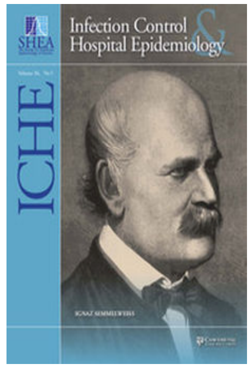

Electronic Recognition of Hand Hygiene Technique and Duration

Valerie Galluzzi, Ted Herman, D. J. Shumaker, D. R. Macinga, J. W. Arbogast, Elena M. Segre, Alberto M. Segre and Philip M. Polgreen

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CONCISE COMMUNICATION

Electronic Recognition of Hand Hygiene Technique and Duration

Valerie Galluzzi, MS;[1] Ted Herman, PhD;[1]
D. J. Shumaker, BS;[2] D. R. Macinga, PhD;[2]
J. W. Arbogast, PhD;[2] Elena M. Segre, BA;[3]
Alberto M. Segre, PhD;[1] Philip M. Polgreen, MD, MPH[4]

We captured 3-dimensional accelerometry data from the wrists of 116 healthcare professionals as they performed hand hygiene (HH). We then used these data to train a *k*-nearest-neighbors classifier to recognize specific aspects of HH technique (ie, fingertip scrub) and measure the duration of HH events.

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The World Health Organization (WHO) provides specific guidelines regarding hand hygiene (HH) technique,[1] yet prior studies of HH technique note considerable deficiencies in practice.[2-5] Most of these studies rely heavily on the use of florescent dyes, an approach of limited utility in clinical settings, and one which cannot capture HH duration, an important determinant of efficacy. Although a few commercial auditing systems also claim to monitor technique, they cannot recognize individual elements of HH practice, such as the 7 steps in the WHO guidelines or those in the European Normal 1500.[1] For example, no existing system captures whether a healthcare professional (HCP) performs the recommended fingertip scrub (ie, rotational rubbing of the right finger tips in the left palm and vice versa), nor do they measure the duration of HH events. The goal of this project was to develop and test custom-built wrist-based sensors to monitor HH technique that, using only accelerometery data, can reliably discern elements of HH (ie, the WHO-recommended fingertip scrub) and measure HH event duration.

METHODS

To assess HH technique, we designed and built a system consisting of 2 wearable, programmable, battery-powered wireless computing devices, each with a 3-dimensional accelerometer (3DA) capable of measuring acceleration along *X*, *Y*, and *Z* axes. Participants wore these watch-like sensors on each wrist; a similar device mounted on an alcohol-based rub dispenser signaled dispensing events, causing each wrist sensor to record 16 seconds of 3DA data at 125 samples per second (125 Hz). The data were then uploaded wirelessly to a computer.

We collected data from 116 different HCPs at the University of Iowa. Subjects included a mix of nurses, doctors, and other HCPs. Measurements were taken while HCPs executed 3 distinct HH events: (1) wild-type HH (ie, what HCPs do normally when practicing HH, without fingertip scrub), (2) fingertip scrub (ie, rotational motion designed to distribute sanitizer to fingertips and nails), and (3) no HH (ie, moving about without HH activity). We also collected (4) a series of mixed wild-type/no HH events, in which HCPs perform HH and then immediately start moving about when finished: a human observer recorded HH duration. Before starting, all subjects were given the same instructions.

For each HH event, the 16 seconds of 3DA data from each wrist was split into fragments consisting of approximately 0.5 seconds of 3DA measurements and labeled by type of event. We extract 23 descriptive features from each fragment and use the resulting feature vectors to train a *k*-nearest neighbors (KNN) classifier, a commonly used machine-learning method.[6] The classifier is then used to predict labels for new fragments on the basis of the labels assigned to the *k*-closest training data fragments (here, $k = 3$) in the implicit 23-dimensional feature space. We evaluate our classifier using tenfold cross validation and report the average performance.

To determine whether we can detect duration of a HH event, we trained a KNN classifier on all available labeled event data and applied it to each series of fragments in the mixed-event data described previously. The duration of the HH event was determined by the transition to fragments labeled no HH within the series, and the resulting duration was then compared with that reported by the same human observer.

No identifying information was recorded, and our institutional review board ruled that this project did not constitute human subjects research. Our software was written in Python, and we used Weka, version 3.6, for the KNN classification.

RESULTS

Table 1 shows the results of the tenfold cross validation test. Most of the fragments from each class were correctly identified, with the lowest recall belonging to the wild-type motions at 85.4%. Note, however, that although the wild-type motion and fingertip scrub were occasionally confused with one another by our classifier, they were seldom confused with no HH.

