the middle lumbar segments with progressing age, reducing the lumbar curvature and the RoM (Skaf et al., 2011). However, Youdas et al. (2006) measured both an increase and a decrease in LL with progressing age. As indicated previously, with aging an increase in LL is not normally expected; however, to rule out the possibility, more evidence is required. An increase or decrease may be dependent on the characteristic sagittal profiles and orientation of the pelvis, lumbosacral joint and sacrum (Bernhardt and Bridwell, 1989; Roussouly et al., 2005); therefore the evolution of LL during aging could vary among different sagittal profiles for the sagittal balance and stability requirements.

For the RoF, five studies were included in the meta-analysis. The results substantially support the view that males have a greater RoF, particularly in the 20s and 50s age groups, with less difference in the 30s and 60s. With respect to aging, the current results pro-

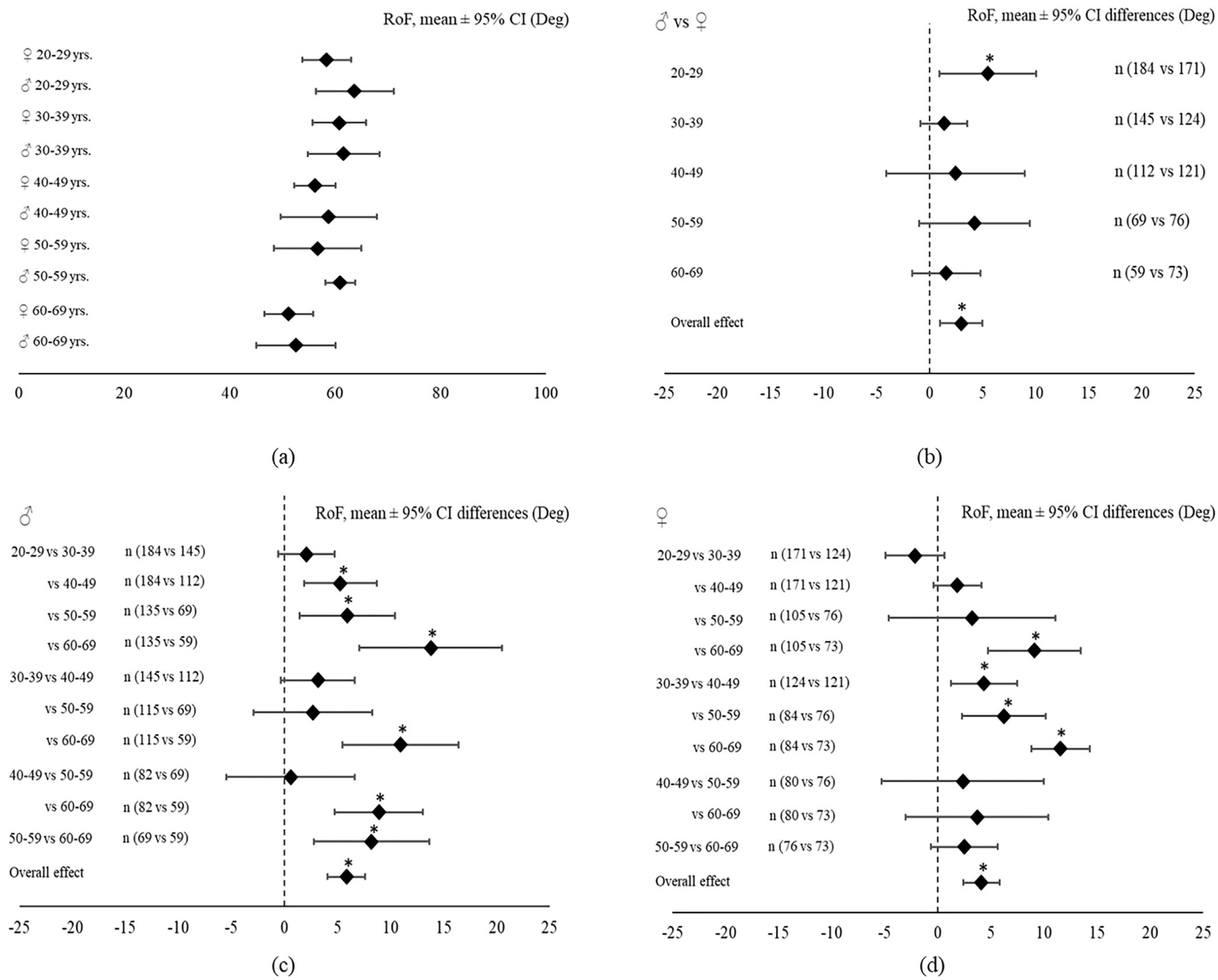

Fig. 4. Range of flexion (RoF). Five studies included for meta-analysis (Dreischarf et al., 2014; McGregor et al., 1995; Russell et al., 1993; Troke et al., 2005; Van Herp et al., 2000). For 50–59 and 60–69 yrs. age groups, Dreischarf et al. (2014) not included. (a) Mean and 95% confidence interval (CI) for males and females of different age groups. (b) Mean and 95% CI differences between males and females. (c) Mean and 95% CI differences in males because of age. (d) Mean and 95% CI differences in females because of age. For sex differences, if means difference >0°, it represents males have a larger RoF than females; For age differences in males and females, if means difference >0°, it represents age group 1 has larger RoF than age group 2.

vide evidence of a non-monotonic decrease in the RoF from 20s to 60s. This is in agreement with the fact that the stiffness of the spinal segments increases because of aging in intervertebral discs (Galbusera et al., 2014).

