Harnessing Digital Phenotyping to Deliver Real-Time Interventional Bio-Feedback

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ABSTRACT

With the decreasing cost and increasing capability of sensor and mobile technology along with the proliferation of data from social media, ambient environment and other sources, new concepts for digital prognostic and technological quantification of well-being are emerging. These concepts are referred to as digital phenotyping. One of the main challenges facing the development of these technologies is the design of easy to use and personalised devices which benefit from interventional feedback by leveraging on-device processing in real-time. Tangible interfaces designed for well-being possess the capabilities to reduce anxiety or manage panic attacks, thus improving the quality of life for both the general population and vulnerable members of society. Real-time bio-feedback paired with Artificial Intelligence (AI) presents new opportunities for mental well-being to be inferred allowing individually personalised interventional feedback to be automatically applied. This research explores future directions for bio-feedback including the opportunity to fuse multiple AI enabled feedback mechanisms that can then be utilised collectively or individually.

CCS CONCEPTS

• Human-centered computing • Ubiquitous and mobile computing• Ubiquitous and mobile computing systems and tools

KEYWORDS

Tangible User Interfaces, Artificial Intelligence, Intervention, Feedback, Well-being , Pervasive Computing

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1 Introduction

According to the Mental Health Foundation, a quarter of the population will experience some form of mental health problem in the course of a year [1]. Anxiety is one of the most prevalent mental health problems in the UK and elsewhere, yet it is still under-reported, under-diagnosed and undertreated [1]. With the decreasing cost and increasing capability of sensor and mobile technology, along with the proliferation of data from the ambient environment and other sources, new forms of Human-Computer Interaction (HCI) will emerge which are more dynamic than desktop and conventional ICT settings. Also, new concepts related to the moment by moment quantification of health and well-being, known as "Digital Phenotyping" can be harnessed [20]. These concepts, new advancements in HCI and the impact of the mental health issues identified above, have led to increased explorations of how HCI research can valuably contribute to mental health and well-being.

Limited attention has been given to the design of technological management and interventions for individuals who might benefit from self-support tools [15] [27] [28]. Existing technologies commonly range from online therapy programs (e.g., Computerized Cognitive Behavioural Therapy (CBT) for depression [10]) and self-help systems, to designs that supplement psychotherapy by providing additional content to support mindfulness [9] and remote monitoring [21]. These systems are limited to the monitoring of clients using sensors while relying on users to act, be able to recognise and verbalise, or self-report accurate information in relation to their health and physiological status. Users often do not, or may not, know how to respond, therefore providing specific direct physical feedback (e.g. tactile or vibration) may ameliorate this effect. In addition, the difficulty in accessing possible vulnerable and underserved groups have made it challenging to design more effective interventions that can be tailored to their needs, where technology can have a life-changing impact. In this paper, we describe our exploration of real-time haptic and bio-feedback modalities to transform well-being.

2 Background

The adoption of tangible user interfaces enables people experiencing poor mental well-being to interact with physical devices often leading to a greater emotional attachment [19]. Tangible interfaces are ideal to embody a range of sensors to infer mental well-being in addition to different feedback mechanisms that act as interventions [29] [26].

Previous work shows vibrotactile and haptic feedback have been utilised to improve mental well-being. Good vibes [16] used a haptic sleeve to provide feedback based on the user's heart rate. Good vibes helped reduce participants' heart rate by 4.34% and 8.31% during two stress tests compared with the control group. EmotionCheck [8], a vibrotactile based feedback simulating heartbeats aimed to regulate anxiety by providing false heart rate feedback in the form of subtle vibrations on the wrist. Doppel [4] also used haptic feedback in a wearable wrist-worn device that aimed to reduce stress before public speaking. The device measured users' heart rate and skin conductance to determine stress with the speed of the vibration dependant on the user's heart rate, providing personalised real-time feedback. When users presented a speech to induce stress, the skin conductance data showed users wearing Doppel remained less stressed than the control group. Haptic feedback can also be used to coach users in deep breathing techniques and can provide a sense of presence to help alleviate loneliness which is one of the leading causes of poor mental well-being in older adults [1]. This research shows that haptic feedback delivers many clear benefits, especially when the feedback is personalised, by providing a distraction which often improves mental well-being [14] and is used as a coping strategy for people suffering from mental health conditions [7] albeit more research is required to fully explore its potential impact.

In addition to haptic feedback, it is also possible to guide users' behaviour. Squeeze, Rock and Roll [5] is an interactive technology providing dynamic tactile feedback that aims to improve well-being by gradually guiding the user to reduce their fidgeting behaviour, as many people do when stressed. However, while people acknowledged that the device helped them relax, no stress reduction was found. Guiding users' behaviour is a novel approach to improve mental well-being although possibly less effective than haptic feedback as some people may find the action of rolling or twisting objects relaxing.

