Evaluation of tactile cues for simulated patients' status under high and low workload

Nuphar Katzman[1], May Gellert[1], Joseph J. Schlesinger[2], Tal Oron-Gilad[1], Jeremy R. Cooperstock[3] and Yuval Bitan[1]

[1]Dept. of industrial Engineering and Management, Ben-Gurion University of the Negev, Be'er-Sheva, Israel
[2]Dept. of Anesthesiology, Vanderbilt University Medical Center, Nashville, USA
[3]Dept. of Electrical and Computer Engineering, McGill University, Montreal, Canada

The intensive care unit (ICU) is one of the most complex areas in hospital care, as patients require continuous monitoring by physicians and nurses. Currently, clinicians are informed about the patients' physiological conditions through visual color-coded signals and auditory alarms. Previous studies have shown that vibrotactile cues can be used to inform clinicians of a patient's vital signs status, either in a unisensory or multisensory alarm scheme. We present the results of the first in a series of experiments devoted to examining the feasibility to use tactile cues to convey detailed physiological information about more than one patient, rendered through a lower-leg tactile interface. The current experiment utilized a simulated clinical environment with 14 undergraduate students. Participants were required to interpret information delivered by the tactile interface, for two different patients, while they performed a continuous cognitively demanding task. Results indicate that under such conditions, it is possible to deliver critical information with a successful interpretation rate of approximately 85% but not without cost to the continuous demanding task. Future experiments should evaluate more tactile patterns in order to increase their interpretation success rate, and evaluate the use of these tactile cues with clinicians.

INTRODUCTION

The intensive care unit (ICU) is an area of the hospital where the sickest patients are treated. The complexity of performing tasks, even routine tasks, is increased by the constraints of insufficient or unavailable information, by stress, and by frequent and unpredictable interruptions (Alvarez & Coiera, 2005). Nurses are responsible for patient care through continuous monitoring and management of treatments (Potter et al., 2005). Bitan et al. (2004) described two forms of actions that the intensive care nurses perform: they respond to events, such as alarms, and they initiate actions, often according to some more or less pre-determined schedule. The high number of alarms in the ICU varies from one alarm every 37 minutes to almost 10 alarms per hour (Chambrin et al., 1999; Görges, Markewitz, & Westenskow, 2009; Lawless, 1994; Siebig, Kuhls, Imhoff, Gather, & Wrede, 2010; Tsien & Fackler, 1997). The main purpose of an alarm is to redirect attention from something that is less important to something that requires more attention at a particular time or place (AAMI, 2011). However, if there are too many alarms, they can interfere with nurses' ability to schedule their routine tasks efficiently. If nurses respond to each of the very frequent alarms, they will not be able to perform the pre-scheduled actions (Bitan, Meyer, Shinar, & Zmora, 2004).

In order to decrease the number of auditory alarms in the ICU, we consider, instead, the use of tactile alarms. Previous studies have shown that vibrotactile cues can be used to inform clinicians of a patient's vital signs status alone or in a multisensory alarm setup (Burdick et al., 2018; Cobus, Ehrhardt, Boll, & Heuten, 2018; Fouhy, Santomauro, Mclanders, Tran, & Sanderson, 2015). The cues can indicate the status of a patient's vital functions such as a radical change in heart rate or oxygen saturation (Mclanders, Santomauro, Tran, & Sanderson, 2014). Other implementations, e.g., physiological monitoring for anesthesiologists, were shown to improve attention management and multitasking during continuous patient monitoring (Ferris & Sarter, 2011).

Our work described here aims to examine the feasibility of tactile cues to convey detailed information about the medical state of two patients through the same tactile interface. The motivation is the fact that the nurse-patient ratio in intensive/critical care settings is often higher than

1:1. To the best of our knowledge, most studies involving vibrotactile cues in medical environments have only considered the vital signs of a single patient. Therefore, the current study aims to investigate a complex vibrotactile setup designed to inform participants as to the identity of the patient, and her vital signs, through the use of vibrotactile cues, in a scenario involving a participant-patient ratio of 1:2. The experiment is intended to serve as a foundation for future research in clinical environments with clinicians. Before we conduct experiments with nurses, a simulation was executed with undergraduate students under laboratory conditions.

