Beyond the Technology: Wearables and the Cultural Compass

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He kokonga whare ka kitea, he kokonga ngākau e kore e kitea.
A corner of a house may be seen and examined; not so the corners of the heart.

For professionals engaged in human interaction and technology usage, engaging with individuals constitutes an integral aspect of our responsibilities. When conducting any form of user study, it becomes crucial to thoroughly examine potential ethical or cultural biases that may exist within us, our data, or our methodologies. Although this consideration is not novel, the integration of wearable technology has introduced new dimensions to user studies that may not have been previously apparent. In this article, we identify cultural factors that need to be taken into account when operating in culturally significant spaces. This is achieved through a user study centred around wearable technology. Cultural considerations revolve around the awareness required for participants' cultural backgrounds and the treatment of their data within this cultural context. This article highlights the need to consider not only usability and commodification, but also the value in returning to foundational theories that underpin this research field. While many of us partake in the feast of innovation and progress, the time has come to strive for a more equitable instrumentation and measurement research landscape.We propose that in situations where cultural and racial differences influence participant expectations and technical outcomes, it is no longer acceptable or appropriate to continue in research without actively investigating the associated cultural factors.

I. Introduction

As specialists, collaboration with various individuals such as end-users, stakeholders, and co-designers holds a central role in our work. The nature of these engagements varies, contingent on the specific stage of the design process and the methodologies employed, including co-design, participatory design, and persona usage. The evolution of computing and the prevalence of lightweight, wearable technology have expanded the scope of studies conducted with potential end-users. Assessing on-body or wearable systems demands distinct interaction approaches compared to studies conducted two decades ago. Consequently, our work in these studies has drawn parallels with disciplines like psychology and health, influencing the way we investigate and explore human and instrument interactions.

Aotearoa, New Zealand, provides a unique context where Western knowledge coexists with mātauranga Māori, the indigenous knowledge of the Māori people. This distinctive setting allows for a shift in focus, bringing to the forefront factors that have traditionally received less attention in research. In this environment, indigenous perspectives, specifically Māori perspectives, have an opportunity to be acknowledged in a culturally appropriate manner. The signing of Te Tiriti o Waitangi in 1840 established a framework for interactions between the Māori people and government institutions, embodying principles of active protection, equity, and recognition of Māori self-determination and sovereignty. Within the realm of research, te tiriti serves as a guiding document, ensuring the meaningful inclusion and leadership of Māori in projects that impact Māori outcomes [1]. By recognizing mātauranga Māori, we hope to foster inclusivity, improve cultural understanding, and increase responsiveness to the diverse needs and perspectives of indigenous communities.

This article delves into an interdisciplinary project examining the Muse Electroencephalography EEG headband's use as a benchmark for cognitive fatigue identification. The project involves conducting studies with end-users to gather EEG baseline data and other psychometric information. Through the use of the headset we evaluate the effectiveness of commercial wearable technology to identify fatigue in everyday settings, diverging from controlled laboratory environments. The process of structuring and executing these studies has underscored two vital considerations often overlooked by many. Firstly, there is a need to expose emerging practitioners to multi-disciplinary study methods, particularly from psychology and health, to enhance their understanding of the implications of their studies. Secondly, within a context where cultural and racial disparities impact participant expectations and technical outcomes, it is imperative to proactively investigate these factors. This proactive approach helps mitigate cultural offense and prevents biased data caused by the removal of outliers attributed to racial differences. These reflections not only shape the trajectory of our research but also offer valuable insights for practitioners navigating similar contexts, paving the way for more equitable and ethical approaches in the field of instrumentation and measurement.

II. Case Study

The case study occurred at the University of Waikato in Aotearoa, New Zealand on its Hamilton campus. Five participants between the age of 22 and 34 were recruited through word of mouth and approval was given through the human research ethics committee of the University of Waikato under the project number HREC(HECS)2023#20. All participants confirmed consent and were aware that they could withdraw from the study at any point up to two weeks post-participation. The case study involved the use of a laptop, a joystick, and the Muse EEG system. The Muse headband sits across the forehead and the ears, containing five dry electrodes. It provides four channels (AF7, AF8, TP9 and TP10) and one reference electrode (FpZ), recording data from the frontal and temporal regions of the cerebral cortex through the Mind Monitor app via Bluetooth on an Android phone.

