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Identifying an Optimal Sampling Method to Estimate Postural Risk in a Dynamic Work Task

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Abstract

Introduction: The Rapid Upper Limb Assessment (RULA) is an ergonomic assessment tool used to screen for risk of musculoskeletal injury due to working posture. The RULA is traditionally applied once during a work task to approximate overall risk. No method exists for estimating a RULA score for work requiring frequent shifts in posture across an extended period of time.

Purpose: The goal of this study was to identify an optimal sampling method for applying the RULA across a long time-period that accurately represents overall risk.

Methods: Four right-handed female dental hygiene students were video recorded from three angles while performing hand scaling during patient clinic visits (88.97 minutes on average). RULA was continuously scored across the entire session, updating the score when a significant postural shift lasting for more than 15 seconds occurred. A time-weighted average (TWA) RULA score was calculated. Three sampling methods were evaluated: equivalent interval samples, random samples, and random samples selection weighted within "clock positions." Each method was compared to the TWA using a paired samples t-test and percent difference.

Results: TWA RULA across the four students ranged from 3.4 to 4.3. Preliminary sampling averages using 10 samples were all within 0.2 of the TWA. Further iterations evaluating various sample sizes is ongoing.

Discussion: Preliminary results suggest that all three sampling methods provide a reasonably accurate approximation of the TWA score at the sampling rate tested. Future iterations of this analysis will be continued to identify the minimum required sampling rate to meet our TWA criterion.

INTRODUCTION

The Rapid Upper Limb Assessment (RULA) is an ergonomic assessment tool that utilizes categorical classifications of working posture and level of exertion to predict the potential for musculoskeletal injury to the upper body (McAtamney & Nigel Corlett, 1993).

The most commonly accepted method for applying RULA is to observe a single instance that is thought to be representative of the average posture while performing a task. While this method is simple and cost effective, it unfortunately does not adequately capture all fluctuations in posture over the course of an entire work shift. This may be esepcially true for dynamic work tasks, when work tasks or context vary across the day, or when fatigue leads workers to adopt suboptimal postures at later times in a work shift (McDonald, Mulla, & Keir, 2019).

An alternative to single-sample estimates is automated high-frequency posture sampling using motion capture via infrared cameras and retroreflective markers (Person, Hodgson, & Nagy, 2001). While this method allows for extremely high postural sampling rates on the magnitude of greater than one per second, these systems are expensive and not widely accessible. Additionally, motion capture cannot be easily used in the field since a dedicated capture space is required and the markers can impede natural motion.

The Time Weighted Average (TWA) is a standard method of reporting exposures in the fields of Ergonomics and Industrial Hygiene when comparing to Permissible Exposure Limits (PEL). As such, the TWA of the continuous RULA data will be utilized as the gold standard measure. The TWA is calculated with the following formula (Llanes, 2016):

$$TWA = \frac{t_1C_1 + t_2C_2 + \ldots + t_nC_n}{t_1 + t_2 + \ldots + t_n} \tag{1}$$

Where:

t=time

c=concentration

Dental Hygiene Students as Experimental Population.

Dental hygienists are especially susceptible to work-related musculoskeletal disorders (MSDs) due to the required repetitve arm motions and awkward trunk and neck postures required to perform their daily tasks (Ohlendorf et al., 2017). Furthermore, the prevalence of MSD symptoms in this population has been observed to be as high as 83% (Morse, Bruneau, & Dussetschleger, 2010). Musculoskeletal pain has been most associated with the use of dental instruments to remove heavy calculus from the teeth, or hand scaling (Humann & Rowe, 2015). As they are learning proper techniques, dental hygiene students spend extensive time with patients (e.g., up to 3 hours per sesion), adopting widely varied postures throughout, making them ideal for examining RULA sampling methods.

Purpose.

The purpose of this study was to identify a sampling method that accurately estimates an individual's RULA TWA across the dynamic task of hand scaling in dental hygienists.

METHODS

Participants and Experimental Setup.

