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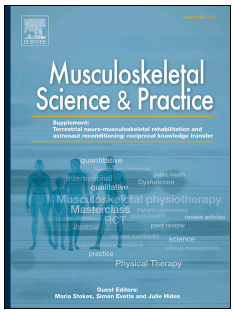

Normative values of cervical range of motion for both children and adults: A systematic review.

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Normative values of cervical range of motion for both children and adults: a systematic review.

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Abstract

Study design: Systematic review.
Objective: To synthesize studies reporting normative values of active cervical range of motion (ROM) in healthy children and adults.
Summary of background data: Evaluating active cervical ROM is part of routine assessment of patients with neck pain. Interpretation of outcomes necessitates having normative data per age category. Currently available normative values differ across studies, perhaps due to (the measurement properties of) the devices used.
Methods: A systematic review according to PRISMA guidelines was conducted. Electronic searches included EMBASE, MEDLINE, Web of Science, Cochrane, CINAHL and Google Scholar databases from inception to August 2018. Included studies had to involve healthy subjects in which active cervical ROM was assessed or when determining normative values was the aim of the study. Methodological quality of the included studies was assessed using an adapted version of the QUADAS. A mean value was re-calculated for the total group in case data were presented per gender per age-category only. When possible, data were pooled.
Results: From 2151 unique hits, 217 articles were selected for full text assessment, after which 162 articles were excluded. Data were extracted from 55 articles using 16 different measurement devices. Twenty-five studies were rated as being of “low risk of bias”. Only data from studies evaluating the CROM device and Zebris could be pooled.
Conclusions: This systematic review revealed that although a large number of studies assessed normative data for active cervical ROM, the methodological quality of most studies was low and the heterogeneity between studies was high. Only the normative data for active cervical ROM using the CROM device seems to be useful. Overall, reference values for measuring active cervical ROM is unclear for most measurement devices.

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INTRODUCTION

Optimal cervical range of motion (ROM) is essential for maximizing function of the cervical spine. Additionally, a recent systematic review identified that total active ROM is significantly decreased in patients with neck pain when compared to healthy individuals [1]. Physical therapists usually measure ROM, as improving ROM is often a goal developed for treatment. The American Physical Therapy Association guidelines for the management of neck pain recommends clinicians to use “easily reproducible activity limitation and participation restriction measures associated with their patient’s neck pain to assess the changes in the patient’s level of function over the episode of care” [2, 3]. Visual estimation of ROM is not recommended [2-5]. The Cervical Range of Motion (CROM) device, the standard goniometer, and the inclinometer are the most commonly used tools to measure cervical ROM [2, 3]. Several systematic reviews have concluded the CROM device is both reliable and valid in patients with non-specific neck pain [4, 5]. The single inclinometer [4, 5], Spin-T goniometer [4, 5] and The EDI-320 [4] are also reported to have good reliability and concurrent validity but reportedly require further evaluation [4, 5]. A large number of sophisticated devices are available to measure cervical spine ROM (e.g. FASTRAK, Flock-of-birds, Cervical Measurement System, CA-6000 SMA, Zebris system), some of which are likely more appropriate for research purposes than for everyday clinical use [5].

Normative ROM values are necessary to classify a patient as being restricted. Additionally, it is evident that age has an impact on ROM [6, 7]. There is a high number of studies reporting gender is not important in terms of normative values [7-17]. Consistently, one systematic review stated there are no important gender differences in ROM [7]. Conversely, another systematic review concluded there are differences in ROM only in some particular age categories, mainly in flexion-extension and not consistently in favour of male or females [6]. Surprisingly, these authors did not include studies (in their meta-analysis) that concluded “there is no

difference in ROM between both genders" [8-13], therefore results are likely to be biased.

Normative values differ among studies, which sometimes consist of small sample sizes per category of interest. Reported differences in normative values can be problematic when being used as a reference; when is a value considered to be 'abnormal'? Moreover, normative values can differ based on the equipment used, therefore it is important to compare the cervical ROM of a particular patient with normative values using a similar instrument.

There seems to be an increasing interest in systematic reviews on normative values [18-23]. A systematic review on normative values regarding cervical range of motion was published in 1999 but did not present normative data per age category per instrument [7]. To our knowledge, no systematic review on normative data on children has been previously published. Therefore, the aim of this systematic review was to summarize and pool normative values of ROM in healthy children and healthy adults, taking age and the measurement instrument into account.

METHODS

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines were used as the basis for our systematic review [24]. The protocol of this review was registered *a priori* in PROSPERO (CRD42018108547).

Literature search

A research librarian, together with the lead author (MTG) conducted the electronic search. Electronic searches included EMBASE, MEDLINE, Web of Science, Cochrane, CINAHL and Google Scholar from inception to August 2018. Eligible studies were identified using MeSH (Medline), Thesaurus (EMBASE, CINAHL) and free text words such as 'range of motion', 'goniometry', 'cervical spine', 'neck', 'normative data', 'normal value', 'reference value'. The search strategy is presented in Appendix 1.

Inclusion criteria

Studies were included if they involved healthy humans in which active cervical ROM was assessed and if assessing normative values was the objective. In an effort not to

miss any relevant information however, studies focused on e.g. validating a measurement product presenting descriptive measures (e.g. mean or median) and spread (e.g. standard deviation, standard error or interquartile interval) per age category on healthy subjects were also included (in case ranges were described, a range of 10 years was deemed appropriate. If no range was reported, studies were only included if they had a very small SD (<1.5)). Studies were excluded if individuals were pregnant, had a history of cervical surgery, had treatment for neck pain in the past year or had serious/severe diseases. Studies focused on assessing cervical ROM using imaging techniques such as radiography, CT or MRI were also excluded. No language restrictions were applied. Only results from full reports were included in this analysis.

Study selection

Articles retrieved from the database searches were imported in EndNote X9 (Thomson Reuters) and duplicated references were removed. A published inclusion strategy using EndNote was used [25]. Two investigators (MTG and ET) independently screened the titles and abstracts (excluded articles are listed in Appendix 2) to identify articles that would potentially meet the eligibility criteria. The full text of these articles was reviewed and the articles satisfying eligibility criteria were selected. Finally, the reference lists of the selected articles were screened to identify further relevant articles. Disagreements were solved by discussion or through arbitration by a third review author (JC). The excluded studies were listed and their bibliographic details with the reason for exclusion.

