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Paul Ullucci

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Reliability of Smartphone Inclinometry to Measure Upper Cervical Range of Motion

Paul A. Ullucci, Frank Tudini, and Matthew F. Moran

Context: Assessment of upper cervical range of motion (UCROM) and mobility is commonly performed in the clinical setting for patients suffering from headache, neck pain, and vestibular dysfunction. Reliable and reproducible measurement of this motion is often difficult or too expensive to perform in the clinical setting. Smartphone applications using the device's internal gyroscope offer an easy and inexpensive means of measuring UCROM, but their reliability has not been reported in the literature. **Objective:** To assess the reliability of an inclinometer application installed on 2 different devices (iPhone 6 [IP] and android [AN]) and to measure UCROM in a healthy population. **Design:** Two examiners assessed passive UCROM. Each examiner was assigned to a specific smartphone, and a repeated-measures design consisting of 3 trials for each examiner–phone was performed. The order of testing was randomized, and the examiners were blinded to UCROM measures. **Setting:** Laboratory. **Participants:** A total of 38 subjects (19 females and 19 males; age: 23.8 [1.2] y) without pain or injury to the neck or spine for at least 3 months. **Intervention:** Each examiner passively flexed the head fully, rotated the head fully in 1 direction, and then in another. Peak rotation measures were recorded from each smartphone. Three trials were performed for each phone, with a 2-minute break between examiners/phones. **Main Outcome Measures:** Intraclass correlation coefficient using a 2-way mixed, absolute agreement model was obtained (1) between each examiner–phone and (2) within each examiner–phone for the measurements in each rotation direction. **Results:** Interphone/examiner reliability comparing average peak and total UCROM for each device was excellent (.87, .81). Intraphone/examiner reliability, determined across 3 trials, was also excellent (AN right rot. = .91, AN left rot. = .96; IP right rot. = .98, IP left rot. = .95). **Conclusion:** UCROM can be reliably measured using a smartphone inclinometer application.

Keywords: upper cervical spine, inclinometer, atlanto-axial joint, atlanto-occipital joint

Measurement of cardinal plane cervical range of motion (CROM) is routinely performed in physical therapy.¹ Cardinal plane motion such as cervical flexion and extension is important clinically but has not been found to identify specific limitations in upper cervical mobility that could be causing or contributing to the patient's pain and dysfunction.^{1,2} Accurate assessment of upper cervical mobility and upper CROM (UCROM) is critical in the evaluation and treatment of those with pathology that can be influenced by the upper cervical spine, such as headache, migraine, vertigo, concussion, and postconcussion syndrome.¹⁻⁶

The cervical flexion and rotation test was developed specifically to assess mobility in the upper cervical spine. It is a commonly used manual examination procedure and considered a reliable measure of UCROM.^{2,6-8} Blanpied et al² state that because of its high level of specificity (.91), the cervical flexion and rotation test should be performed to rule in cervicogenic headache.

Findings from research investigating vertigo, concussion, postconcussion syndrome, migraines, and cervicogenic headache all state that the upper cervical spine and atlanto-axial and atlanto-occipital joints must be evaluated and mobility deficits addressed in patients suffering from these conditions.¹⁻⁶ Despite these recommendations, a limited number of publications describe the prevalence of UCROM mobility deficits in these varying patient populations.^{6,9} This lack of foundational information can be attributed to the high cost and difficulty of accurately measuring UCROM using the currently available gold-standard techniques,

such as video motion analysis, radiographs, and the CROM device (Performance Attainment Associates, Lindstrom, MN). Identifying an inexpensive and readily available tool to measure UCROM would allow researchers and clinicians to effectively measure UCROM and better define upper cervical mobility deficits as they relate to these varied conditions.

Improvements in and the increased availability of portable and inexpensive technologies currently allow smartphone users to assess 3-dimensional movements in real time using various applications. This technology has been found to be both reliable and valid when measuring range of motion in multiple joints, including cardinal plane range of motion of the cervical spine.^{9,10}

There is, however, a gap in the literature demonstrating the efficacy of this technology specifically for measuring UCROM. One inclinometer-based application, Clinometer (plaincode, Stephanskirchen, Germany), uses the device's internal sensors to measure multiplanar movements in real time, with a self-reported measurement accuracy of $\pm 0.1^\circ$. This reported accuracy is comparable with the more expensive gold-standard measures used to measure UCROM in a laboratory setting. To our knowledge, no published works collaborate their claims or supporting the use of this particular application to measure UCROM in humans. The purpose of this study was to evaluate the reliability of the Clinometer application in both iPhone (IP) and android (AN) devices when measuring UCROM in a laboratory setting.

Methods

Two clinically trained doctoral researchers with more than 40 years of combined manual clinical experience performed this laboratory study.

Ullucci and Moran are with the Department of Physical Therapy & Human Movement Science, Sacred Heart University, Fairfield, CT. Tudini is with Campbell University. Ullucci (ullucci@ SacredHeart.edu) is corresponding author.

Each examiner was assigned to measure UCROM using either the IP or AN device and were blinded to their own UCROM measures.

A convenience sample of 38 healthy, college-age students (19 females and 19 males; age: 23.8 [1.2] y) (Table 1) without limited range of motion, stiffness, pain, or injury in the neck or spine for at least 3 months took part in this study. All participants read and signed the appropriate informed consent documentation as required by the Sacred Heart University Institutional Review Board that approved this study.