The experimental procedure unfolds in three distinct phases: Pre-task, task, and post-task. During the pre-task phase, participants first completed the Stanford Sleepiness Scale (SSS) and the Victoria Stroop Test (VST). Following this, participants closed their eyes for five minutes, initiating the commencement of EEG recording before the task phase begins. This process is repeated at the end of testing in the post-task phase, with participants once again undergoing a five-minute resting state with closed eyes. The task phase involved participants engaging with the Open Multi-Attribute Task Battery (OpenMATB) flight task simulator for an uninterrupted 90-minute duration, during which EEG measurements were continuously recorded. Both real and simulated piloting tasks have proven effective at inducing cognitive fatigue, as evidenced by EEG measurements [2,3]. To induce cognitive fatigue in this study, the OpenMATB simulator was employed (Figure 1). This open-source program, designed for behavioral research, encompasses four tasks simulating a piloting experience. These tasks assess various behavioral and cognitive domains, including multitasking, vigilance, and mental workload. For this study, OpenMATB was customized by removing one of the four tasks and eliminating the scheduling view displaying upcoming task events to participants. Consequently, participants engaged in three tasks for the 90-minute duration: the system monitoring task, the tracking task, and the resource management task. In the system monitoring task, participants observed four gauges labelled "Temp1", "Pres1", "Temp2", and "Pres2". Each gauge featured an arrow oscillating around the midline, eventually reaching the top or bottom. Participants were required to press the corresponding key (F1, F2, F3, and F4) to return the arrow to the midline. Success led to a yellow bar lighting up at the bottom, while failure resulted in a red bar. The tracking task involved using a joystick to manoeuvre a crosshair within a blue dotted box at the screen's center. Lastly, the resource management task required participants to regulate the flow of fuel between various tanks and reserves, aiming to maintain two specific tanks filled to halfway throughout the task.

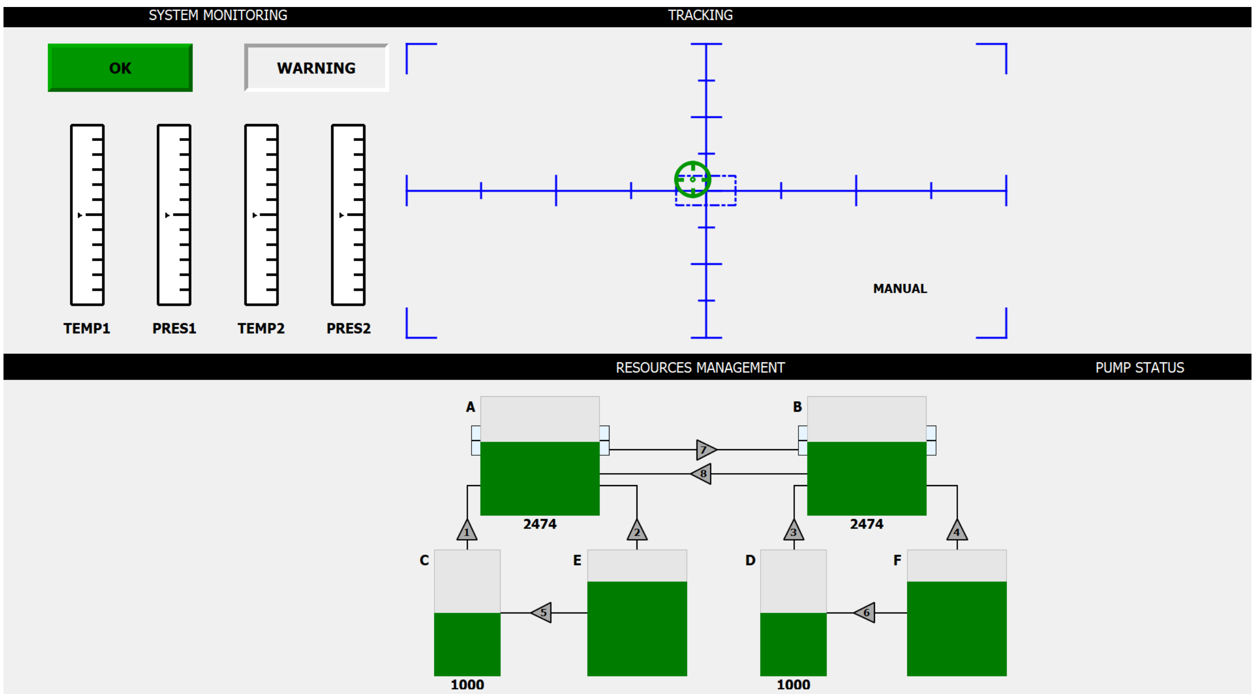

Figure 2. OpenMATB cognitive task

III. Results

Participants' results from the SSS and VST were recorded, both before and after the cognitive task. Figure 2 shows the results of the and illustrates that 80% (4 out of 5) of the participants experienced a significant increase in subjective cognitive fatigue after completion of the 90 minute cognitive task (pre-task shown in blue in the figure, post-task shown in orange). The remaining 20% (1 out of 5) of participants showed no change in subjective cognitive fatigue. No participants showed a decrease in subjective cognitive fatigue following the cognitively intensive task. The difference between subjective cognitive fatigue scores before and after the cognitively intensive task were statistically significant ($F(1,4) = 11$, $p = .029$, $\eta p^2 = .733$). Participants illustrated very little difference in the objective psychometric cognitive fatigue scores pre and post task (Victoria Stroop Test).