Quality assessment

All included articles were independently assessed by two raters (MTG and ET) for methodological quality and risk of bias (RoB). We used the checklist of Castro et al. [21], which is based upon the QUADAS [26], a checklist for the assessment of the methodological quality of both randomized and non-randomized studies of health care interventions [27] and other topics deemed important for the purpose of the systematic review. We slightly modified these specific topics, as the measurement of strength and ROM differ. The scale used, consists of 15 items, and covers three sections: (a) Study sample; (b) Test procedure and data analysis; and (c) Results presentation. Each item was rated as either ‘yes’, ‘no’, ‘unclear’ or ‘not applied

/applicable' (Table 2). A study was considered high RoB (low quality) when it received five or more 'no' or 'unclear' rates; and a study was considered low RoB (high quality) when it received less than five 'no' or 'unclear' rates. The consensus-agreement approach was used in the case of disagreement between the two reviewers. A third reviewer (JC) was consulted if consensus could not be reached. The Cohen *k* was used to calculate the interrater reliability of methodological scoring between raters [28]. The Cohen *k* identifies the percentage agreement between raters that would occur beyond chance.

Clinical appropriateness

In an effort to comment on clinical appropriateness, manufacturers were approached for pricing quotes and Instructions for use in an effort to make an expert opinion-based judgement by all authors on the viability of clinical use in private practice, looking at cost and user-friendliness.

Data extraction and analysis

Two investigators (MTG and ET) independently extracted the following information from each of the included studies: study objective, participant invitation process, number of participants, age, gender, measurement instrument studied, test protocol and information about the raters. Next, data on the outcome of interest was extracted for studies with low RoB, or when no low RoB studies were available for a specific instrument: the mean cervical range of motion in degrees and a standard deviation in all one-dimensional directions in "full cycle" (flexion plus extension, left plus right rotation, left plus right lateral flexion) and/or "half cycle" (flexion, extension, lateral flexion right, lateral flexion left, rotation right, rotation left) per age category. In case the researchers felt important data was missing, the authors of the original study were contacted.

Analysis

We re-calculated a mean value for the total group in case data was presented per gender per age-category only, as presenting normative values per age category was the primary objective of this review and a large number of studies report that gender is not important in terms of normative [7-17].

Data were pooled only when studies were considered to be of low RoB and also considered to be clinically homogeneous e.g. when they: 1) used a similar experimental protocol, 2) used a similar age classification, and 3) calculated parameters were found. Combined data pooling was performed [29].

RESULTS

The search strategy resulted in a total of 2150 unique hits. Of these, 217 articles were selected for full text assessment based on their title and abstract. Reference checking resulted in one additional study. Evaluation of the full text resulted in exclusion of 162 articles. Finally, 55 articles, evaluating 16 different measurement devices, were included (see Figure 1). A list of the excluded papers is presented in appendix 2 and 3.

Not all manufacturers were able to provide pricing quotes or Instructions for use for each individual instrument. Also, pricing was not always comparable, as some instruments were discontinued or an updated version has replaced the studied original. Therefore, we deemed in inappropriate to present this as a result of this paper. From the data we were able to retrieve, however, we made an expert opinion-based judgement on the viability of clinical use in private practice, taking cost and user-friendliness into consideration. We judged the CROM, Cervical Measurement System and goniometers or inclinometers to be the most viable for clinical practice.

Insert figure 1 near here

Description of studies

Table 1 describes the characteristics of the population and table 2 provides a description of the test protocol of the included studies (online supplementary files). The agreement between both raters on the methodological overall quality was κ= 0.85 (95%CI: 0.81 - 0.89) indicating almost perfect agreement [30]. There was no need to discuss disagreement with the third review author.

The CROM device was most often used (in 12 studies) [8, 9, 31-40], followed by the Goniometer or Inclinometer (10) [12, 41-49], Zebris (6) [13, 14, 17, 50-52], Vicon (5) [53-57], optoelectronic system BTS (4) [58-61], Cervical Measurements System (3) [62-64], CA 6000 Spine Motion Analyzer (3) [15, 65, 66], Electrogoniometric Penny & Giles (3) [67-69], 3 SPACE Isotrack (2) [10, 70], digital videography (2) [31, 71], Coda device (1) [72], Polhemus Liberty (1) [11], Polaris system (1) [16], Antenna (1) [73], and IMU sensors (1) [74].

Risk of Bias assessment

Thirty studies were classified as having a high RoB and 25 studies as having a low RoB. The methodological quality of the studies is presented in Table 3. The main categories with poor methodology were categories 4 (sample size), 5 (rater experience), 7 (validity) and 10 (randomization).

Normative data as a pooled result per device is presented in tables 4.1 and 4.2. Summarized results per measurement device are presented per category (considered to be appropriate/less appropriate for clinical care). Normative data based upon low RoB studies which could not be pooled are presented in table 5.1 to 5.3. Measurement devices included in high RoB studies only are described.

Insert table 1, 2, and 3 near here

Pooled normative data per device

Cervical Range of Motion (CROM) device

The CROM device (Performance Attainment Associates, Roseville, USA) uses three separate inclinometers attached to a frame. The CROM device has been reported to be both reliable and valid in several systematic reviews [4, 5].