A group of 4 right-handed students (0M/4F) were recruited for this study. Continuous video recordings were captured during routine patient visits using GoPro Hero 4 cameras (GoPro, Inc.; San Mateo, CA) placed in front, side, and overhead orientations (Figure 1). Use of three cameras ensured that all body positions and joint angles were captured as the dental hygienists frequently shifted to different "clock positions" around the patient's mouth (with 12 o'clock directly above the patient). The video files were imported into a behavioral coding software (Observer XT; Noldus Information Technologies, Inc.; Leesburg, VA) where occupational activities were coded. The RULA was applied only to video segments that contained event tags indicative of hand scaling for calculus removal.

The University of Southern California Institutional Review Board approved the study protocol (IRB: HS-15–00004), and all participants and their patients gave written consent to be recorded after being informed of the nature of this study.

Continuous RULA analysis.

To obtain gold standard TWA RULA scores for comparison, separate RULA evaluations were completed each time a subject's posture changed for a period of 15 seconds or more. The traditional method of using a paper RULA form was found to be tedious and inefficient given how frequently the subject's operating posture would change. As such, a graphical user interface application was developed to facilitate this process (Figure 2). The app allowed for any postural shifts to be easily updated and the overall risk score was automatically recalculated. Each time the posture was recalculated, the user specified the start and end time in the recording. After clicking the "write to file" button, the observed interval was added to the continuous timeline. Once all shifts in posture were recorded, a TWA RULA score was calculated for each of the 4 participants.

Sampling Methods.

We evaluated three sampling methods in this analysis:10 samples taken at random, 10 samples taken at evenly spaced time intervals throughout the duration, and 10 random samples selected from different clock positions with frequency of samples distributed relative to the percentage of time the subject spent in each clock position. For example, if the subject spent 40% of the time in the 9 o'clock position, 40% of the samples were taken from time points where the subject was at 9 o'clock.

Statistical Methods.

A criterion of ± 0.5 points on the final RULA score was used to determine whether or not each sampling method was accurate. We used the Bland-Altman limits of agreement method (Bland & Altman, 1986) to evaluate each sampling method against the TWA RULA score.

Final RULA outcome scores were categorized into recommended actions (1–2 acceptable; 3–4 investigate further; 5–6 investigate further and change soon; 7 investigate and change immediately). The established criterion is meant to minimize the probability of obtaining a score that transitions the RULA score to a different action category. Since RULA scores are represented in whole numbers, < 0.5 is the upper limit of acceptable bias as anything higher would round up to the next point. The Bland-Altman method quantified bias and 95% confidence intervals for each sampling method.

RESULTS

Continuous RULA Data.

The continuous RULA scores are shown below (Figure 3). Risk scores remained at or below a 4 for the majority of the time with the exception of one subject, who exhibited a RULA score of 5 for roughly half of the session. High risk postures (5–7) occurred for very brief periods of time. These periods were so brief that they had very little effect on the TWA score.

Bland-Altman Analysis.

As can be seen in the the Bland-Altman plots (Figure 4), none of the sampling methods demonstrated significant bias (|max; min|: 0.11; 0.09), and the 95% confidence intervals did not exceed the criterion of ± 0.5 points on the final RULA score (max; min: 0.29; 0.19). The observed data can also be found in Table 1.

DISCUSSION

All of the sampling methods tested in this preliminary evaluation fit within the variability criterion (± 0.5 points) for the overall RULA score. In addition, there was not a large amount of variability between the three methods. The minimal bias and variability are likely due to the fact that we did not observe a substantial amount of variability in working posture.

Limitations.

These data and findings are not generalizable to all work tasks. The objective of this study was to establish a model for identifying an optimal sampling method that would provide minimal error when approximating a TWA RULA score.

The duration of all observations used in this data set were under 4 hours, which is likely not long enough to see any fatigue effects on posture.

Projected Outcomes and Future Work.

Preliminary results indicate that a valid sampling method would be a viable substitute for the TWA RULA. We plan to investigate lower sampling rates of each method to identify the lowest number of samples required to still provide a reasonably accurate approximation of the TWA for this working population. Development of a robust dataset demonstrating variability across sampling methods and sizes will help to identify the most efficient method that can be applied to a variety of work settings.

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REFERENCES

Bland JM, & Altman DG (1986). Statistical methods for assessing agreement between two methods of clinical measurement. Lancet, 1(8476), 307–310. [PubMed: 2868172]

Humann P, & Rowe DJ (2015). Relationship of Musculoskeletal Disorder Pain to Patterns of Clinical Care in California Dental Hygienists. J Dent Hyg, 89(5), 305–312. [PubMed: 26519494]

Llanes S (2016). How to Calculate the Time-Weighted Average (TWA). 26th Annual CIHC Conference, 27(3).