Visual feedback provides many positive benefits as light on ambient displays affects the production of melatonin, which may restore normal circadian rhythm [1], and may help alleviate sleep disturbance in people with dementia [30]. Alternatively, visual feedback can be used to guide users' behaviour. BioFidget [17] used multi-coloured lights to assist users practising deep breathing exercises resulting in the majority of users improving their heart rate variability showing they were less stressed.

Audio feedback can also be used to guide users' behaviour or to provide a sense of companionship when experiencing loneliness or stress. A children's toy was developed that relied upon vocal interactions and audio feedback to calm children at the hospital [13]. The children who used the toy spent more time playing with it than comparative toys, and their behaviours conveyed they were not stressed. Furthermore, listening to music or a story to help the elderly or a child sleep when feeling anxious or lonely can improve well-being and ultimately lead to a greater quality of life [12] [11]. In addition, both audio and visual feedback have been combined to provide relaxation training, helping to manage pain and anxiety in young children during medical procedures [18].

Robotics have also been utilised to reduce stress and loneliness in the elderly. Paro [23] is a robotic seal that embeds tactile sensors enabling the force and location of interactions to be measured, and relevant audio and robotic movement feedback to be delivered. Paro helped reduce stress in a day service centre for elderly adults, increased users' social interactions and helped improve reactions to stress in a care home [3].

Gentle, therapeutic controlled pressure, placed on certain points along energy zones (reflex points) can provide healing touch and massage. A headband has been developed that uses two low powered massage motors to provide massage therapy with the aim of providing "significant reductions in physiological stress" [6]. The massage motors were tested on 4 participants with 3 of these responding well to the feedback and becoming less stressed, showing the possibility for massage therapy to be further utilised in stress reduction devices. However, more research needs to be conducted to confirm its capabilities in improving mental well-being as the device was only tested with four participants.

Hand warming is the simplest method of establishing increased voluntary control of the sensitive vasomotor system [2], which can be affected by stress. Squeeze and heat to reflect skin conductance data has been explored to create emotional awareness in everyday life settings [24]. Cool me down is another tangible interface that utilised heat to help ground people's senses although was not as successful in improving mental well-being as other techniques to ground senses such as 'Hurt me' which applied a moderate painful stimuli [25].

3 Biofeedback Design for Well-being

Tangible interfaces can provide aesthetically pleasing user interfaces that are capable of providing interventional feedback with the aim of improving mental well-being. Based on a behavioural model, a stress scale will be utilised, in order to assess the current affect states of the user and based on these scales, feedback responses will be delivered. Data processing will be carried out locally while further processing could be completed on mobile devices and the cloud. The interfaces can therefore be used as standalone devices, however by connecting to a smartphone it will benefit from alternative features and functionalities such as a user setup page and graphical representations of the data. Analysing the use of the tangible interfaces will be linked to mental well-being factors and will contribute to early detection and prevention of negative mental states.

When designing devices to improve mental well-being it is imperative to involve end users at each stage of the development process to ensure user acceptance and high usability. The demonstration of existing interventional feedback examples help users understand how such interfaces can function. This enhanced understanding of mental well-being tangible interfaces and possible interventional feedback enables participants to devise new realistic designs and conclude the most beneficial feedback.

3.1 The Data and AI Framework

Recent advances in physiological sensors and Artificial Intelligence (AI) especially Deep Learning and the use of Recurrent Neural Networks (RNN) with LSTM are increasing the accuracy in which mental well-being can be classified [22]. RNNs enable the raw data from the physiological and environmental sensors within the tangible interfaces to be used to classify mental well-being without feature extraction being first required. AI can then control when the interventional feedback should be applied in real-time.

AI can additionally influence the form of interventional feedback applied. By monitoring and learning each user's behaviour when various interventional feedback are applied the most beneficial feedback can be issued on an individual basis. AI presents new opportunities for personalised interventional feedback resulting in new feedback modalities and different feedback patterns that can be applied to individuals when experiencing varying mental well-being states.

The use of AI does present its own set of challenges as a vast labelled dataset is first required to train the model. Collecting data is a challenging proposition as it requires individuals to use tangible interfaces to label their well-being in real-world environments without the application of interventional feedback. Privacy is another key challenge as AI requires a large amount of mental well-being data to be collected which is highly personal. To increase privacy all classification models should be run locally on the tangible interfaces but it is challenging to find processors that are small enough to be embedded within the tangible interfaces and powerful enough to run the model in real-time.

