Chapter 1
Meaningful Interaction with Physiological Computing

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Abstract Physiological data can be used as input to a computerised system. There are many types of interaction that can be facilitated by this form of input ranging from intentional control to implicit software adaptation. This type of interaction directly with the brain and body represent a new paradigm in human–computer interaction and this chapter will discuss how meaning is associated with data interpretation and changes at the interface. The chapter will categorise the different systems physiological input allows and discuss how interaction with the system can be made meaningful for the user.

Introduction

The general mode of human interaction with computing systems has remained unchanged for the last 30 years. We communicate our intentions overtly to the computer via peripheral devices such as the keyboard and mouse. The advent of tablet computers and gesture recognition presents a challenge to traditional methods of input control but the basic interaction paradigm remains unchanged. There are other alternative paradigms under development that allow the user to communicate with a computer without any need for overt forms of input control. Brain–computer interfaces (BCI) are designed to read actions and intentions directly from the cortex of the brain by translating signals into actions at the interface (Tan and Nijholt 2010; Allison et al. 2012). Thereby replacing the physical based motion involved in traditional input controls by monitoring the source of the perceptual-motor chain in the brain. The same logic applies to those

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systems that translate eye movements into cursor control at the interface (San Agustin et al. 2009), where directed gaze is a proxy for motor control.

The development of BCI and eye control systems represents an alternative form of input control that is directive and intentional, just like pointing and clicking with a mouse. In these cases, the mode of input control is novel but the mechanics of human–computer interaction (HCI) remain essentially unchanged. There is another form of human–computer communication where the form of HCI is novel and the mechanics of the interaction are neither deliberate or volitional in any conventional sense. In this case, the nervous system of the user is monitored during the HCI and the resulting data is used to characterise the cognitive, emotional or motivational status of the user, these data provide a dynamic representation of the psychological status of the individual, which is relayed to the system in order to inform a real-time process of software adaptation (Fairclough 2009). This method of "wiretapping" the psychophysiology of the individual may have profound implications for the future of HCI. Previous research into affective computing (Kapoor et al. 2007) and adaptive automation (Wilson and Russell 2007) have demonstrated how physiological data can be used to trigger software adaptation that is timely and intuitive. Hence, a frustrated user receives help in order to avoid an escalation of anger (Klein et al. 2002), the autopilot on an aircraft cockpit is activated in time to alleviate high mental workload experienced by the pilot (Kaber et al. 2005), and the computer game makes an upward adjustment of difficulty to challenge a bored gamer (Gilleade et al. 2005). These biocybernetic control systems (Pope et al. 1995) rely on implicit monitoring of the psychophysiological status of the user and can be used to promote desirable psychological states and/or to mitigate those negative emotions or hazardous states of awareness (Prinzel 2002) that could be detrimental to the health and safety of the individual.

One innovation of biocybernetic control is the ability for software to adapt to the individual in a highly personalised way. Hence, the physiological computing system is capable of dynamic adaptation in order to tailor the interaction to a particular person or a particular usage scenario. Biocybernetic control is also capable of taking an initiative and adapting the interface in order to shape the experience of the human according to a predefined agenda, i.e. to mitigate frustration or promote positive affect. The capacity of adaptive software to operate upon the human represents a fundamental change in how people and computers work together, as the autonomy of the technological system is enhanced and human–computer interaction is shifted toward a dyad that may be more accurately characterised as 'teamwork' between user and computer (Klein et al. 2004).

Categories of Physiological Computing System

Physiological computing systems fall into two broad groupings. The first are designed to extend the body schema, i.e. the representation of the body used to guide perceptual-motor tasks that are targeted and volitional. These functions are guided by intentionality, when we want to reach out to touch an icon or click a link to go to a particular web page. For routine activities, such as picking up a coffee cup or opening a door, the body schema guides action at an unconscious level. The body schema rests upon a sense of agency, of being the initiator or source of a movement or action (Gallagher 2005). The second category of physiological computing system is concerned with self-perception of those dynamic processes that occur within the body and contribute to an awareness of a psychological state. *This body image has been defined as "a complex set of intentional states and dispositions… in which the intentional object is one's own body*" (p. 24) (Gallagher 2005). With respect to physiological computing applications, augmentation of the body image is achieved by monitoring spontaneous changes in physiology and adapting the interface in response to a dynamic representation of the body image. In addition, as we are using physiological measures to represent psychological processes, the intentional object extends beyond the physical body to those interoceptive pathways (Craig 2003) that inform self-awareness across a number of psychological states. This 'wiretapping' approach may be used to capture a range of physiological data, such as: physical activity (running, walking) as well as psychological processes, such as increased mental workload or frustration, and markers of health e.g. a hypertensive user monitoring blood pressure. This type of physiological computing system facilitates the perception of self by providing an additional channel of quantitative feedback to the user.