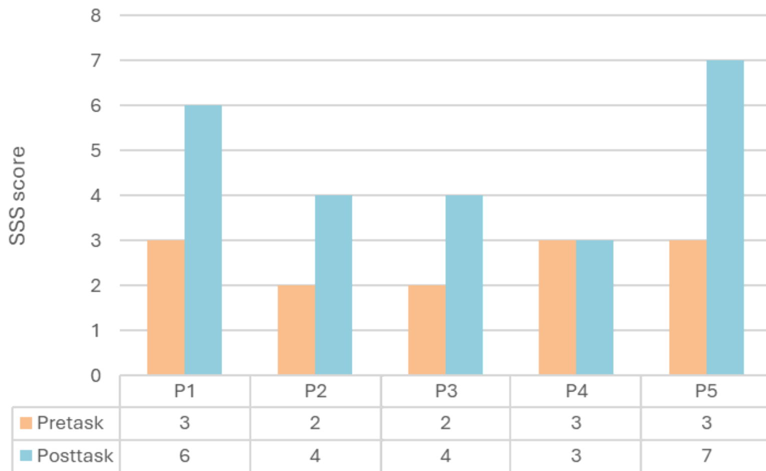

Figure 2. Stanford Sleepiness Scale pre and post task scores

EEG data streams were recorded during the five minute resting periods before and after the cognitive task, and throughout the 90 minute cognitive task. Data streams were recorded for four channels (AF7, AF8, TP9 and TP10), recording data from the frontal and temporal regions of the cerebral cortex. The raw values recorded for each channel were split into Delta, Theta, Alpha, Beta, and Gamma bands.

Delta has a frequency of 3 Hz or less. The waves of this category tend to have the highest amplitude, but are the slowest (in frequency). It is the dominant rhythm in infants under 1 year-old and during stages 3 and 4 of sleep. Theta has a frequency of 3.5 to 7.5 Hz and is commonly dominant in children up to 13 years of age and people of any age while they are asleep, but is unusual to be dominant in awake adults. Alpha has a frequency of 7.5 to 13 Hz, it is commonly seen in people of any age group, but is especially dominant in those over 13 years old while they are relaxing. Beta activity is characterised by having a frequency of 14-30 Hz. The beta rhythm is generally seen as ‘normal’ and is the dominant rhythm expected in those who are alert, anxious or have their eyes open. Gamma activity is considered to be the fastest brain activity. It has a frequency range of more than 30 Hz. The gamma rhythm is associated with cognitive functioning, learning, memory, and information processing.

Splitting the raw values recorded for each channel (AF7, AF8, TP9 and TP10) into Delta, Theta, Alpha, Beta, and Gamma bands resulted in twenty data streams, both pre and post task (Delta_TP9, Delta_AF7, Delta_AF8, Delta_TP10, Theta_TP9, Theta_AF7, Theta_AF8, Theta_TP10, Alpha_TP9, Alpha_AF7, Alpha_AF8, Alpha_TP10, Beta_TP9, Beta_AF7, Beta_AF8, Beta_TP10, Gamma_TP9, Gamma_AF7, Gamma_AF8, Gamma_TP10). Figure 3 illustrates the data streams for Delta_AF8, Theta_AF8, Alpha_AF8, Beta_AF8, and Gamma_AF8 during the five minute resting period before the cognitive task for Participant 1.

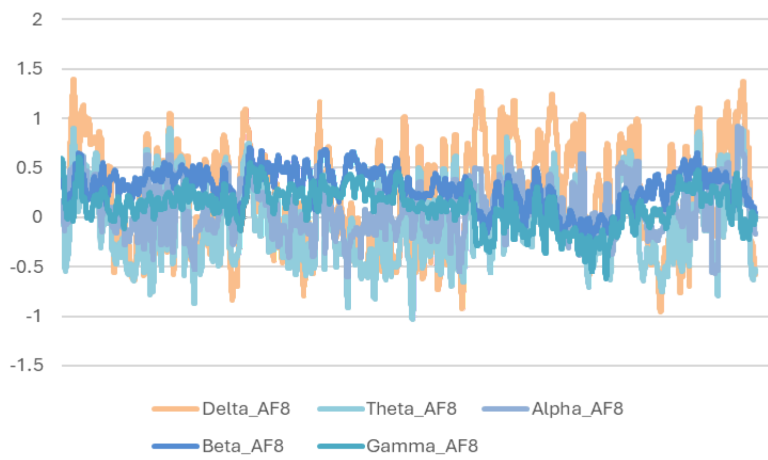

Figure 3. Delta, Theta, Alpha, Beta, and Gamma band activity from AF8 during pre-task resting state (P1)