The CROM device was the most commonly used device (n=12) to determine normative values [8, 9, 31-40]. Most studies were rated as low RoB studies [8, 9, 31-33, 36, 37, 39, 40]. Normative values (half cycle) are presented per age category in table 4.1. For six age categories data could be pooled, as the age categories were identical, studies were rated as low RoB and the protocols were considered to be acceptable and comparable (although there were differences in warming up). In the age category 11-20 there was a high number of athletes (football). Subgroup-analysis revealed the ROM of athletes significantly differed from the non-specified

population in all movement planes. However, in the age category 20-30 this difference did not remain for every movement. We therefore chose to present data for the non-specified population and the athletes separately as well.
ROM appeared to be greatest in the 1st decade of life (age 8-10), slowly decreasing with age and more rapidly in the 5th decade of life.
Insert table 4.1 near here

Zebris

The Zebris uses ultrasound microphone markers on a helmet and a shoulder cap which receive signals from the transmitters located in the measuring unit (Zebris Medizintechnik GmbH, D88316, Isny, Germany). There is positive data from primary studies regarding reliability (intra and intertester reliability)[13, 75] and validity [75, 76].
Six studies were included using the Zebris [13, 14, 17, 50-52], the primary aim of the majority of studies was determining normative values [13, 14, 17, 50]. Half of all studies were rated as low RoB studies [14, 17, 50]. Pooled normative values are presented per age category in table 4.2. For six age categories data could be pooled for full cycle ranges. One low RoB study could not be used to pool data, as different age categories were presented, therefore the data of this study is presented individually. ROM appeared to be greatest in the 2nd decade of life, slowly decreasing with age and more rapidly in the 6th decade of life.

Insert table 4.2 near here

Comparing the CROM and Zebris

Pooled values for full cycle ROM for both the CROM device and Zebris are presented in figure 2. These normative values differ. The data of the Zebris is based upon a smaller number of participants then the CROM device data is.

Please insert Figure 2 near here.

Summarized data of measurement devices considered to be appropriate for clinical care

The following measurement devices were deemed appropriate for clinical care as they were not expensive and are relatively easy to use.

Goniometer and inclinometer

A systematic review concluded that the single inclinometer is found to be reliable, however the construct validity of the single inclinometer, the universal goniometer and rangiometer were rated as doubtful [4] questioning the utility of these devices. Ten studies using a goniometer/inclinometer were included [12, 41-49]. The primary aim of the majority of studies was to determine normative values [12, 44-49]. Five studies were rated as low RoB studies [12, 41, 44, 45, 47]. Data could not be pooled, as the instruments used and protocols were not considered to be acceptably comparable. Normative values of low RoB studies are presented per age category in table 5.1. As a general trend, greatest ROM was observed in the 2nd decade of life, again slowly decreasing and with a more rapid decrease in the 6th decade.

Insert table 5.1 near here

Cervical measurements system, CMS

The Keno®-cervical measurement instrument uses two inclinometers on a frame (Kuntoväline Oy & David Fitness & Medical Ltd, Helsinki, Finland). There is positive data regarding reliability from two studies [64, 77] and validity (and nearly as valid as the CROM device) [64].

There were 3 studies included using the CMS [62-64]. Two studies were designed to determine normative values [62, 64] and all were rated as low RoB studies. Data could not be pooled, due to different age categories. Summarized normative values are presented per age category in table 5.4. A general slow decrease in ROM with increasing age was observed but none of the studies included participants in the 6th decade of life.

Insert table 5.2 near here

Summarized data of measurement devices considered to be less appropriate for clinical care

The following measurement devices were deemed less appropriate for clinical care as they were expensive and are relatively difficult to use. These devices are more likely used for research purposes.

The number of studies using the measurement devices differed: Vicon (5) [53-57], Coda device (1) [72], Polhemus Liberty (1) [11], Polaris system (1) [16]. Initially 3 studies were included using the CA 6000 Spine Motion Analyzer [15, 65, 66], however one study was eventually excluded as the same data was used as in another study [65]. For some instruments there is positive information on validity (VICON [56, 78], CODA device [72] for the CA600 only on the lumbar spine [79]) and reliability (VICON [56, 78], CA6000 [66, 80]). However, for the Polhemus Liberty and Polaris no information is available, although both studies [11, 16] using these devices were rated as low risk, this should be interpreted with caution. For all other devices only one study was rated as low risk as well [15, 53, 72].

Normative values based upon low RoB studies are presented per age category in table 5.3.

<u>Devices used by high risk studies only</u>

Studies using the optoelectronic system BTS [58-61], Electrogoniometric Penny & Giles [67-69], 3 SPACE Isotrack [10, 70] were rated as being of high risk. A number of studies used measurement devices or procedures which are not considered to be appropriate for contemporary clinical practice, as e.g. the markers/ cameras were not described in detail, authors manufactured the device themselves and studied it only once and/or the devices were no longer commercially available [31, 71, 73, 74, 81]. All of these studies were rated as high risk as well. Due to the nature of the missing information of the instruments and high risk rating we did not present data, we consider this not to be useful. However, the results are available from the authors upon request.

DISCUSSION

Main findings

This review established pooled normative data for several age categories for specific measurement instruments. We consider ‘normal’ ROM to be the pooled mean ± 1SD. Some studies had irregularities in their papers; e.g. Swinkels et al. described a

different number of repetitions. We found a large number of studies with small sample sizes and studies using a measurement instrument that had not been validated. Two studies rated as low RoB studies, used non-validated measurement instruments (Polhemus Liberty and Polaris), therefore this data should be interpreted with caution. Instruments such as Zebris and Vicon are only validated for healthy populations. A number of measurement devices, such as the Zebris and Isotrack, have evolved and it is unknown if this influences the validity and the measurement properties and thereby the normative values described for these measurement instruments.

Comparison to the literature

There is a scarcity of literature to compare this review with. One previous review with the aim to assess the influence of age and gender on ROM, stated they created a normative database using (non-)radiological devices [6]. As the aim of the review was not completely focused on normative data, the results cannot be compared. They included a smaller amount of studies (29 studies on non-radiological devices). Moreover, studies included in their review were excluded in ours (e.g. as there were no results/degrees presented per age category and only the conclusion regarding the influence of age was presented in the results). No normative values were presented per measurement device and no pooled normative data was created.

Strengths and limitations

This is the first review on this topic. Methodological scores are based on the purpose of this study, but some papers had a different focus. These studies should not be considered to be inappropriate per se, but for the purpose of this review they are ranked as high RoB studies. There is no generally accepted tool available to assess methodological quality of this type of study; we did however modify a tool that has been used previously. Some studies used a measurement device which could be used in different ways, e.g. using camera's or sensors. When this placement was not described in detail the procedure was rated as not appropriate. Additionally, as an exclusion criteria we stated participants should not have been treated for their neck pain in the past year. However, most studies did not explicitly state this.