Females displayed a larger RoE in all age groups than males. A common view is that greater LL in females is the reason for a larger RoE, which corroborates with ours results. However, this remains debatable because of the observations to the contrary. Loebl (1967) implied that greater LL in standing posture reduced the RoE as subjects were close to their maximally extended posture. With aging, the decrease in the RoE displayed a monotonic and similar pattern in both sexes.

RoLB and RoAR, were symmetric between the left- and right-side measurements. The sex-based differences for the RoLB were minimal and non-significant. However, with aging, a significant decrease in RoLB was estimated in both sexes. With aging, the RoAR displayed differences in the pattern of variation between males and females. Males tended to display an increase in the RoAR from the 30s to 60s, whereas there was a decrease from the 20s to 60s age groups in females. Here, only three studies (McGregor et al., 1995; Troke et al., 2005; Van Herp et al., 2000) were pooled; therefore, more studies are required to substantiate these results. When considering the biomechanics, it could be speculated that the basis for this difference in RoAR could be due to the differences in the sagittal profiles between males and females and the way lumbar facets are locked during the axial rotation.

Although investigators relied on radiological techniques for accurate measurements, non-radiological techniques were frequently used to determine LL and the RoM due to ease of performing repetitive trials. As shown in the present study (Fig. 2.) and recently discussed by Pan et al. (2018), differences in measurements exist between radiological and non-radiological instruments. However, irrespective of the measuring instrument, several other factors could exacerbate the differences in measurements. Numerous publications lacked consistency in the definitions of the reported parameters. For example, Been and Kalichman (2014) discussed how different assumptions and the