EEG signals captured during performance of the cognitive tests were processed offline using EEGlab software, running on Matlab software. The data was sampled at 150 Hz and band pass filtered (1-35 Hz band pass filter), the timestamps of interest were taken (pre-test and post-test). This data was re-referenced to the average of the mean signal, detrended and baseline corrected (first 200ms of signal). The signals were bundled into epochs and then subjected to a spectrum threshold-based artifact removal procedure, where any 500-ms window containing signal fluctuations exceeding 10 dB were rejected. The clean signal was subjected to time frequency analysis to obtain the estimated instantaneous power. This analysis was performed by convolving the fast Fourier transform (FFT) power spectrum of the signal with a family of complex Morlet wavelets and eventually taking the inverse FFT [4]. Power at each frequency bin was defined as the squared magnitude of the results of the convolution and averaged across the frequency bands. To ensure normal distribution, all power estimates were subjected to a logarithmic (log10) transformation prior to statistical analysis. Table 1 shows the normalised power estimates for the Alpha band for each channel (AF7, AF8, TP9 and TP10) both pre and post task.

Table 1. Normalised power estimates for the Alpha band for each channel

	Pretest		Posttest	
Electrodes	Mean	SD	Mean	SD
TP9	-2.06	2.70	-9.14	5.24
AF7	-0.92	2.43	-5.44	3.32
AF8	-1.25	1.24	0.96	2.25
TP10	-2.09	1.98	-2.63	0.68

Table 2. *p*-values pre and post cognitive task

Pre vs Post	p values	df	F value	partial eta squared
AF7 Theta	0.079	1,4	5.491	0.579
AF8 Theta	0.482	1,4	0.599	0.130
AF7 Alpha 1	0.102	1,4	4.485	0.529
AF8 Alpha 1	0.249	1,4	1.817	0.312
AF7 Alpha 2	0.123	1,4	3.812	0.488
AF8 Alpha 2	0.027*	1,4	11.795	0.746
AF7 Beta 1	0.328	1,4	1.241	0.237
AF8 Beta 1	0.033*	1,4	10.167	0.718
AF7 Beta 2	0.165	1,4	2.875	0.418
AF8 Beta 2	0.066	1,4	6.304	0.612

Note: * $p < .05$.

A repeated measure ANOVA was conducted to compare the normalised power estimates for each channel and each band, before (pre) and after (post) participants undertook the cognitively intensive task. Analysis of this data (Table 2) has shown that AF8 High Alpha power is significantly ($F(1,4) = 11.795$, $p = .027$, $\eta p^2 = .746$) increased at post test compared to pre test (highlighted orange). The result of a statistically significant increase in alpha power at AF8 after the cognitively fatiguing task is congruent with findings in previous literature, associating frontal alpha power increases with cognitive fatigue [2, 5]. We also found a significant increase ($F(1,4) = 10.167$, $p = .033$, $\eta p^2 = .718$) in beta activity at AF8 Low Beta (highlighted blue). Low beta waves (12–15 Hz), known as "beta one" waves, are associated mostly with quiet concentration [6]. This increase in low beta waves could be an indication of increased cognitive workload, as also illustrated by [7]. The combination of these findings suggests that participants were experiencing both an increase in cognitive fatigue (AF8 High Alpha) and an increase of cognitive workload (AF8 Low Beta).

IV. DISCUSSION

As Māori researchers based in Aotearoa, New Zealand, those of us involved in this study approach the nature of science and research with a unique perspective compared to the broader academic community. In studies of this nature, special attention must be given to our Māori participants, as the head, including the hair, holds significant tapu (sacred) value in Māori culture. Tapu, also translated as restricted or prohibited, is a quality inherent in people, places, and objects, believed to ensure personal safety and health [8]. With this view it is arguable that without prior knowledge of protocols surrounding the head that the user study would not have been successful in two critical ways. The first is that participant recruitment would have been limited due to the improper handling of tikanga (protocol/procedure) involving the head, evoking apprehension about participating in such studies at all. Secondly, participant trust would not be valued reciprocally from the researcher meaning participants would no longer wish to participate in the study.