We pooled data of the CROM device and the Zebris, even though there were differences in the warm up procedures. The position of measuring etc. however were quite identical, we therefore felt it was appropriate to pool these data.

Clinical implications

Cervical ROM is considered to be useful in clinical decision making [2, 3, 82, 83]. Restricted ROM is a criterion in diagnosing cervicogenic headache and clinically important spine injuries [83]. Moreover, restricted ROM is considered a negative prognostic factor for patients with neck pain [83]. “Restricted” however, is undefined. The current normative database using the CROM device presented in this systematic review can potentially be of value in order to label a patient as being restricted, when compared to a ‘normal’ value. There is no particular cut off value for an individual, as there is not one “normal” value for any direction. Normal should be considered as a value within a range of “normal range of motion”. For example, for people in their 30s, cervical rotation between 65 and 83 degrees can be considered as “normal range of motion”. ROM may be informative to clinical decision making and is moderately valuable when considered as one component within a suite of assessment items.

Future research

Although several studies have been performed to assess normative data for cervical ROM, there is still a lot unknown. For most devices there is no accurate normative database available. Additionally, it is unknown if variables such as race influence normative values of ROM. Therefore, large studies on normative data for all commonly used measurement devices would be of importance.
Recently, the use of smartphone applications (utilizing the device's internal gyroscope), offer an easy and inexpensive means of measuring cervical ROM. Validity and reliability of smartphone applications have been assessed but larger cohorts have yet to be measured in order to establish normative data in healthy controls [84-86].

CONCLUSION

This systematic review revealed that although a large number of studies assessed normative data, the methodological quality of most studies was low and the

heterogeneity between the studies was high. Differences were mainly due to equipment, procedure and age categories. Normative values of active cervical ROM differ across measurement devices. Therefore, only the normative database for active cervical ROM using the CROM device seems to be useful. “Normal range of motion” seems to have a substantial bandwidth, as the SDs are of importance. Overall, reference values for measuring active ROM is unclear for most measurement devices. There is still a scarcity of comparable research on normative data.

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FIGURE 1. Inclusion

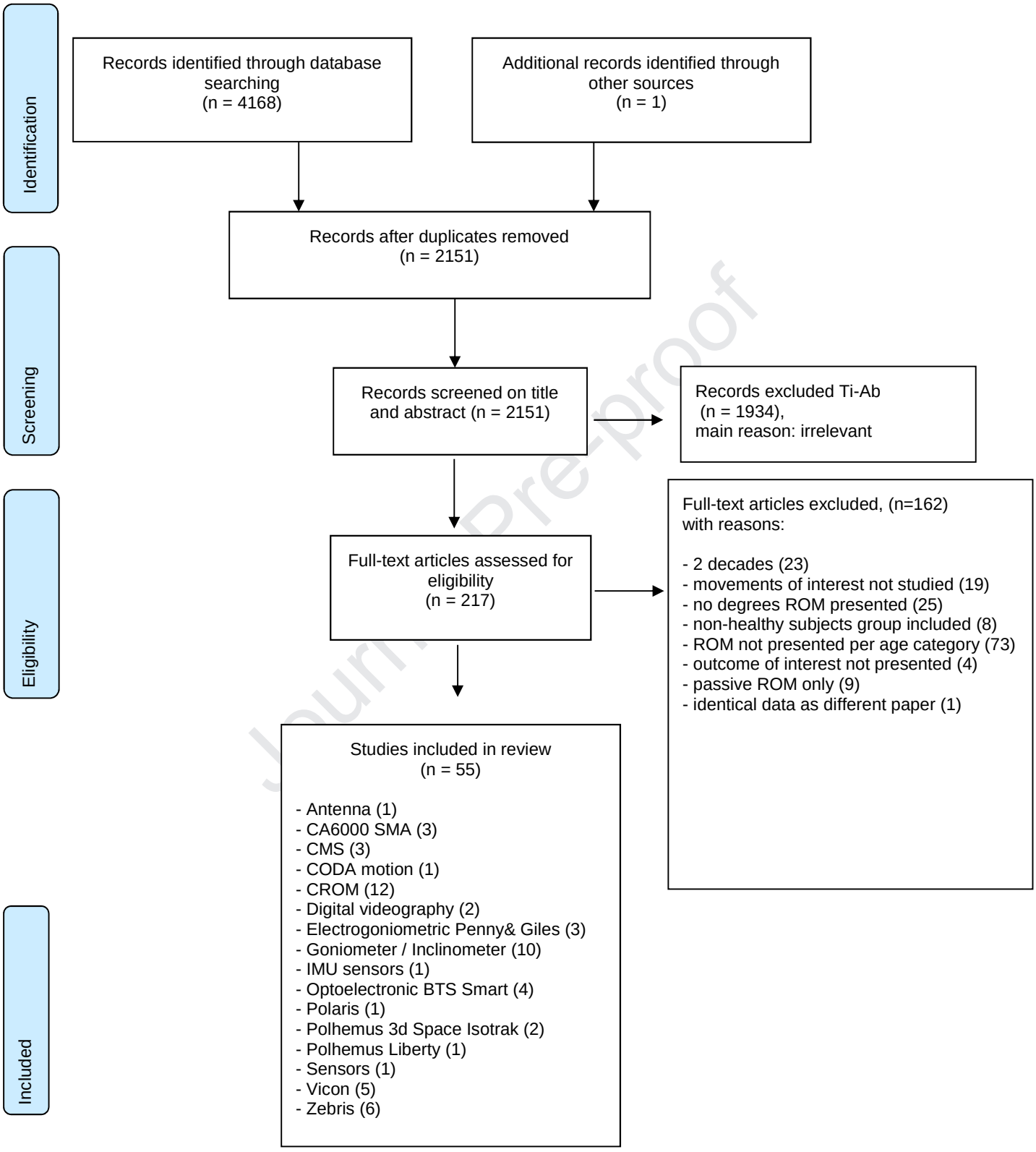
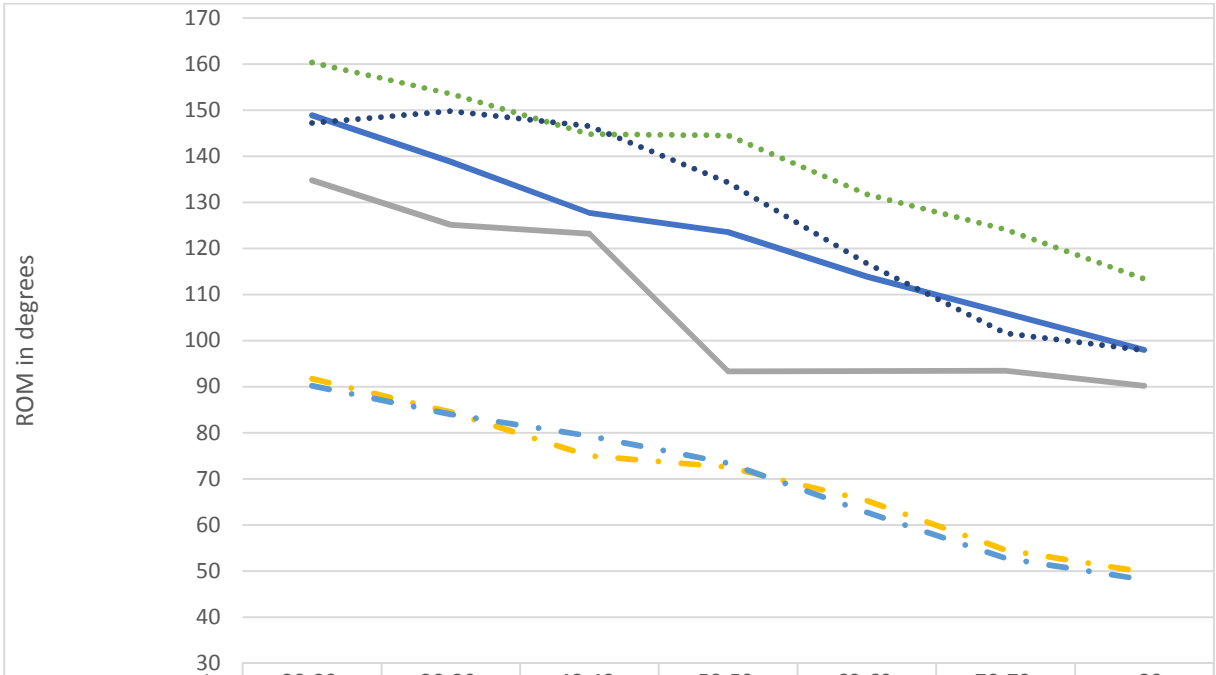