Order of testing, AN versus IP, was randomized using a coin, with heads indicating AN and tails indicating IP. The direction of the subject's head was rotated first was also randomized using a coin, with heads indicating right and tails indicating left.

Subjects were placed in a seated position, as described by Amiri et al,⁸ with their hair suitably positioned to allow visualization of the device and to ensure that the device was properly secured to the head (Universal Head Strap; Velocity Clip, Lake Tahoe, CA) (Figure 1):

1. The smartphone and head strap were positioned on the subject's head, and straps were tightened to prevent movement.
2. The subject's head was passively flexed to end range, with neutral rotation and neutral side bending by the examiner. The head strap position was adjusted until the application read zero,

Table 1 ROM Measurements

	Mean	SD
iPhone		
Right rotation	50.0	11.3
Left rotation	52.1	10.8
Total ROM	102.1	21.0
Android		
Right rotation	47.4	6.6
Left rotation	47.6	9.0
Total ROM	95.0	12.7

Abbreviation: ROM, range of motion. Note: Total ROM was calculated by adding mean left and right rotation together.



Figure 1 — Testing position.

thereby establishing a “neutral” starting position. The subject's head was actively returned to the upright starting position.

3. The subject maximally flexed, extended, rotated right, rotated left, side bent right, and side bent left actively to normalize cervical planes of cardinal motion and ensure that the head strap and phone combination remained securely fixated on the head. The subject's head was actively returned to the upright starting position.
4. The examiner passively flexed the subject's neck to end range.
5. The examiner passively rotated the subject's head in 1 direction until the examiner perceived no further range of motion or the subject reported pain. UCROM was recorded by a research assistant to ensure that the examiner moving the head was unaware of the measures.
6. The subject's head was passively rotated in the other direction and the measure recorded, as above.
7. The subject then returned his or her head to its normal resting position and rested for 20 seconds.
8. Steps 1 to 7 were repeated to obtain 3 trials for that device.
9. The head strap and phone were then removed, and steps 1 through 8 were repeated to obtain 3 trials for the other device.

If at any time the subject or examiner reported or perceived a lack of fixation of the device, the trial was discarded and the entire testing procedure was repeated. This protocol produced 3 measures of UCROM in each direction (left and right) for each device. Data were analyzed using SPSS software (version 24; IBM Corp., Armonk, NY). The intraclass correlation coefficient (ICC) was calculated using a 2-way mixed, absolute agreement model (1) between each examiner–phone and (2) within each examiner–phone for the measurements in each rotation direction.

Results

Total UCROM measures were calculated for each device by adding the average left and average right UCROM measurements. Average of left, right, and total UCROM for each device is provided in Table 1. Data for reliability are presented in Table 2 for interphone/examiner and intraphone/examiner. A multivariate analysis of variance was performed to determine whether there was a difference in UCROM measurements by sex. Analysis reveals that males had significantly greater left, right, and total UCROM compared with females using either phone ($P < .001$).

Table 2 Reliability Table

	ICC	Confidence interval		P
		Upper	Lower	
Interphone/examiner				
Mean peak ROM	.872	.786	.928	<.001
Mean total ROM	.817	.575	.914	<.001
Intraphone/examiner				
Android left	.962	.936	.979	<.001
Android right	.912	.849	.951	<.001
iPhone left	.951	.917	.973	<.001
iPhone right	.979	.964	.988	<.001

Abbreviations: ICC, intraclass correlation coefficient; ROM, range of motion.

Discussion

This published study is the first to measure UCROM using both IP and AN smartphone technology coupled with an inclinometer application. The data demonstrated that UCROM can be reliably measured using these devices in a laboratory setting. The reliability measures for between-phone and within-phone measures were high (ICC > .81) and are consistent with those found in other studies examining the reliability of smartphones coupled with various applications to measure total CROM.^{9,10} This study and previously published reports demonstrate that smartphone technology can reliably measure both total CROM and UCROM.^{9,10} The results of this study suggest that smartphones, using the Clinometer application, can be used to reliably measure UCROM.

This study found that in nonsymptomatic male and female subjects of college age, there was significantly ($P < .001$) greater left, right, and total UCROM in males compared with females. There appears to be a gap in the literature reporting differences in UCROM differences in males versus females. Ogince et al⁶ noted that males had greater UCROM than females; however, this difference was not statistically significant in a population of subjects with cervicogenic headache. The lack of statistical significance in the Ogince et al⁶ study may be because their participants were symptomatic and placed in the supine position during measurements, whereas our subjects were sitting, healthy, without complaints of pain or stiffness, and of college age.

The modified flexion and rotation test has been shown to have a 91% diagnostic accuracy in identifying limitations in UCROM in subjects suffering from cervicogenic headache.⁶ Ogince et al⁶ relied on expert clinician judgment combined with manual measurement using a modified CROM device to identify those with limited UCROM. This study also relied on expert clinician judgment to determine the end range of cervical rotation while performing the cervical flexion and rotation test in a sitting position and was able to reveal similar data while concurrently measuring UCROM with a smartphone inclinometer application. The cost of the equipment used in this study, excluding the phones themselves, is less than \$15. This study demonstrated that clinicians can quickly and inexpensively measure UCROM reliably in their patients by using a head strap, smartphone technology, and a commercially available inclinometer application.

Conclusion

Using a smartphone inclinometer application combined with an inexpensive camera mount can reliably measure UCROM in college-age students.

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