In this study participants were informed beforehand about the necessity of placing an EEG headset on their heads. This permission was gained above and beyond the requirements of the human ethics research committee. Although a simple act, seeking permission expresses, to a degree, the level of prior knowledge attained by the researcher and indicates their level of cultural competence within the Māori world. Negligent treatment of Māori participants by ignoring these types of factors can lead to the continued lack of participation and involvement of Māori in areas where Māori stand to gain considerable benefit. If current practices are ignorant of these types of cultural considerations it can have the devastating effect of perpetuating the historically rooted mistrust Māori and indigenous communities have toward Western knowledge and the sciences. Conversely, by understanding the importance of tapu researchers can help solidify the centrality of mātauranga Māori (Māori knowledge) for Māori participants and enhance the recruitment and retention of Māori participants leading to more representative data collections in Aotearoa, New Zealand [9].

In addition to this the concept of whakawhanaungatanga (building relationships) emphasizes the importance of researchers gaining cultural competency. Whakawhanaungatanga holds immense significance in the Māori worldview, where whakapapa (genealogy; spiritual ancestral connections) forms the bedrock of all existence. While allocating time for relationship-building may appear bureaucratic and incur additional costs, it plays a crucial role in ensuring the recruitment and retention of Māori participants, aligning research goals with Māori aspirations. New Zealand stands in a unique position to lead these types of initiatives and provides a starting point for the development of culturally inclusive paradigms for research.

Furthermore, cultural safety considerations can extend beyond the physical form of participants to their data. For EEG data quality, maintaining a clear signal-to-noise ratio (SNR) is crucial. Impedance, measuring electrical flow resistance in an EEG circuit, affects data quality. Hair, a poor conductor of electricity, increases impedance. While conductive hydrogel can be applied to mitigate this, evidence shows varying impedance levels, especially with African hair types, even with hydrogel application. This poses challenges in clinical settings and may contribute to misdiagnoses, and underrepresentation of minority groups in data sets, due to reduced SNR. While this issue initially appears related to phenotype rather than cultural safety, it cannot be excluded from the cultural safety discussion. Indigenous cultures, including those in the Pacific, may be disproportionately affected, emphasizing the need to address this potential outworking of systemic racism and bias in EEG studies in the Pacific.

The future trajectory of instrumentation and measurement in Aotearoa, New Zealand, especially in EEG studies, should delve into Māori perspectives on the mind, well-being, and identity. Guided by te tiriti, instrumentation and measurement endeavors in this country should prioritize heightened collaboration with Māori, aligning with Māori aspirations.

While impeding technological progress is undesirable, unbridled advancement in a technological era fails to guarantee the ethical and effective utilization of modern innovations. Furthermore, if the benefits of certain technological innovations are only available to certain groups, we are left to ask:

Are you as researchers contributing to the systemic and perpetual issues of lack of indigenous participation in your research? How do you know are/are not?

At what cost is the instrumentation and measurement community moving forward and innovating? Is it really moving forward if we are not all moving together?

What value do indigenous perspectives hold in your area of research? How can you find out?

Perhaps what the community needs is a break from the emphasis on usability and commodification, returning to the foundational theories that underpin its existence. While many of us partake in the feast of innovation and progress, the time has come to strive for a more equitable instrumentation and measurement research landscape.

V. Conclusion

This article has delved into the realm of participatory case studies by employing EEG headsets to discern cognitive fatigue. Drawing insights from the researchers' experiences throughout this study, a set of cultural considerations has been unravelled. From scrutinizing the utilization of EEG headsets as wearable technology, to navigating the complexities of inducing fatigue, and monitoring participant performance, this paper emphasizes the intricacies of cultural implications in user studies. The scope extends beyond the immediate case study to encompass broader considerations for instrumentation and measurement studies. Cultural safety takes centre stage, urging researchers to be cognizant of the cultural nuances that may impact participants. It prompts a critical examination of cultural biases in both participatory studies and data collection processes. Simultaneously, the spotlight is cast on the enduring effects case studies have on participants mental and physical well-being. As we wrap up our exploration, the discourse shifts to the imperative need for proactive engagement with cultural and racial disparities. Acknowledging their potential influence on participant expectations and technical outcomes, this article champions a forward-thinking approach to explore these factors. In essence, this article not only presents a compelling participatory case study but also sets the stage for a more nuanced and culturally sensitive landscape in instrumentation and measurement research. By recognizing and addressing the multifaceted considerations, researchers can forge a path toward inclusive, ethical, and impactful studies in the burgeoning field of wearable technology and cognitive science.

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