COMPARISON OF WRIST ANGLES BETWEEN TWO ESTABLISHED BIOMECHANICAL MODELS

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The purpose of this study was to identify differences between two established methods for wrist angle calculation (U.L.E.M.A. by Jaspers et al. & model by Metcalf et al.) during range of motion (ROM) movement tasks. Reflective markers, representing both hand models, were placed on anatomical landmarks of 10 healthy participants. Sagittal plane ROM of the wrist was analysed during open and closed hand wrist flexion/extension. Differences in ROM of the wrist flexion/extension were found for both tasks over the entire movement cycle (closed hand=12.4° (±10.1), open hand=10.3° (÷7.0°)). In particular, differences in extension are noticeable during wrist movement with open hand, though, an offset correction in neutral position might influence this outcome. Potential reasons for these variances are identified and should be taken into account when utilizing the hand model.

KEYWORDS: hand model, upper extremity, range of motion

INTRODUCTION: Since the extrinsic finger muscles (Flexor digitorum profundus, flexor digitorum superficialis, Flexor pollicis longus, Abductor pollicis longus, Extensor digitorum communis, Extensor pollicis longus) originate in the forearm and thus span across the wrist, wrist movement is relevant for many clinical questions, especially after traumatic injury or surgical procedures. 3D motion analysis becomes a frequently used tool for the upper extremity and hand, thanks to improvements in camera technology and the use of smaller markers. Compared to other instruments such as goniometry or instrumented gloves 3D motion analysis avoids greater discomfort for patients (Reissner et al. 2019) and is suitable to quantify wrist movement. Unfortunately, there remains an insufficient body of research concerning hand and finger kinematics utilizing 3D motion analysis techniques (Reissner et al. 2019).
One frequently used upper limb model is the so-called U.L.E.M.A. (Upper Limb Evaluation in Motion Analysis) approach (Jaspers et al. 2011a, Jaspers et al. 2011b), which includes the joints between shoulder and hand. The hand including the fingers is considered as the most important part of the human body, especially during activities of daily living (ADL), U.L.E.M.A., though, does not account for such intrinsic hand movements (i.e., finger joints). Existing hand models, which include finger joint movements, differ considerably in various studies, because of the different objectives of a model and the complex structure of the hand and upper extremity (Rau et al. 2000, Lee and Jung 2015). Models with one marker per segment are used for clinical applications (Metcalf et al. 2008, Carpinella et al. 2006). The main advantage is the intuitive and repeatable placement of the markers and the reduced number of markers on the skin. This not only increases the comfort of the participants, which is crucial for measuring fine motor skills, but also ensures ease of use (Metcalf et al. 2008, Lee and Jung 2015). Unfortunately, one of the main disadvantages of such models is the lower accuracy. To assess wrist as well as intrinsic hand movements, a hand model was adopted by the authors using one marker per segment. The calculation of the wrist is based on a study by Metcalf et al. (2008) which explicitly suggests the use on patients. Here, the wrist joint is calculated between a forearm and hand plane and is defined by 3 degree of freedoms, while vector dot products are used to calculated 3D joint angles. Studies such as Reissner et al. (2018), however, state that the calculation should be performed with Euler angles (e.g., in U.L.E.M.A.), as there is enough space on the forearm to place enough markers. Both approaches, though, have never been compared with each other during directed movements at the wrist. Therefore, the aim of this study was to compare both hand models' wrist angles and account for potential differences.

METHODS: The study has been approved by the local ethical board (2020-15528). In total ten healthy participants were included (age: 35 +/-12 years, male/female: 6/4) who gave informed consent before the measurement. Participants were included in the study if they had no injuries to the included arm within the last 2 years. Participants were recorded by two orthogonal video cameras, which were placed sagittal to the arm of interest and frontal to the sitting position. A total of 14 infrared cameras (Qualysis 8x Oqus 500+; 4 Miqus, Gothenburg, Sweden) were, furthermore, used to track the 24 reflective markers (Diameter: 4mm) on the hand and four reflective markers on the forearm (12.5mm) representing the U.L.E.M.A. model and adopted hand model including the wrist of Metcalf (Figure 1). 3D motion data for both models were, therefore, simultaneously sampled at a rate of 100 Hz. All participants executed a standardized measurement protocol for the upper extremity, which included activities of daily living, range of motion tasks, as well as specific spasticity testing.