FIGURE 2. Pooled mean full range ROM for Zebris and CROM device across age decades.



Decades	20-29	30-39	40-49	50-59	60-69	70-79	> 80
F-E_Zebris	148.9	138.8	127.7	123.5	113.9	106	98
F-E_CROM	134.8	125.1	123.2	93.3	93.4	93.5	90.2
LF_Zebris	91.7	84.5	75	72.6	65.3	54.6	49.8
LF_CROM	90.2	84	79.3	73.4	62.7	52.8	48.1
ROT_Zebris	160.3	153.5	144.8	144.5	131.7	124.1	113.4
ROT_CROM	147.2	149.8	146.5	134.3	116.7	101.6	97.9

ROM = range of motion; F-E = full range flexion-extension; LF = full range lateral flexion; ROT = full range axial rotation.

TABLE 3. Quality assessment.

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total-score
Adegoke 15	Y	Y	Y	Y	N	Y	Y	Y	N	UC	Y	Y	NA	Y	UC*	Low RoB
Alahmari 17	Y	Y	Y	Y	Y	Y	N	Y	Y*	N	Y	Y	UC[b]	Y	UC*	Low RoB
Arbogast 07 C	Y	Y	Y	N	N	Y	Y	Y	Y*	UC	Y	Y	NA	Y	UC*	Low RoB
Arbogast 07 DV	Y	Y	Y	N	N	Y	N	Y	Y*	UC	Y	Y	NA	Y	UC	High RoB
Assi 14	Y	Y	Y	N	N	Y	N	Y	Y*	N	Y	Y	NA	Y	Y	Low RoB
Balogun 89	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	UC[a]	N	N	High RoB
Barati 17	Y	N	Y	N	N	Y	N	Y	Y*	N	Y	Y	N	Y	Y	High RoB
Budelman 16	Y	Y	Y	N	Y	Y	Y	Y	Y*	N	Y	Y	NA	Y	Y	Low RoB
Bulgheroni 98	Y	N	Y	N	N	Y	N	Y	Y*	N	Y	Y	UC	Y	N	High RoB
Buck 59	UC	N	N	Y	Y	Y	N	Y	Y*	UC	Y	Y	N	Y	UC*	High RoB
Cagnie 07	Y	Y	Y	N	N	Y	Y	Y	Y*	N	N	Y	Y	N	Y	High RoB
Castro 00	Y	Y	Y	Y[p]	N	Y	N	Y	Y*	UC	Y	Y	Y	Y	UC*	Low RoB
Chi 05	Y	Y	Y	N*	N	Y	Y	Y	Y*	UC	Y	Y	NA	Y	UC*	Low RoB
Christensen 98	Y	Y	Y	N	Y	Y	N	Y	Y*	N	Y	Y	Y	N	UC*	High RoB
Davies 16	Y*	Y	Y	N	N	Y	Y	Y	Y*	UC	Y	Y	NA	Y	Y	Low RoB
Demaille-W. 07	Y	N	Y	Y	Y	Y	Y	Y	Y*	N	Y	Y	NA	Y	UC*	Low RoB
Doriot 06	Y	Y	Y	N	N	Y	N	N	Y*	UC	Y	Y	N	Y	UC	High RoB
Farooq 16	Y	Y	Y	N*	Y	Y	N	Y	Y	N	Y	Y	Y	N	UC*	High RoB
Feipel 99	Y	Y	Y	Y	N	Y	N	Y	Y*	UC	Y	Y	Y	Y	Y	Low RoB
Ferlic 61	Y	Y	Y	N	N	Y	N	N	Y	UC	Y	Y	UC	Y	UC*	High RoB
Ferrario 02	Y	Y	Y	Y	N	Y	N	Y	Y*	UC	Y	Y	N	Y	UC*	High RoB
Guo 09	Y	Y	Y	N	N	Y	N	Y	Y*	Y	Y	Y	NA	Y	UC*	Low RoB