METHOD

Participants

Fourteen undergraduate students (7M/7F) aged 21-28 (M = 26.2, SD = 2.1) participated in the research. One participant's data were excluded due to partial data loss attributed to technical problems. Participants received course credit for their participation and were free to withdraw from the study at any time. Ethical approval was granted from the Ben-Gurion University of the Negev ethics committee.

Apparatus

Experimental Environment. The experiment was conducted at the "Human Systems Integration in Healthcare" (HSI-H) laboratory. The lab contains two identical work stations. Each station includes a desktop computer with a 22" screen. Participants were situated approximately 0.7 m from the screen, wearing the tactile system and anti-noise earmuffs.

Tactile Interface. The tactile system consists an Engineering Acoustics Inc. (EAI) tactor controller Eval2.0 regulating two EAI-C2 tactors stitched to two fiber straps, one tactor on each strap. Informed by the study of Gay-Betton et al. (2017), which suggested the leg as a suitable locus for wearables in ICU and ORs, the straps were worn around the lower leg, one above the ankle and the second under the knee, over the participant's clothes. The tactors were positioned on the lateral side of the leg (Figure 1).

Continuous Task – N-Back Task. Participants were required to accomplish a computerized N-back task. In this task, participants were presented a sequence of letters one at a time, and had to decide if the current letter was the same as the one presented N trials ago; if so, they had to press the "M" key, otherwise, they had to press the "X" key. Two levels of difficulty were examined in the experiment, N_back={1,2} (Figure 2). Each letter was presented for 2000 ms, with a delay of 500 ms between successive letters. Each N-back session lasted 450 s and contained 180 screens. The task simulates cognitive load at varying levels of difficulty. The experiment was executed through the PsyToolkit© open source software.

a b

Figure 1. a) Tactile interface located on the lower leg; b) EAI-C2 tactor

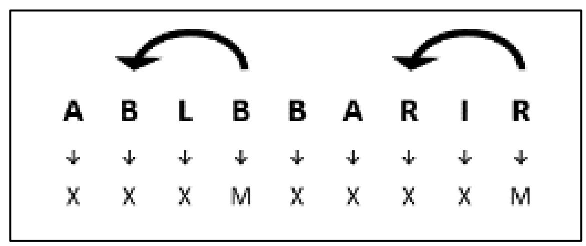

Figure 2. Instructions for N_back task for N=2

Deciphering Tactile Cues Task. Participants were required to interpret information presented through eight possible tactile signal combinations. These were designed to provide data about the patient number (#1 vs. #2), type of vital sign (Heart Rate (HR) vs. Blood Pressure (BP)) and its value (High vs. Low). The information was distinguished by vibration patterns and the activated tactors (see example in Figure 3).

Each tactile signal consisted of two parts. The first part, delivered via both upper and lower tactors simultaneously, indicated whether the message referred to patient #1 (one long pulse) or patient #2 (two short pulses). The second part, which was rendered twice in succession, was delivered by actuation of one tactor only, the upper, by the knee, for "High" and the lower, near the ankle, for "Low" vital sign level. For hypothesized ease of association, identification of the vital sign was based on the corresponding syllable pattern, “heart rate”, as two short vibrations, and “blood pres-sure” by one long pulse, followed by two short ones.

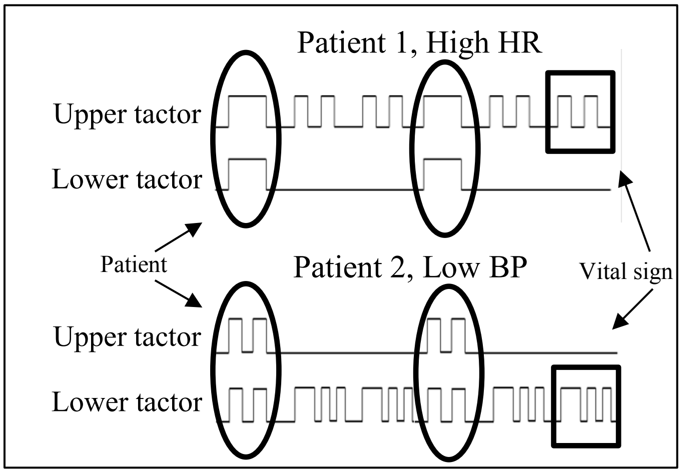

Figure 3. Illustration of tactile signal combinations. The top signal is for patient 1 conveying high HR, note that vital signs were administered twice.