McAtamney L, & Nigel Corlett E (1993). RULA: a survey method for the investigation of work-related upper limb disorders. Appl Ergon, 24(2), 91–99. [PubMed: 15676903]

McDonald AC, Mulla DM, & Keir PJ (2019). Muscular and kinematic adaptations to fatiguing repetitive upper extremity work. Appl Ergon, 75, 250–256. doi:10.1016/j.apergo.2018.11.001 [PubMed: 30509533]

Morse T, Bruneau H, & Dussetschleger J (2010). Musculoskeletal disorders of the neck and shoulder in the dental professions. Work, 35(4), 419–429. doi:10.3233/WOR-2010-0979 [PubMed: 20448321]

Ohlendorf D, Erbe C, Nowak J, Hauck I, Hermanns I, Ditchen D, … Groneberg DA (2017). Constrained posture in dentistry - a kinematic analysis of dentists. BMC Musculoskelet Disord, 18(1), 291. doi:10.1186/s12891-017-1650-x [PubMed: 28679450]

Person JG, Hodgson AJ, & Nagy AG (2001). Automated high-frequency posture sampling for ergonomic assessment of laparoscopic surgery. Surg Endosc, 15(9), 997–1003. doi:10.1007/s004640080155 [PubMed: 11443453]

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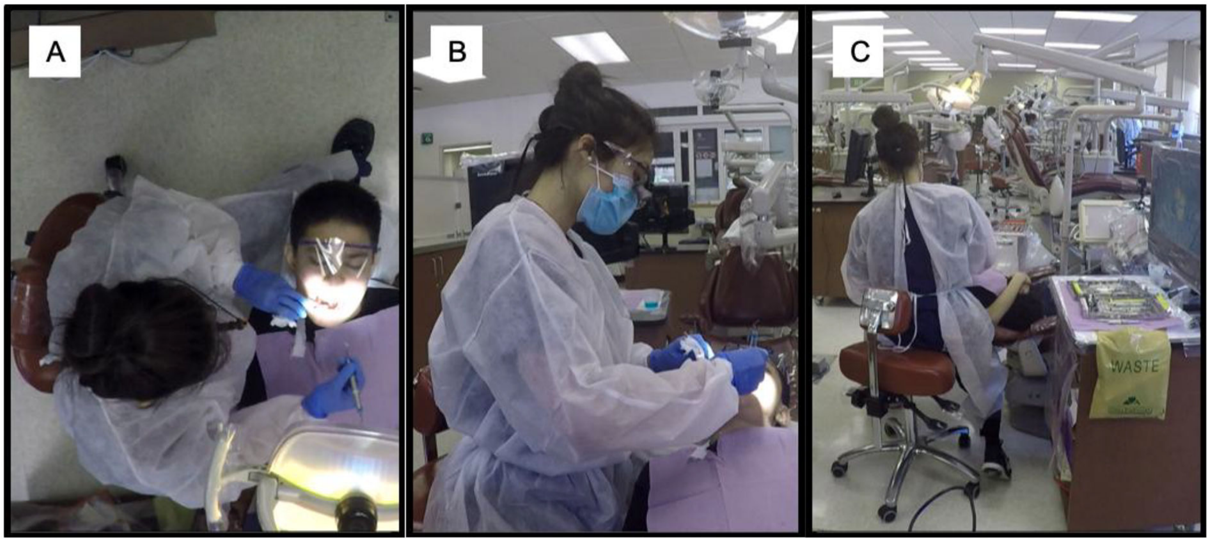

Figure 1.
Video recording area with cameras mounted at overhead, front, and side orientations