There are three distinct categories of physiological computing system Fairclough 2011): input control, biocybernetic adaptation and ambulatory monitoring. As stated earlier, our conventional mode of HCI involves expanding the body schema. This psychomotor control loop is the basis for interaction with a keyboard/mouse, touchscreen or gesture-based control. The physiological computing approach can be applied to this type of input control interaction by capturing activity related to the psychomotor control loop originating from either the cortex or sites of motor output. Electrooculography (EOG) refers to the measurement of the muscles that control vertical and horizontal eye movements. Eye movement can be used to control a cursor moving in two-dimensional space and intentional eye blinks used as a selection mechanism (see Majaranta and Bulling in the current volume). These interfaces have been developed for users with physical disability, but it is plausible that healthy users can also benefit from this kind of input control. BCIs offer an alternative mode of input control. Rather than tapping the final stage of the psychomotor loop, most BCIs are designed to capture electrocortical activity at source: the intention that precedes movement, the spark of activation in response to a particular item, the localisation of visual attention. BCIs offer a highly novel form of hands-free interaction capable of communicating with standard screen-based technologies as well as specialised devices such as prostheses. Like muscle controlled interfaces, BCIs function as an alternative form of input control designed to emulate the functional vocabulary of standard devices, such as the keyboard and mouse. All forms of BCI are treated as alternative modes of input control that operate within the human–computer interaction paradigm, in other words, they allow the user to communicate intentional actions via a command interface. Therefore, issues like novelty, ease of use, communication bandwidth and speed of information transfer are important influences on user acceptance.

The third category of physiological computing is called biocybernetic adaptation. These systems monitor spontaneous activity from the brain and the body in order to capture psychological states relating to performance and wellbeing. These states include psychophysiological signatures of emotions, such as anger, frustration or fear; in this respect these systems overlap with affective computing technology (Picard 1997). Changes in cognition related to mental workload may be also measured via involuntary patterns of psychophysiology (see Peck et al. in current volume). For certain categories of computer software, such as games or auto-tutoring systems, we may be interested in changes in both cognition and emotion, i.e. when someone is mentally overloaded (too much information, not enough time), they also may experience anxiety or anger. This type of biocybernetic adaptation encompasses a wide array of software applications, from the control of adaptive automation to human–robot interaction (see Sarkar in current volume). Regardless of precise context, biocybernetic systems are fundamentally designed to deliver software adaptations that will be perceived as timely, intuitive and ‘intelligent’ by the user.

The biocybernetic category of physiological computing systems relies on passive monitoring of psychophysiology. The user behaves in a naturalistic fashion and spontaneous physiological responses are recorded and relayed to a monitoring system. This surveillance function of physiological computing systems is most prominent in the final category that we have called ambulatory monitoring. It is reasonable to assume that all three categories of physiological computing system will rely on lightweight and unobtrusive ‘wearable’ sensors. In some cases, the user may only connect to the system when they are working within a particular context or using a specific piece of software. Other users may wear sensor apparatus during every waking hour, some may even have implanted sensors capable of transmitting data for every second of every day. The flow of physiological data from person to system is the lifeblood of all systems already described, these data drive the algorithms used to facilitate computer control or software adaptation, but they may be recorded for other purposes. One obvious group of candidates for continuous physiological monitoring are those people with chronic health problems who are being treated as out-patients. Basic autonomic functions, such as heart rate, blood pressure and respiration patterns, could be recorded wirelessly and made available to qualified medical staff who wish to monitor those individuals outside of a medical facility. Alternatively, a social network of carers, close friends and family members may be granted access to real-time data feeds from patients for purposes of monitoring or reassurance. This is the concept of “body blogging” where physiological data is made available in a public or private web domain for the purpose of medical monitoring or social networking (Gilleade and Fairclough 2010). This approach to physiological monitoring could also be useful to an individual engaged in a life-logging or self-tracking project. The big difference between the ambulatory monitoring approach and BCI/biocybernetic adaptation is that the purpose of the physiological data in the former is feedback and data visualisation, for the individual and other connected people, and unlike the later does not necessitate real-time adaptive control.

The three categories of physiological computing systems are intended to represent a continuum rather than a hard distinction between different types of system. It is anticipated that modes of physiological computing control will be used in combination with conventional modes of input control (mouse, keyboard, console, gestures). It is easy to imagine an integrated system where BCI working alongside conventional input control. The introduction of biocybernetic adaptation is complimentary to conventional input control because it may be used for the adaptation of settings and special commands (Fairclough 2008); hence, a user could interact with a virtual character via keyboard/mouse who responds to their emotional state with a repertoire of affective inflections and expressions. The key point is that physiological computing is intended to enhance conventional modes of HCI, not to replace them.