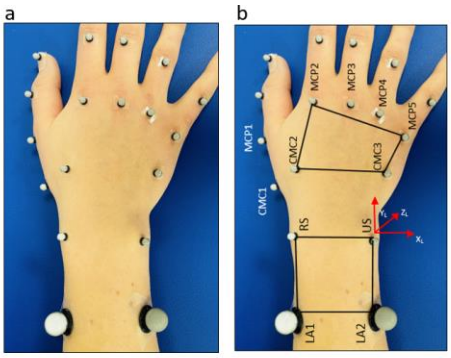

Figure 1: a: Marker placement for both models. b) forearm and handplane and local coordinate system used in the Metcalf et al. 2008 hand model

Wrist motion was captured for both closed and open hand flexion/extension. In both trials, participants were instructed to flex and extend the wrist as much as possible to measure active range of motion (ROM). Three repetitions of each trial were performed. The kinematic data for both ROM trials were processed using two different calculation methods. The first method is based on vector dot products between a forearm segment and a hand segment (Figure 1). Metcalf et al. 2008 described the method as follows: The vectors were defined using four markers on the forearm and hand. For the flexion/extension angle of the wrist, the normal vector to each plane is calculated. For the angular movement between the two planes, the dot product between the forearm and hand planes is used. The U.L.E.M.A. model (Jaspers et al. 2011a, Jaspers et al. 2011c) is used as the second method. Anatomical coordinate systems and joint rotation sequences of the model are based on ISB guidelines (Wu et al. 2005).

A movement cycle was defined from neutral position of the wrist to the next neutral position of the wrist after maximum extension and flexion. Events were set manually shortly before the next movement cycle (neutral – flexion – neutral – extension – neutral) started. All three repetitions of the trial were used for data processing. Trajectories were filtered in QTM using a butterworth filter with a cutoff frequency of 10 Hz. Further data processing and angle calculation was undertaken using Python (Version 3.11.3) for the hand model (i.e. wrist of Metcalf) as well as using open source pipeline U.L.E.M.A. in MATLAB. Movement cycles of both tasks were time normalized (0–100%) and ROM was calculated.

Statistical analysis was performed in RStudio (Version 2023.12.1.; C-ran package, psych). As ROM data was normally distributed (Shapiro-Wilk Test), the parameter was analyzed using a two-sided t-test for dependent samples to assess significant differences ($\alpha = 0.05$) between both angle calculations models for each movement trial.

RESULTS: Figure 2 shows joint angles of both models during wrist motion with closed (a) and open (b) hand, respectively. Both movements show significant differences between the two models (Table 1). With closed hand, models differ in average 12.4° (÷10.1°), with open hand 10.3° (±7.0°), while the U.L.E.M.A. model results overall in higher angles than the model of Metcalf.

Table 1: ROM (in degree) for closed and open hand ROM tasks for each participant using both calculation models. SD = standard deviation.

	Hand CLOSED [°]			Hand OPEN [°]		
	U.L.E.M.A.	Metcalf	difference	U.L.E.M.A.	Metcalf	difference
Participant 1	130.9	104.9	26.0	127.2	105.7	21.5
Participant 2	106.7	102.8	3.9	118.9	112.3	6.6
Participant 3	122.0	118.8	3.2	136.9	125.4	11.5
Participant 4	144.6	125.6	19.0	146.7	131.5	15.2
Participant 5	126.9	114.4	12.5	116.6	110.8	5.8
Participant 6	110.3	100.3	10.0	113.9	110.6	3.3
Participant 7	143.6	135.9	7.7	132.6	125.3	7.3
Participant 8	130.9	129.4	1.5	135.3	131.6	3.7
Participant 9	160.6	128.9	31.7	162.6	140.6	22.0
Participant 10	130.6	122.4	8.2	124.7	118.2	6.5
Mean (sd)	**130.7 (16.1)**	**118.3 (12.4)**	**12.4 (10.1)**	**131.5 (14.9)**	**121.2 (11.4)**	**10.3 (7.0)**
p	***0.0038***			***0.0012***		