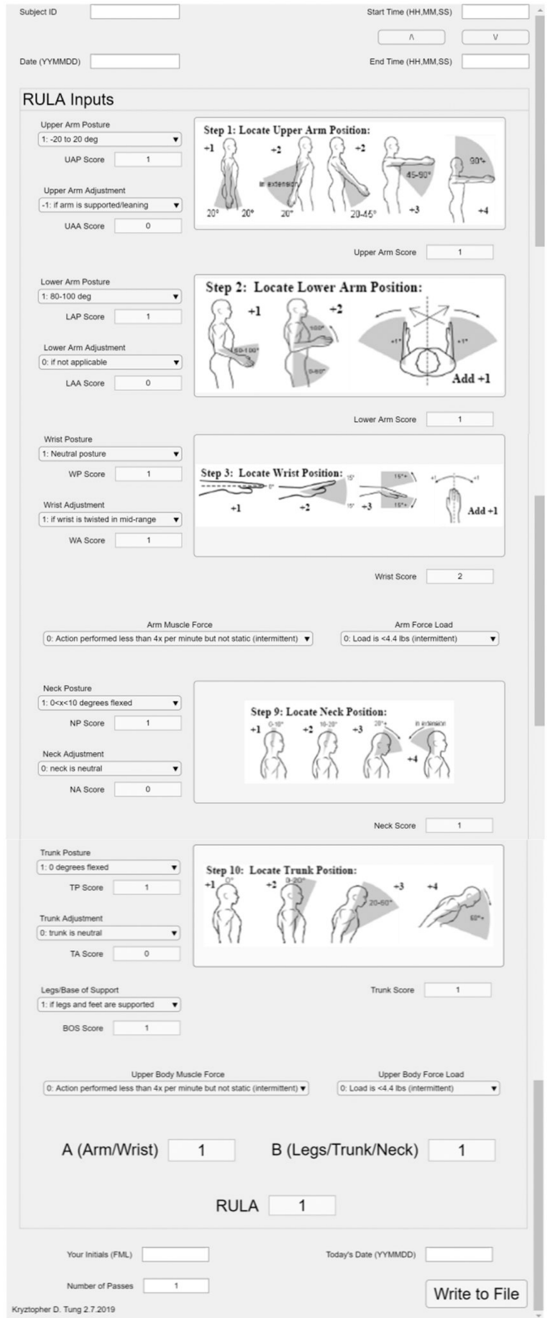

Figure 2.
Screenshot of the RULA app developed to facilitate continuous postural evaluation