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total-score
Guth 95	Y	Y	Y	Y	N	Y	Y	Y	Y*	UC	Y	Y	UC[a]	Y	UC*	Low RoB
Hamilton 14 a	Y**	N	Y	N	N	Y	Y	Y	Y*	UC	Y	Y	NA	N	Y	High RoB
Hamilton 14 b	Y**	YP	N	N	N	Y	N	N	N	UC	Y	Y	NA	Y	Y	High RoB
Henmi 06	UC	Y	N	N	N	Y	Y	N	N	UC	Y	N	UC	N	UC	High RoB
Hole 95	Y	Y	Y	N	Y	Y	Y	Y	Y*	Y	Y	Y	UC	Y	Y	Low RoB
Hwang 15	Y	Y	Y	N	N	Y	N	Y	Y*	UC	Y	Y	UC	Y	UC	High RoB
Kauther 10	Y	Y	Y	Y	Y	Y	N	Y	Y*	UC	Y	Y	N	Y	Y	Low RoB
Kim 13	Y	Y	Y	N	N	Y	N	Y	Y	N	Y	Y	UC	Y	UC*	High RoB
Kuhlman 93	Y	Y	Y	N*	N	Y	Y	Y	Y	UC	Y	Y	NA	Y	UC*	Low RoB
Kuo 09	Y	Y	Y	N	N	Y	N	Y	Y	UC	Y	N	NA	Y	Y	High RoB
Lansade 09	Y	Y	Y	N	N	Y	N	Y	Y*	Y	Y	Y	Y	Y	Y	Low RoB
Lewandowski03	UC	N	N	UC	N	Y	N	UC	UC	UC	Y	Y	UC	N	UC*	High RoB
Lynch 08	Y	Y	Y	Y	Y	Y	Y	Y	Y*	UC	N	N	Y	N	Y	Low RoB
Malmström 06	Y	Y	Y	N	Y	Y	Y	Y	Y*	Y	Y	Y	Y	Y	Y	Low RoB
McKay 17	Y	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	Y	Y	Y	Low RoB
Natalis 99	Y	N	Y	N	N	Y	N	Y	N	UC	Y	N	Y	Y	N	High RoB
Nyland 04	Y*	Y	Y	Y	Y	Y	Y	Y	Y*	N	Y	Y	Y	Y	Y	Low RoB
Peolson 00	Y	Y	Y	N	Y	Y	Y	Y	Y*	N	N	Y	NA	Y	UC*	Low RoB
Ramiro 12	Y	Y	Y	Y	N	N	N	Y	Y*	N	Y	N	Y	N	UC*	High RoB
Schenkman 96	Y	N	Y	N	N	Y	Y	Y	Y*	UC	N	Y	UC	N	UC*	High RoB
Schöps 97	Y	Y	Y	Y	Y	Y	N	Y	Y*	UC	Y	Y	UC[a]	N	UC*	High RoB
Schreiber 01	Y	N	Y	N	N	Y	N	Y	N	N	N	Y	Y	Y	N	High RoB
Sforza 02	Y	Y	Y	N	N	Y	N	Y	Y*	UC	Y	Y	UC	Y	UC*	High RoB
Smith 07	Y*	*Y*	Y	Y	Y	Y	Y	Y	Y*	Y	Y	Y	Y	Y	Y	Low RoB

Study	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total-score
Song 18	Y	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	NA	Y	UC*	Low RoB
Swinkels 14	Y	Y	Y	Y	N	Y	Y	Y	Y*	UC	Y	Y	Y	Y	Y	Low RoB
Szulc 11	Y	N	Y	N	N	Y	N	UC	UC	UC	Y	Y	UC	Y	Y	High RoB
Theobald 2012	Y	Y	Y	N	N	Y	N	Y	N	N	N	Y	UC	N	UC*	High RoB
Tommassi 09	Y	Y	Y	N	N	Y	N	Y	Y*	N	N	Y	NA	N	UC*	High RoB
Trott 96	Y	Y	Y	N	N	Y	N	Y	Y*	UC	N	Y	UC	N	UC*	High RoB
Walmsley 96	Y	Y	Y	N	N	Y	N	Y	Y*	Y	Y	N	UC	N	UC*	High RoB
Wendt 13	Y	Y	Y	N	N	Y	N	UC	UC	UC	Y	Y	UC	Y	Y	High RoB
Youdas 92	Y	Y	Y	N	Y	Y	NA	Y	Y	N	Y	Y	Y	Y	Y	Low RoB

1* footballplayers, 1** rugby players, [a] unclear if only healthy people participated, 4* not appropriate sample size calculation for normative data but appropriate for the purpose of the study (effect size), 9* no standardized sentences, but standardized procedure with regards to the instructions, 13 *a procedures not appropriate, *b= no reference to the results or data presented, 15* no assessment of normality described
Notes: Items considered for rating: 1. Was the study population appropriate?; 2. Was the study population adequately described (i.e., sex, age)?; 3. Was the description of selection criteria presented?; 4. Was the sample size appropriate (e.g. justification through calculation or guidelines)?; 5. Was rater experience described?; 6. Was the measurement device described; 7. Was there a description about the validity of the instrument used?; 8. Were the standardization of positions and movements performed and properly described?; 9. Was the participants instructions described during the test?; 10. Were the order of tests randomized or counterbalanced?; 11. Were the outcome measures clearly described?; 12. Were all directions of movement separately described or was a rationale described if not?; 13. Were measures of reliability (e.g., ICC s, SEM) presented in case of multiple raters or referenced to reliability in similar situations?; 14. Were results clearly described (with regards to normative data)?; 15. Were appropriate inferential statistics presented?