Table 2 shows the results of a second cross validation test measuring the performance of a classifier on a single subject's event data after training on the remaining subjects' event data. The fact that mean precision and recall values in Table 2 are lower than those in Table 1, coupled with higher median than corresponding mean values in Table 2, strongly suggest the presence of outliers; thus, classifier performance is very good on a notable majority of subjects (confirmed by examination).

Finally, we note that our system was reliably able to estimate cessation of HH activity in the mixed event data roughly 0.75 seconds before the human observer's mark. A linear correlation analysis performed on paired observer/system duration values yields a coefficient of determination $R^2 = 0.95$,

TABLE 1. Element Recognition Task Data by Number of Fragments in Each Class

	Predicted events			
Actual event	Wild type	Fingertip scrub	No HH	Recall, % of observed events (n = 10,375)
Wild type	2,893	434	62	85.4
Fingertip scrub	386	3,180	31	88.4
No HH	88	75	3,226	95.2
Precision, % of observed events (n = 10,375)	86.0	86.2	97.2	…

NOTE. Data are no. of fragments in each class, unless otherwise indicated. Recall is defined as the number of true positives divided by the sum of true positives and false negatives (also referred to as sensitivity), and precision is the number of true positives divided by the sum of true positives and false positives (also referred to as positive predictive value). HH, hand hygiene.

a regression slope of 1.0, and an intercept of −0.74 seconds, consistent with an observer reaction time in the usual 0.75-second range.

DISCUSSION

Our results confirm that accelerometry data can be used both to detect a specific HH motion and to estimate the duration of HH events under routine clinical conditions. The exact relationship between HH technique and disease transmission risk reduction is unknown. Also, there is some debate regarding the importance of technique; although clearly pathogens may linger on poorly sanitized hands, especially around the fingertips and nail beds, increasing the possibility of disease transmission. Moreover, multiple reports indicate that technique does play an important role in HH effectiveness,[2-4] with Widmer et al[3] showing that technique training produces a significant decrease in the bacterial counts from the hands of HCPs. However, Kampf et al[7] showed that a "responsible application" approach (where subjects were instructed to simply cover their hands) compared favorably to the WHO recommendations. Similarly, Chow et al[8] found that bacterial load was reduced regardless of technique. These studies, however, used 3 mL of product, whereas HH dispensers typically dispense only 0.6–1.3 mL.[9] HCPs are unlikely to dispense multiple times per HH event. Thus, technique may well be more important when less than 3 mL of product is used.

Future studies should continue to explore the relationship between HH technique, duration, volume of product and antimicrobial efficacy. Some efforts have focused on image-based recognition,[10] but these entail performing HH within camera view. Commercially available accelerometry-based HH compliance monitors (eg, Hyginex) do not recognize specific hand actions (such as the fingertip scrub) or deliver estimates of HH event duration, and because they are only worn on 1 wrist, they cannot exploit the relative movement of both hands, which is a factor that substantially improved performance (data not shown).

Our work has several limitations. First, we focus primarily on the fingertip scrub, largely because HCPs frequently miss sanitizing the nail bed. Second, our measured precision and recall can be improved, although most reported error was attributed to just a few presumably idiosyncratic subjects. We expect that our ability to discriminate will improve with larger training sets. Finally, additional work is necessary to determine whether HH elements can be adequately discriminated from other coordinated bimanual activities (eg, changing wound dressings).

Despite these limitations, we demonstrate the promise of accelerometery for measuring HH technique and duration. With use of alcohol-based products now ubiquitous, we need to ask the questions "if HH is worth doing, is it not worth doing well?" and "how well is well enough?" Answering these questions requires a reliable means to measure HH technique in real-world clinical settings.

TABLE 2. Element Recognition Task Data for Average Measured Performance

Event	Mean recall, %	Median recall, %	Mean precision, %	Median precision, %
Wild type	81.1	84.4	81.1	86.1
Fingertip scrub	83.8	87.5	83.8	86.2
No HH	94.3	100	94.3	100

NOTE. Values shown represent average measured performance for a single remaining subject assuming that data from all other subjects had been available for training. Note that median values consistently exceed mean values, suggesting the presence of a small number of outlier subjects with low recall and precision. HH, hand hygiene.

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Affiliations: 1. Department of Computer Science, University of Iowa, Iowa City, Iowa; 2. GOJO Industries, Akron, Ohio; 3. Department of Health and

Human Physiology, University of Iowa, Iowa City, Iowa; 4. Departments of Internal Medicine and Epidemiology, University of Iowa, Iowa City, Iowa.

Address correspondence to Philip M. Polgreen, MD, MPH, Carver College of Medicine, Department of Internal Medicine, University of Iowa, Iowa City, IA 52242 (philip-polgreen@uiowa.edu).

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