Procedure

Participants were invited individually to the HSI-H lab for a one-hour session. Following instructions and signing a consent form, they performed the first part, which consisted of an introduction and training of the N-back task. Participants then completed the N-back twice, first with N-back=1 and then with N-back=2.

Next, the experimenter gave a short briefing about tactile cues and their meaning. The participants were instructed to simulate a situation in which they receive information about patients in ICU. The participants then completed a five-minute training session, first on the tactile alerts alone, followed by a short trial that included the N-back task (for N-back=1). Following the training, participants completed the N-back task together with the tactile cues, for N-back=1 and N-back=2, in counter-balanced order.

For each N={1,2} in the tactile condition, participants received 12 tactile cues, for a total of 24 such cues. The cues were selected semi-randomly, ensuring that all 8 cues will be presented over the two levels together, resulting in presentation of each cue 2-4 times. Successive stimuli were presented with a random time gap of 20-60 s between them. Participants were asked to verbally describe the perceived meaning of the alerts (e.g., “patient number 2 has high blood-pressure”).

RESULTS

N-back task success rates

In order to analyze the success rates, two states were defined. If the current letter was the same as the one presented N trials ago, it was defined as 'Target', otherwise 'Distractor'. Every state had three possible reactions: correct, incorrect, no-response. The ratio between 'Target' and 'Distractor' was on average approximately 1:4, i.e., for every 'Target' letter there were 4 'Distractor' letters. For the 'Target' state, a correct response represents a 'HIT', and an incorrect response, a 'MISS'. For the 'Distractor' state, a correct response represents a 'Correct Rejection’ (CR), and an incorrect response, a 'False Alarm’ (FA). For each state, no-response represents no action taken in the 2000 ms time limit defined for each letter.

Correct response ratios were calculated as the ratio of 'HIT' to total ‘Target’ events, and of 'CR' to total 'Distractor' events, as shown for each condition in Figure 4. A chi-square test of independence was performed to test the differences between each pair of conditions for each ratio, finding significance for both 'HIT' ratio, χ^2 (df=3)=177.09, $p<0.001$. and 'CR' ratio, χ^2 (df=3)=89.752, $p<0.001$.

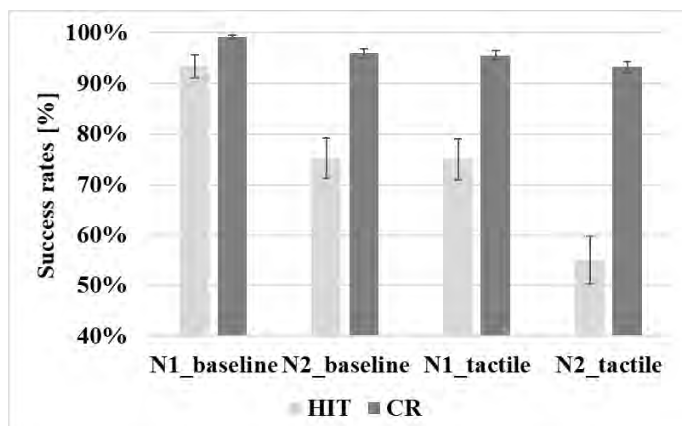

Figure 4. Success rates by condition

In addition, ‘No response’ ratios were calculated as the ratio between ‘No response’ and number of state events, i.e., both ‘Target’ and ‘Distractor’ events. A chi-square test of independence was performed to test the differences between conditions, finding significance for both ‘No response for Target’ ratio $\chi 2$ (df=3)=13.335, $p<0.005$, 'No response for Distractor' ratio $\chi 2$ (df=3)=65.325, $p<0.001$.

N-back task response time

A Linear Mixed Model (LMM) was used to analyze the effect of the task demands and influence of tactile cues on the log transform of the response times (only for correct responses) in the N-back task (Figure 5 presents the *predicted mean RT*). The model included the task demand and tactile cue as dependent variables, and the participant as a random effect. There was a significant effect for task demand and ($F(1, 8602)=521.57$, $p<.001$) for tactile cues ($F(1, 8602)=243.85$, $p<.001$) on participants' ln(RT). An interaction between task demand and tactile cues was found ($F(1, 8602)=128.5$, $p<.001$). Although responses under the tactile condition were faster, i.e., smaller ln(RT), accuracy on the N-back task decreased. Further examination of this effect in a subsequent informal test demonstrated that response time decreased further in an additional baseline condition following the tactile condition. This suggests that faster response time is due, at least in part, to increased familiarity with the N-back task as a result of learning effects.