*Agreement after discussion. n: no; y: yes; na: not applicable; uc: unclear.

TABLE 4.1 Normative values using the CROM

Age category (Number of participants)	Flexion (SD)	Extension (SD)	Rotation left (SD)	Rotation right (SD)	Lateral flexion left (SD)	Lateral flexion right (SD)
3-5 (26) [31]	55.8 (5.5)	75.3 (7.2)	68.8 (9.2)	68.1 (8.8)	47.6 (7.1)	51.3 (6.7)
6-8 (22) [31]	60.3 (5.0)	77.2 (6.6)	73.8 (10.3	74.2 (9.6)	50.2 (5.5)	51.4 (5.6)
8-10 (106) [36]	65.8 (12.6)	85.4 (13.9)	77.0 (7.3)	77.0 (7.3)	57.5 (8.2)	57.5 (8.2)
9-12 (19) [31]	62.8 (9.1)	75.3 (12.1)	76.1 (8.7)	76.6 (9.2)	47.3 (6.1)	48.1 (5.5)
11-19 (Pooled 302) [33, 37, 39, 40]	58.9 (9.7) *	70.1 (6.8) *	68.0 (5.1). *	67.9 (5.3) *	44.6 (5.0) *	44.1 (4.7) *
Normal population (40) [40]	64.0 (8.6)	84.8 (13.2)	71.4 (8.4)	74.5 (8.7)	46.5 (7.0)	46.9 (7.4)
Athletes (Pooled 262) [33, 37, 39]	58.1 (10.0)	67.9 (5.8)	67.5 (4.6)	66.9 (4.7)	44.3 (4.6)	43.7 (3.7)
20-29 (Pooled 254) [8, 9, 32, 37, 40]	59.7 (11.1) *	75.1 (11.3) *	73.8 (8.1) *	73.4 (7.8)	45.5 (7.3)	44.7 (7.4)
Normal population (Pooled 184) [8, 9, 32, 40]	58.4 (10.4)	76.8 (11.1)	74.6 (7.4)	75.2 (6.6)	45.0 (7.0)	44.7 (6.4)
Athletes (Pooled 70) [37]	63.3 (13.0)	70.7 (12.0)	71.8 (10.0)	68.5 (11.0)	46.8 (8.0)	44.7 (8.0)
30-39 (Pooled 163) [8, 9, 40]	55.4 (9.2)	69.7 (10.5)	74.5 (8.8)	75.3 (8.0)	42.1 (7.5)	41.9 (7.6)
40-49 (Pooled 159) [8, 9, 40]	56.2 (9.4)	67.0 (10.4)	72.7 (9.0)	73.8 (9.4)	39.8 (8.0)	39.5 (9.0)
50-59 (Pooled 157) [8, 9, 40]	50.8 (9.3)	63.0 (10.8)	67.1 (8.9)	67.2 (8.1)	36.6 (7.2)	36.8 (7.3)
60-69 (Pooled 44) [8, 40]	42.1 (8.0)	60.6 (11.2)	57.7 (7.6)	59.0 (8.4)	31.8 (6.2)	30.9 (7.0)
70-79 (Pooled 40) [40]	39.2 (8.8)	54.3 (12.3)	49.9 (8.4)	51.7 (9.5)	26.0 (7.6)	26.8 (7.3)
80-89 (Pooled 38) [40]	40.4 (8.7)	49.8 (12.9)	48.6 (9.9)	49.3 (9.3)	23.1 (6.9)	25.0 (6.0)

90-99 (Pooled 14) [40]	36.4 (9.8)	53.6 (17.7)	49.9 (11.5)	48.5 (11.1)	24.6 (7.5)	22.4 (8.0)

* Significant difference between athletes and the non-specified population

TABLE 4.2 Normative values using the Zebris

Age category (Number of participants)	Flexion (SD)	Extension (SD)	Rotation left (SD)	Rotation right (SD)	Lateral flexion left (SD)	Lateral flexion right (SD)
15-25 (56) [50]	140.14 (17.67)		150.78 (18.05)		94.97 (18.64)	
20-29 (Pooled 70) [14, 17]	148.9 (11.5)		160.3 (10.5)		91.7 (9.4)	
(20) [17]	70.7	73.9	81.0	78.9	47.1	46.7
25-35 (52) [50]	135.36 (17.33)		157.78 (20.19)		96.84 (20.64)	
30-39 (Pooled 28) [14, 17]	138.8 (4.4)		153.5 (5.5)		84.5 (5.6)	
(20) [17]	71.9	66.7	76.7	77.7	43.1	40.5
35-45 (38) [50]	128.93 (18.8)		148.63 (14.97)		88.88 (17.52)	
40-49 (Pooled 39) [14, 17]	127.7 (11.0)		144.8 (7.5)		75.0 (6.3)	
(20) [17]	68.9	60.3	73.9	73.8	37.6	38.8
45-55 (37) [50]	116.81 (17.96)		134.14 (19.44)		78.84 (24.01)	
50-59 (Pooled 48) [14, 17]	123.5 (11.4)		144.5 (9.2)		72.6 (8.0)	
(20) [17]	69.3	58.2	75.0	73.9	40.0	37.7
55-65 (26) [50]	111.81 (15.34)		131.32 (25.13)		76.31 (14.44)	
60-69 (Pooled 45) [14, 17]	113.9 (8.5)		131.7 (8.8)		65.3 (7.1)	
(20) [17]	65.9	48.8	67.6	64.9	31.4	32.7
65-79 (23) [50]	99.07 (12.83)		118.20 (17.64)		67.52 (17.64)	
70-79 (Pooled 42) [14, 17]	106.0 (8.5)		124.1 (7.7)		54.6 (6.7)	
(20) [17]	64.2	38.1	58.9	63.4	27.7	26.3
> 80 (5) [14]	98.0 (11.2)		113.4 (21.3)		49.8 (17.6)	