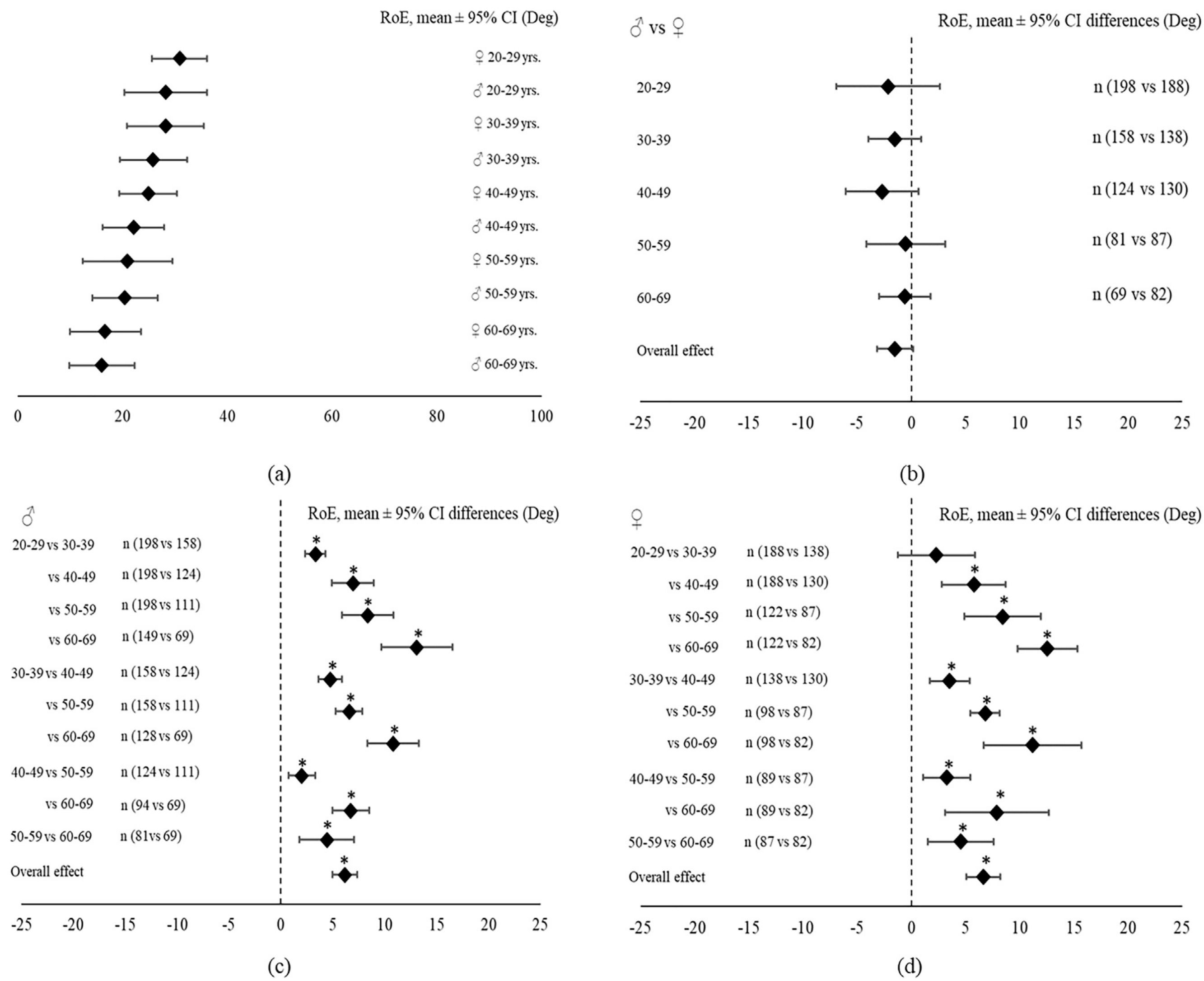

Fig. 5. Range of extension (RoE). Six studies included for meta-analysis (Dreischarf et al., 2014; McGregor et al., 1995; Russell et al., 1993; Saidu et al., 2011; Troke et al., 2005; Van Herp et al., 2000). For 50–59 and 60–69 yrs. age groups, Dreischarf et al. (2014) not included. (a) Mean and 95% confidence interval (CI) for males and females of different age groups. (b) Mean and 95% CI differences between males and females. (c) Mean and 95% CI differences in males because of age. (d) Mean and 95% CI differences in females because of age. For sex differences, if means difference <0°, it represents males have a smaller RoE than females; For age differences in males and females, if means difference >0°, it represents age group 1 has larger RoE than age group 2.

number of vertebrae can significantly affect the measurement of LL (Fernand and Fox, 1985). Inconsistency in the number of vertebrae evaluated for LL is a concern (Frenkel et al., 2018). For the future discourse, consensus among researchers would make the reported data useful and viable for valuable meta-analysis. Likewise, in previous studies, different methods (for e.g. tangent or trigonometric method) for determining LL were considered, which showed differences in the resulting measurements (Norton et al., 2002). Another factor that could influence LL in the standing posture is whether subjects were asked to stand in relaxed or erect posture (Prushansky et al., 2013). For the RoM, most of the studies did not indicate time of day when the measurements were taken. It should be noted that the diurnal variations in spinal disc height (Eklund and Corlett, 1984; Krag et al., 1990; Kramer and Gritz, 1980; Tyrrell et al., 1985) because of rehydration during rest hours or sleep could affect the measurements. A reduction in the RoF, RoE and RoLB was reported after sleep, because subjects measured were less flexible in the morning as compared to in the afternoon (Russell et al., 1992).

In female subjects, history of pregnancy could influence LL or the RoM. During pregnancy, females substantially gain weight, go through hormonal (Dehghan et al., 2014; Marnach et al., 2003) and biomechanical changes such as the adaptation of LL (Yousef et al., 2011) and the RoM (Biviá-Roig et al., 2018). Asymptomatic female subjects with history of single or multiple pregnancies (Letafatkar et al., 2010; Nourbakhsh et al., 2001) could have larger LL (Betsch et al., 2015; Otman et al., 1989) or the RoM (Biviá-Roig et al., 2018; Dumas et al., 1998; Opala-Berdzik et al., 2018); possibly due to postpartum joint laxity or weak abdominal muscles (Gilleard et al., 1996). Therefore, when measuring LL or RoM in asymptomatic female subjects, history of pregnancy could be a major confounder that need to be considered.