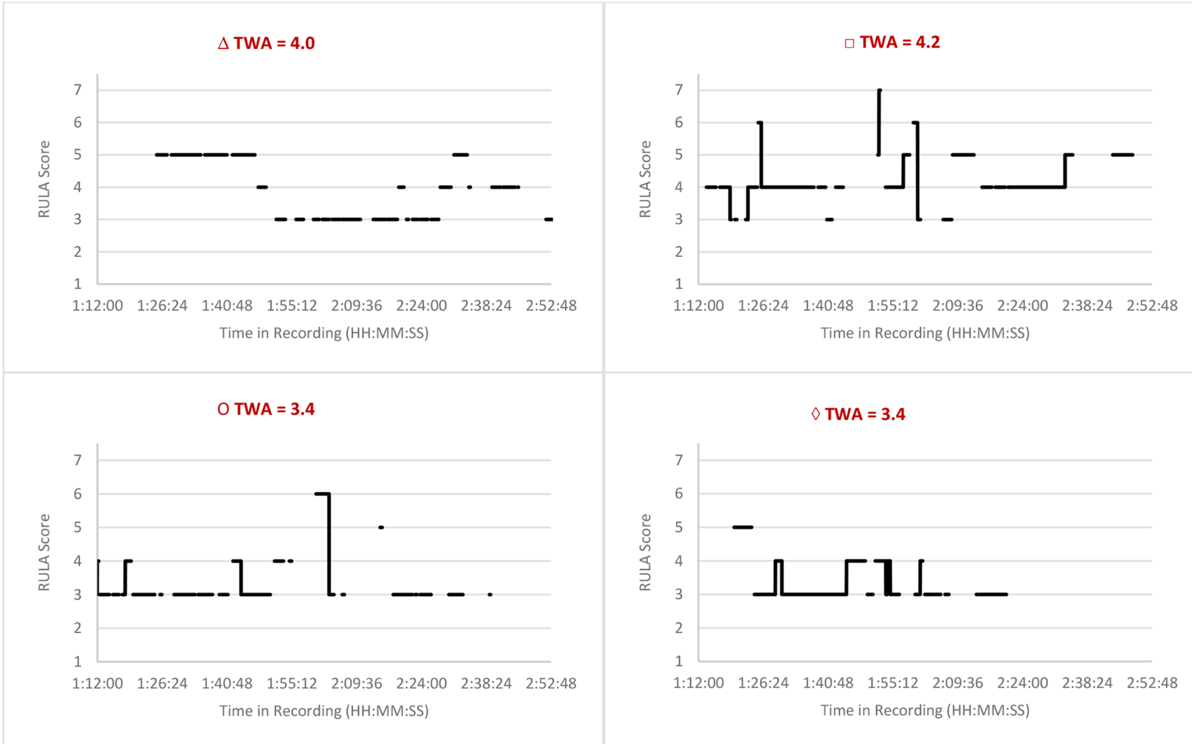

Figure 3.
Continuous RULA data for each participant evaluated

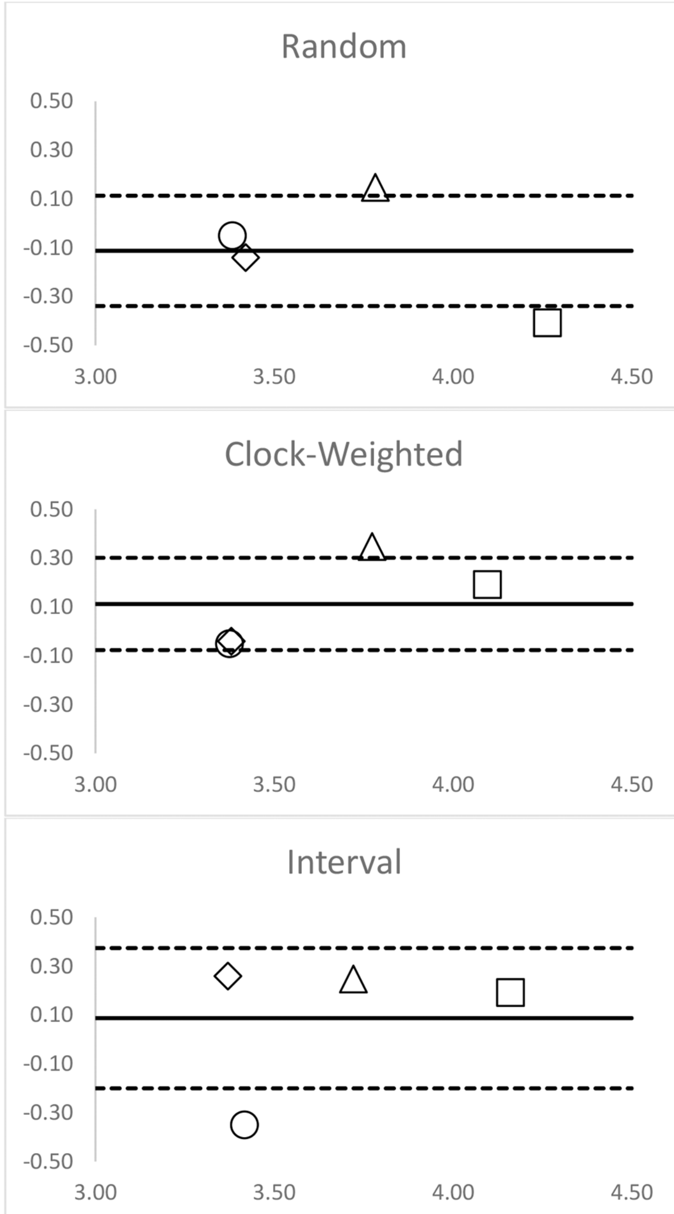

Figure 4.

Bland-Altman plot showing bias (solid) and ± 95% confidence interval (dashed) for each sampling method; each subject's data is represented as such: S01-square, S02-triangle, S03-circle, S04-diamond

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Table 1.

Observed average and bias of each method compared to the TWA RULA score

Subject	TWA Score	Random		Clock Weighted		Interval	
		Avg	Bias	Avg	Bias	Avg	Bias
S01	4.2	4.3	−0.4	4.1	0.2	4.2	0.2
S02	3.9	3.8	0.1	3.8	0.3	3.7	0.2
S03	3.3	3.4	−0.1	3.4	−0.1	3.4	−0.4
S04	3.4	3.4	−0.1	3.4	0.0	3.4	0.3