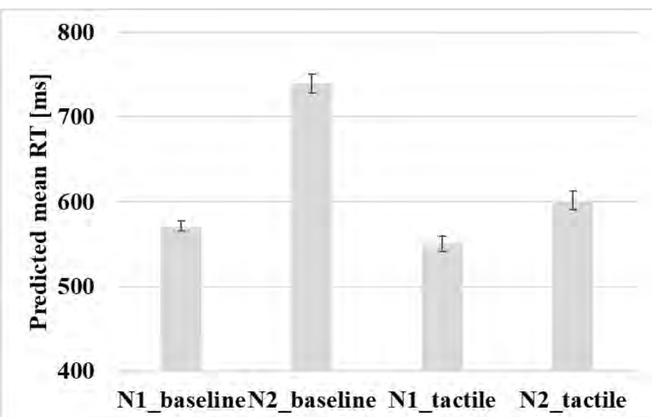

Figure 5. Mean respone time by condition

Accuracy in identifying the tactile cues

For each session with the tactile interface, the ratio of correct tactile cue identification responses to the number of events in the session was calculated (Table 1). A chi-square test of independence was performed to test the difference between conditions, but did not find significance, $\chi2$ (df=1)=0.84751, p=0.643.

Table 1. Accuracy in identifying the tactile cues

	Success rate	S.E.
N=1	87.66%	0.0265
N=2	83.33%	0.0298

Analysis of incorrect identification of the tactile cues

Overall, 46 of the 312 total tactile cues (14.7%) were identified incorrectly (Table 2). Most (31) of the errors misidentified the patient number, while the vital sign was interpreted correctly, for example, confusing Patient #2, High HR with Patient #1 High HR.

Table 2. Distribution of incorrect identification by workload level

Error type	# of errors	
	N=1	N=2
Patient number	13	18
Vital sign	5	3
Vital sign level	1	2
Patient number and vital sign		3
Patient number, vital sign and level		1
Total	19	27

DISCUSSION

The aim of this study was to examine the feasibility of providing physiologic information about two simulated patients through dual loci tactile cues. The N-back task was chosen to provide continuous workload at two different levels of difficulty. In accordance with previous studies involving the N-back task, the results show a main effect of N-back level, with higher difficulty increasing the likelihood of errors. Moreover, adding vibrotactile cues also had a significant negative effect on the success rate in the N-back task, likely because of the greater resources required to complete both tasks simultaneously. Correct identification rate of the tactile signals was approximately 85%, largely *unaffected* by the difficulty level of the N-back task. This is encouraging as the vibrotactile cues have the potential to inform about critical information, as suggested in previous studies (e.g., Ferris & Sarter, 2011; Ford et al., 2008). Although, as mentioned, the performance of the continuous task was worsened by increasing the likelihood of error and response time, the N-back is likely to require *more* continuous attention than the required activity at the ICU, so further examination needs to be done. In addition, the tactile cues need to be compared to other cues (auditory and/or visual) in order to understand the influence on the performance objectively.

As noted in Table 2, patient misclassification accounted for over 2/3 of all incorrect identifications. Future experiments should therefore examine whether the difficulty was due to the order of information presentation, i.e., first the patient number and then the vital sign, or because of the vibrotactile pattern used to represent patients. If the former is found to be responsible, we might consider the addition of a tactile pre-cue as a means of directing participants' attention to the information that follows immediately thereafter.

This work was a laboratory experiment exploring the feasibility of vibrotactile rendering of patient information with a nurse-patient ratio of 1:2. Future research should be conducted under a higher nurse-patient ratio, but also consider similar questions under more realistic clinical conditions, for example, in conjunction with preparation of medication for patients or while attending to administrative tasks. Furthermore, performance should be evaluated while participants are standing and walking, more similar to the real work environment of clinicians.