TABLE 5.1 Normative values using the goniometer / inclinometer

Author, year	Age category (Number of participants)	Flexion (SD)	Extension (SD)	Rotation left (SD)	Rotation right (SD)	Lateral flexion left (SD)	Lateral flexion right (SD)
Goniometer							
Adegoke, 2015, Universal Goniometer [41]	20-30 (100)	40.4 (12.8)	49.7 (12.2)	59.7 (8.9)	60.6 (8.3)	27.7 (7.6)	27.6 (7.6)
Guth, 1995, Myrin gravity goniometer [44] Swimmers	14 (20)	n/a	n/a	84.7 (6.0)	84.7 (7.3)	n/a	n/a
	15 (20)	n/a	n/a	79.7 (7.4)	80.6 (8.1)	n/a	n/a
	16 (20)	n/a	n/a	78.4 (8.8)	79.0 (8.9)	n/a	n/a
	17 (20)	n/a	n/a	80.3 (7.7)	80.3 (5.7)	n/a	n/a
	14-17 (Pooled 80)			80.8 (7.4)	81.1 (7.5)		
Kuhlman, 1993, Gravity goniometer [45]	20-30 (31)	69.4 (7.9)	75.5 (6.3)	92.8 (3.2) (supine)	93.0 (3.4) (supine)	49.0 (4.7)	48.5 (4.6)
Inclinometer							
Alahmari, 2017 Digital Inclinometer [47]	10-19 (26)	67.0 (8.6)	68.4 (10.3)	71.8 (8.8)	70.6 (5.8)	54.6 (7.1)	52.7 (7.3)
	20-29 (72)	64.7 (10.6)	66.3 (13.7)	68.2 (13.8)	67.1 (14.2)	46.0 (9.6)	47.5 (8.4)
	30-39 (34)	60.8 (6.2)	61.6 (7.1)	69.2 (10.1)	67.5 (9.3)	42.3 (6.5)	45.2 (5.3)
	40-49 (37)	58.8 (7.5)	58.5 (7.0)	66.1 (8.0)	65.2 (7.2)	42.5 (6.3)	42.4 (6.0)
	50-59 (29)	57.8 (6.0)	56.5 (8.2)	61.6 (9.4)	56.6 (12.4)	39.7 (7.7)	41.5 (7.4)
	60-69 (32)	56.6 (6.8)	58.8 (8.5)	53.4 (10.1)	55.5 (9.2)	38.8 (8.5)	40.6 (6.8)
	70-80 (3)	56.3 (9.3)	53.0 (8.8)	52.7 (11.2)	53.3 (12.6)	39.0 (8.8)	38.3 (9.3)
McKay, 2017, Bubble inclinometer [12]	4-9 (140)	70.0 (13.0)	81.0 (17.6)	n/a	n/a	n/a	n/a
	10-19 (160)	65.0 (11.4)	70.0 (14.6)	n/a	n/a	n/a	n/a

TABLE 5.2 Normative values using CMS

Author, year	Age category (Number of participants)	Flexion (SD)	Extension (SD)	Rotation left (SD)	Rotation right (SD)	Lateral flexion left (SD)	Lateral flexion right (SD)
Budelmann 2016 [62]	6-12 (34)	73.0 (13.1)	88.0 (9.9)	81.2 (7.6)	80.6 (7.9)	52.1 (5.5)	51.2 (5.4)
Kauther 2010 [63]	18-31 (3547)	47.6 (17.1)	55.4 (19.1)	63.3 (20.2)	63.5 (20.6)	32.9 (13.6)	33.9 (13.6)
Peolsson 2000 [64]	25-34 (23)	68.5	88	87.4	83.6	46.7	47.3
		157 (16.4)		171.4 (18.6)		93.5 (20.6)	
	35-44 (30)	67.5	79.5	79.5	77.0	40.5	44.0
		147 (18.3)		157.0 (18.0)		84.0 (16.3)	
	45-54 (26)	62.8	73.8	75.8	73.3	38.7	41.1
		136.7 (19.4)		148.5 (23.5)		80.3 (21.3)	

* Peolsson only presented SDs for flexion, left lateral flexion and left rotation and full range movements in the sagittal, frontal and transverse planes.

TABLE 5.3 Normative values using devices less likely to be appropriate for clinical care.

Author, year	Age category (Number of participants)	Flexion (SD)	Extension (SD)	Rotation left (SD)	Rotation right (SD)	Lateral flexion left (SD)	Lateral flexion right (SD)
VICON							
Assi 2014 [53]	6-12 (30)	118 (20.0)		134.0 (17.0)		84.0 (14.0)	
CA-6000							
Feipel 1999 [15]	14-19 (68)	70 (10)	61 (14)	75 (12)	75 (13)	47 (9)	48 (10)
	20-30 (133)	66 (10)	57 (15)	72 (9)	71 (10)	44 (7)	45 (8)
CODA							
Song 2018 [72]	20-30 (30)	48.4 (8.4)	55.4 (8.2)				
Polhemus Liberty							
Guo 2011 [11]	20-24 (20)	57.2 (9.5)	64.4 (13.2)	68.1 (7.4)	65.7 (8.6)	42.4 (6.2)	42.7 (7.9)
Polaris							
Lansade 2009 [16]	20-29 (20)	123.5 (18.5)		146.0 (12.0)		86.5 (12.0)	
	30-39 (20)	112.5 (14.0)		141.5 (15.5)		76.0 (19.0)	
	40-49 (20)	120.0 (12.0)		137.0 (10.5)		78.5 (14.5)	
	50-59 (20)	107.0 (13.0)		125.0 (16.5)		67.5 (12.5)	
	60-69 (20)	104.5 (14.0)		119.5 (16.0)		64.0 (15.0)	
	70-79 (20)	102.0 (16.5)		111.0 (14.5)		56.0 (13.5)	
	>80 (20)	81.5 (20.0)		101.0 (22.5)		48.5 (15.0)	

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Highlights

- Reference values for measuring active cervical ROM is unclear for most measurement devices.
- The CROM device and Zebris are the only instruments studied well enough so data could be pooled.
- In 55 included articles, 16 different measurement devices could be evaluated.
- Normative values of active cervical ROM differ across measurement devices.