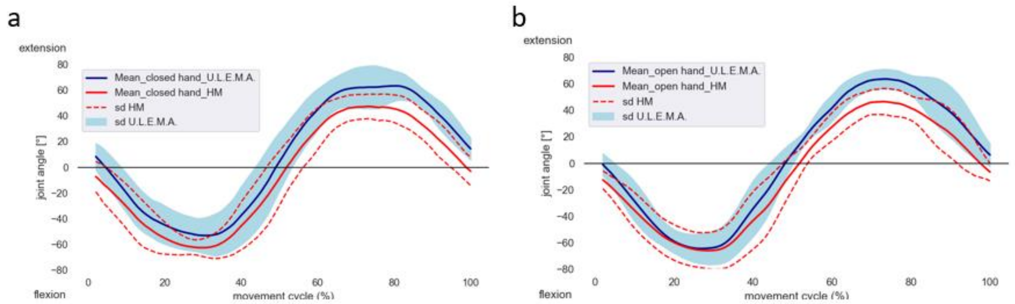

Figure 2: mean wrist joint angle of all participants during ROM with closed hand (a) and open hand (b). Black lines show joint angle calculation using Metcalf model (vector based). The dotted lines in each color show the standard deviation (SD). Orange: Mean wrist joint angle based on U.L.E.M.A. model and calculation. X-axis: movement cycle normalized to 100%

When visually comparing both movement curves between models, biggest differences can be seen during maximal extension (Figure 2). During flexion, model curves are close to each other.

DISCUSSION: It is well known that the angle calculation using Euler angles is more accurate than using cross products and vectors. Nevertheless it's necessary to find out how large these differences are to use the knowledge for further research at the hand. Wrist flexion/extension is a complex movement that occurs between the radius and the first row of carpal bones (radiocarpal joint), as well as between the first and second rows of carpal bones (midcarpal joint). It could already be demonstrated, that consecutively wrist flexion/extension does not precisely occur around the anatomically defined axes (Kaufmann et al. 2006; Foumani et al. 2009). Specifically, during the terminal wrist flexion, an additional relevant radial deviation and supination between the capitate and radius were measured in the CT scans of a cadaver model (Kaufmann et al. 2006). Additionaly, Li et al. 2005 demonstrated a strong coupling between flexion/extension and radial/ulnar deviation during wrist movement. These evasive movements in the wrist joint during wrist flexion/extension in radial/ulnar deviation as well as in pro- and supination may be a reason for a lower ROM when using cross products. Interestingly - in contrast to the cadaver study (Kaufmann et al. 2006) the largest deviation between the Metcalf and the U.L.E.M.A. model was measured during wrist extension. This could be attributed to the fact that both models have a slightly different neutral position. Even though the curve of the joint angles looks similar in both models, there is a significant difference in the calculated ROM in wrist extension/flexion of approximately 10°. Whether these 10° are clinically relevant certainly depends on the specific clinical question at hand. However, the individual differences between the two models in the calculated ROM vary significantly depending on the flexion axis of the wrist. Participant 8 exhibited the smallest difference with 1.5° when the hand was closed and 3.7° when open, which may not be considered clinically relevant. In contrast, participant 9 showed the largest difference in ROM with 31.7° when the hand was closed and 22° when open, which is indeed clinically relevant. In any case, no comparison of absolute ROM values obtained with these two different models should be made. Additionally, it's crucial to examine the offset in each participant's hand neutral position. Another limitation is the lack of radial/ulnar deviation in the hand model, which will be prioritized in the upcoming phases of the model development.

CONCLUSION: When using the hand model according to Metcalf et al. (2008) to assess wrist range of motion in flexion/extension, it is important to be aware that the ROM is underestimated by approximately 10° on average compared to a method using Euler angles (e.g. U.L.E.M.A.). This underestimation can be even greater in individual cases with significant deviation of the wrist axis of motion in ulnar/radial deviation as well as pronation/supination. In addition, individual differences exist which need to be further analysed.

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