ACKNOWLEDGMENTS

Nuphar Katzman is a doctoral student supported by a grant from the US Army Research Laboratory through the GDLS subcontract, GDLS PO 40253724 (B.G. Negev Technologies and Applications Ltd) under Prime Contract no W911MF-10-2-0016 (Robotics Consortium), Robotics CTA 2015-2020, T2C1S3C, Michael Barnes, Technical Monitor. May Gellert in a master student supported by the Paul Ivanier Center for Production Management, Ben Gurion University of the Negev. We would like to acknowledge Professor Gijsbert Stoet who holds the copyright of all PsyToolkit© material. The views expressed in this work are those of the authors and do not necessarily reflect official policy.

REFERENCES

AAMI. (2011). *Clinical Alarms*.

Alvarez, G., & Coiera, E. (2005). Interruptive communication patterns in the intensive care unit ward round. *International Journal of Medical Informatics*, *74*(10), 791–796.

Bitan, Y., Meyer, J., Shinar, D., & Zmora, E. (2004). Nurses? reactions to alarms in a neonatal intensive care unit. *Cognition, Technology & Work*, *6*(4), 239–246.

Burdick, K. J., Jorgensen, S. K., Holmberg, M. O., Kultgen, S. P., Combs, T. N., & Schlesinger, J. J. (2018). Benefits of sonification and haptic displays with physiologic variables to improve patient safety. *Proceedings of Meetings on Acoustics*, *35*.

Chambrin, M.-C., Ravaux, P., Calvelo-Aros, D., Jaborska, A., Chopin, C., & Boniface, B. (1999). Multicentric study of monitoring alarms in the adult intensive care unit (ICU): a descriptive analysis. *Intensive Care Medicine*, *25*(12), 1360–1366.

Cobus, V., Ehrhardt, B., Boll, S., & Heuten, W. (2018). Vibrotactile Alarm Display for Critical Care. *Proceedings of the 7th ACM International Symposium on Pervasive Displays*, 11:1--11:7.

Ferris, T. K., & Sarter, N. (2011). Continuously Informing Vibrotactile Displays in Support of Attention Management and Multitasking in Anesthesiology. *Human Factors*, *53*(6). https://doi.org/10.1177/0018720811425043

Ford, S., Daniels, J., Lim, J., Koval, V., Dumont, G., Schwarz, S. K. W., & Ansermino, J. M. (2008). A novel vibrotactile display to improve the performance of anesthesiologists in a simulated critical incident. *Anesthesia and Analgesia*, *106*(4), 1182–1188.

Fouhy, S., Santomauro, C., Mclanders, M., Tran, J., & Sanderson, P. (2015). Effectiveness of vibrotactile displays of patient vital signs under low and high perceptual-motor task load. *Proceedings 19th Triennial Congress of the IEA, Melbourne 9-14 August 2015 Effectiveness*, *2*(August), 3–4.

Gay-Betton, D. M., Alirezaee, P., Cooperstock, J. R., & Schlesinger, J. J. (2017). HAPTIC: Haptic Anatomical Positioning to Improve Clinical Monitoring. *Proceedings of the Conference on Design and Semantics of Form and Movement - Sense and Sensitivity, DeSForM 2017*.

Görges, M., Markewitz, B. A., & Westenskow, D. R. (2009). Improving alarm performance in the medical intensive care unit using delays and clinical context. *Anesthesia and Analgesia*, *108*(5), 1546–1552.

Lawless, S. T. (1994). *Crying wolf: False alarms in a pediatric intensive care unit*.

Mclanders, M., Santomauro, C., Tran, J., & Sanderson, P. (2014). Tactile Displays of Pulse Oximetry in Integrated and Separated Configurations. *Proceedings of the Human Factors and Ergonomics Society 58th Annual Meeting 2014*, 674–678.

Potter, P., Wolf, L., Boxerman, S., Grayson, D., Sledge, J., Dunagan, C., & Evanoff, B. (2005). *An analysis of nurses' cognitive work: a new perspective for understanding medical errors*.

Siebig, S., Kuhls, S., Imhoff, M., Gather, U., & Wrede, C. E. (2010). Intensive care unit alarms—how many do we need? *Critical Care Medicine*, *38*(2), 451–456.

Tsien, C. L., & Fackler, J. C. (1997). Poor prognosis for existing monitors in the intensive care unit. *Critical Care Medicine*, *25*(4), 614–619.