Moreover, numerous studies, which investigated both sexes, reported combined data for males and females, whereas, some simply did not indicate the type of sex of the subjects. Because many papers showed significant sex differences, separately reporting male and female subjects' measurements would be beneficial

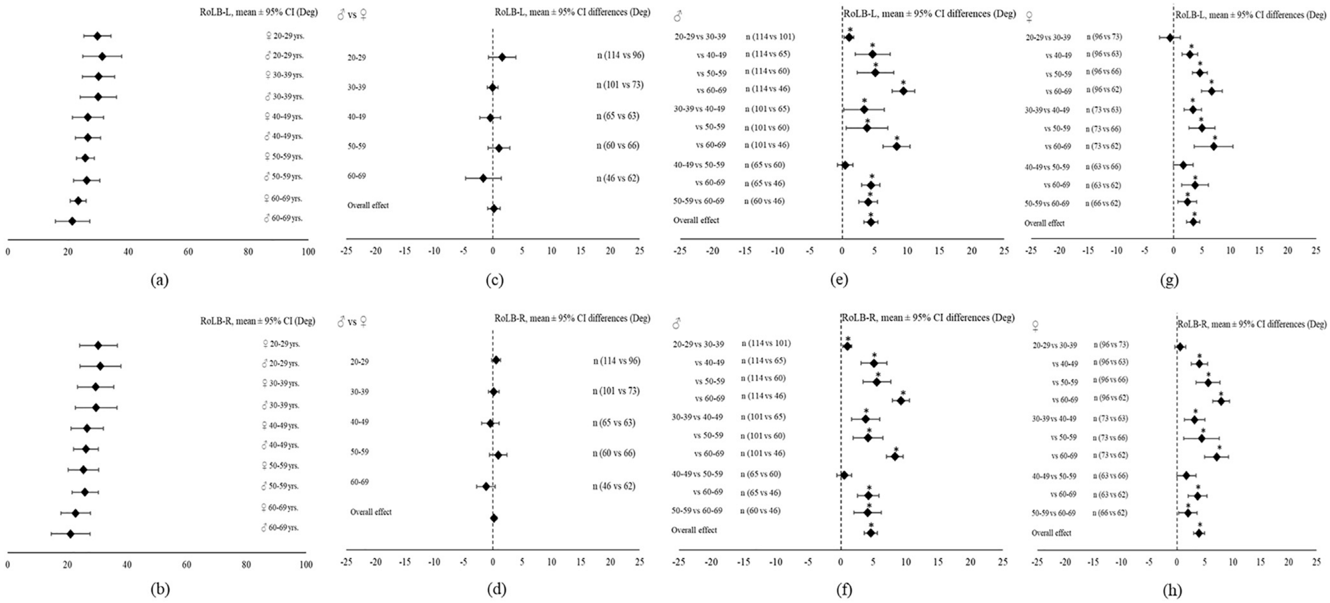

Fig. 6. Range of lateral bending (RoLB). Four studies included for meta-analysis (McGregor et al., 1995; Saidu et al., 2011; Troke et al., 2005; Van Herp et al., 2000). (a and b) Mean and 95% confidence interval (CI) for males and females of different age groups. (c and d) Mean and 95% CI differences between males and females for the left and right RoLB. (e and f) Mean and 95% CI differences in males because of age. (g and h) Mean and 95% CI differences in females because of age. For sex differences, if means difference <0°, it represents males have a smaller RoLB than females; For age differences in males and females, if means difference >0°, it represents age group 1 has larger RoLB than age group 2.