3.2 Prototypes

Multiple prototypes have been developed to cater for different use cases. 3D printed interfaces allow for physiological sensors to be embedded along with various interventional feedback, as demonstrated in figure 1. Haptic feedback is included in the current prototypes capable of issuing various feedback patterns ranging from short, sharp feedback to long, gradual patterns. The feedback pattern issued depends on the ways in which the device is interacted with and the sensory data collected. Additionally, visual feedback in the form of multi-coloured LEDs are embedded allowing for various information to be subtly conveyed to the user. The haptic and visual feedback have been combined to assist deep breathing practices, the haptic motor gradually increases vibrations and the lights change colour instructing users to breath inwards. The haptic motor will then gradually decrease with the lights changing back to their original colour instructing users to breath outwards. The combination of the two interventional feedback mechanisms being combined in one interface allows for them to be used concurrently providing additional stimulation. Alternatively, the AI can select which feedback to use independently to improve mental well-being.

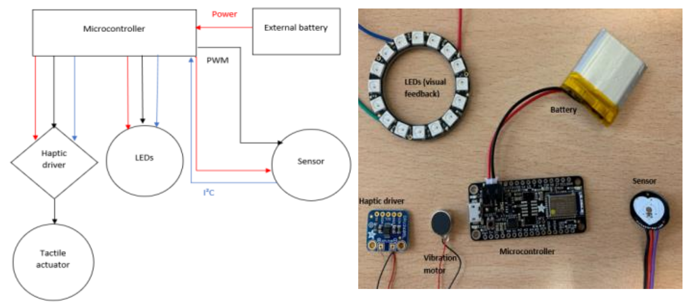

Figure 1: A) Architecture schematic B) Electronic components for multi-feedback interface

Providing real-time personalised feedback based on sensory data is also possible allowing for different haptic feedback patterns to be issued when users' heart rate variability decreases, indicating they are more stressed. The haptic feedback and visual feedback are directly correlated to the sensory data allowing haptic feedback to be issued along with the embedded lights changing colour and intensity as the user becomes stressed.

ElectroConvulsive Therapy (ECT); where a seizure is induced in a patient not for its painful aspect, but for its ability to ground the senses can also be explored as interventional feedback. Through the use of conductive materials, it is possible to produce controlled ECT in the form of minor electric shocks. Providing a small painful stimulus grounds users' senses by using similar techniques as ECT but by utilising minor electric shocks the feedback can be embedded into tangible interfaces. This form of feedback presents many ethical challenges meaning exposure to this feedback must be continually monitored to ensure it does not become uncomfortable or painful. This feedback should not be used to exhibit pain and could be reserved for more severe worsening mental well-being to immediately ground users' senses.

Motors present many new opportunities to provide novel interventional feedback that has not yet been explored. Motors could be utilised in soft children's well-being toys enabling them to move independently and respond appropriately to the child's mental well-being. It is possible for a toy's mouth, arms and legs to move independently. If a device is touched harshly and shaken aggressively the toy can fold its arms and open its mouth visualising the negative emotions being experienced with the aim of guiding users to a more positive state of mental well-being.

Motors have many opportunities beyond children's toys, we propose the use of motors for a new concept of user-guided resistance going beyond user-guided behaviour to enable the feedback to actively push back against the user. User-guided resistance has many possible applications within mental well-being tangible interfaces; buttons, dials or joysticks could push back as they are interacted with or children's toys could resist being moved in specific ways. This new form of feedback differs from user-guided behaviour as the feedback is not gradually guiding the user to stop a specific action. It is instead simulating a sense of presence with the motor serving as another person that the user is interacting with. User-guided resistance also serves as a more engaging and powerful distraction to users than other forms of feedback as it relies upon a physical action being performed. By providing a larger distraction and an increased sense of presence it is hoped user-guided resistance will have a greater impact in improving mental well-being in real-time than existing feedback.

Overall, multiple new forms of interventional feedback have been proposed. Vibrotactile feedback paired with visual feedback provides clear feedback and is the simplest to develop. Novel feedback such as ECT is more complex to embed into tangible interfaces and may be more challenging for users to embrace but is capable of providing more pronounced feedback to immediately ground users' senses. User-guided resistance presents new opportunities for more immersive feedback while still remaining simple to operate and easy to embed into tangible interfaces.

4 Conclusion

Advancements in AI, sensors and tangible interfaces are presenting new opportunities for mental well-being to be sensed and feedback applied automatically, improving individuals mental well-being in real-time. In the future, it hoped that AI can be utilised to provide personalised interventional feedback by analysing which feedback has the greatest positive impact on each individual's mental well-being.

A range of interventional feedback mechanisms to positively impact mental well-being have been explored including the use of haptic feedback paired with visual feedback to communicate well-being and aid deep breathing. Furthermore, minor forms of electroconvulsive therapy to ground users' senses and motors present many new opportunities for mental well-being interfaces to physically interact with users. User-guided resistance has been proposed as an evolution of user-guided behaviour where interfaces can actively push back against the user providing an increased sense of presence. These interventional feedback techniques can now be embedded within tangible interfaces powered by AI and trialled with users to explore the potential impact they may have in improving mental well-being in real-time.

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