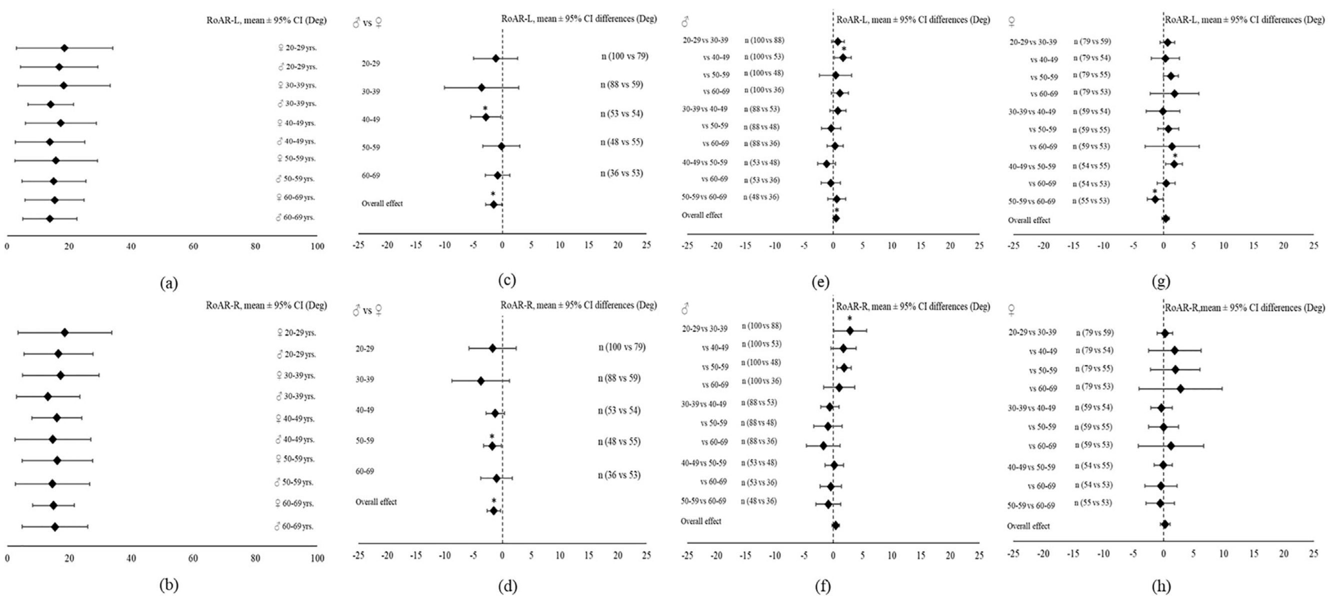

Fig. 7. Range of axial rotation (RoAR). Three studies included for meta-analysis (McGregor et al., 1995; Troke et al., 2005; Van Herp et al., 2000). (a and b) Mean and 95% confidence interval (CI) for males and females of different age groups. (c and d) Mean and 95% CI differences between males and females for the left and right RoAR. (e and f) Mean and 95% CI differences in males because of age. (g and h) Mean and 95% CI differences in females because of age. For sex differences, if means difference < 0°, it represents males have a smaller RoAR than females; For age differences in males and females, if means difference > 0°, it represents age group 1 has larger RoAR than age group 2.

for further investigations. Several papers used different age ranges to group subjects; proper age grouping (e.g., by decade) of the subjects would be more useful for studying the influence of age on the important parameters related to spinal shape and the RoM. In this study, based on the criterion for meta-analyses, studies available for synthesis were limited and therefore the possible presence of bias could not be omitted.

This current review and meta-analysis show that:

(1) Convincing evidence exists for sex differences in LL and the RoF, RoE and RoAR.
(2) LL and the RoF, RoE and RoLB decreased significantly with progressive age.

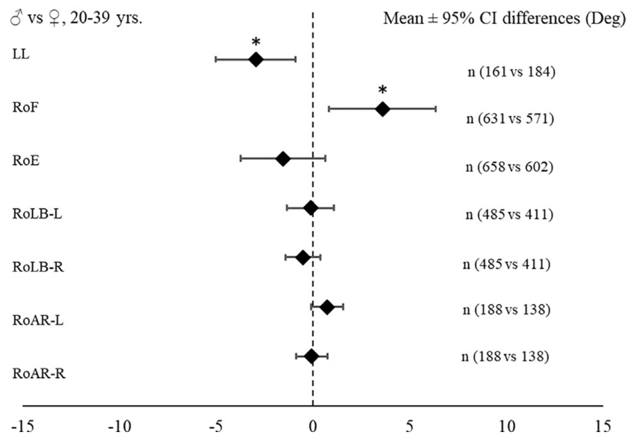

Fig. 8. Mean and 95% CI differences in the 20–39 year age group between males and females for the range of flexion (RoF), range of extension (RoE), range of lateral bending (RoLB) and range of axial rotation (RoAR). For sex differences, if means difference <0°, it represents males have a smaller LL, RoF, RoE, RoLB or RoAR than females.

(3) Significant differences were partially identified between radiological and non-radiological measurement devises.

Conflicts of interest

None.

Acknowledgements

This study was founded by the Federal Ministry of Education and Research (BMBF), Bonn, Germany (MEDITHENA, https://www.technik-zum-menschen-bringen.de/projekte/medithena) and the China Scholarship Council (CSC NO. 201708080090) and is not be conflicted by commercial interests.

Appendices A and B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jbiomech.2018.11.022.

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