The conceptual framework of a biofeedback loop is effectively the parent of all physiological computing systems. Crucial biofeedback concepts, such as fidelity of feedback, real-time control and enhanced self-regulation, are relevant to all four categories of physiological computing. This common ground creates huge potential for convergence and mash-ups between the different types of physiological computing system.

Meaningful Interaction

If the purpose of physiological computing is to extend the body schema and the body image, the challenge for system design is how to connect the intentions and experiences of the user with the interface in a meaningful way. Physiological computing systems are based upon a direct connection between activity in the central nervous system and events at the interface. This biocybernetic loop (Pope et al. 1995) transforms raw physiological data into a semantic classification (e.g. move up/down, angry, excited), which is converted into an adaptive response from the system. Interaction with a physiological computing system is perceived as meaningful by users when events at the interface conform to their expectations or experiences.

The process of analysis within the biocybernetic loop is analogous to an act of translation. In the book God and Golem Inc, Wiener (1964) described a hypothetical system capable of translating English into Russian and back into English; he argued that the degree of similarity between the original document and English text translated from the Russian provided an index of system efficiency, i.e. how well does a re-representation match an original representation. The same analogy may be adopted to understand the inherent complexities of the biocybernetic control loop. In this case, we have a number of systems where intention or experience, as perceived phenomenologically by the person, are converted into physiological data, which are subsequently decoded into an event at the user interface. The first obstacle to meaningful interaction is basically metaphysical; the experience of an intention or psychological state is rich and nuanced compared to an operationalisation of that intention/state via psychophysiological data. This discrepancy has been accurately articulated by Hayes (1999) as the gap between "the plentitude of experience compared to the sparseness of abstraction" (p. 99). Given that a degree of simplification is an essential starting point for representation within the biocybernetic loop, the next challenge is to accurately classify incoming data according to the internal lexicon of the system. If a BCI is designed to recognise two axes of movement (e.g. up/down, left/right), it is important for an intention to move upwards to the right is recognised as such by the system. For biocybernetic adaptation, the identification of a target state (e.g. anger) from a range of other emotional states (e.g. excitement, fear, boredom) should coincide with bodily changes that are consistent with the experience of anger, e.g. increased cardiovascular reactivity and respiration rate. Unlike other categories, the goal of ambulatory monitoring is to represent data records directly to the user or to another user. In this case, the challenge is one of representation and visualisation, to render data meaningful and digestible for the user. The final barrier to meaningful interaction concerns the response from the system at the interface. For BCI, correct identification of the intended direction of movement must be translated into analogous cursor movement. The correct selection of appropriate response for input control is relatively straightforward in comparison with biocybernetic adaptation. The latter may respond in several ways to the identification of a specific user state; in the case of frustration for example, the system could offer help information or automate on behalf of the user or play calming music. If the interaction is to be meaningful for the user, it is important that a system response resonates with experience in some way, to either acknowledge that experience or provide an intervention designed to mitigate negative experience (or promote positive experience).

The following sections will consider the issues surrounding meaningful interaction with respect to three categories of physiological computing: input control (muscle interfaces and BCI), biocybernetic adaptation and ambulatory monitoring (body blogging).

Meaningful Interaction with Input Control

The most significant challenge for systems, such as BCI and muscle control, is utilising physiological signals for input control is matching the speed and intuitive ease of traditional input devices; in addition, the standards of user acceptance in this field has been arguably raised in recent years with the advent of gesture-based input. Given that competition in terms of speed and accuracy from traditional modes of input control is so strong, the designer must consider the motivations of the healthy user and the context of usage when he decides to incorporate eye-based control or BCI (Allison et al. 2007a) into the system. For example, BCI or gaze-control may be used to supplement existing modes of input control, such as gesture recognition or point-and-click devices. We may imagine a system where gestures are used to locate a specific area of the screen and the BCI is deployed to trigger an event or command. Similarly, eye-based tracking may be used to direct a cursor within a document and keyboard or voice input used to edit or add text. We should also consider activities where the hands of the user are fully occupied, e.g. drivers, pilots, surgeons, gamers. It has been argued that "hands-busy" tasks lead to "induced disability" (Allison et al. 2007a) where healthy users have limitations on communication bandwidth that approximate those restrictions experienced by users with physical disabilities. In the "hands-busy" cases, BCI and eye-tracking represent an additional input channel to restore communication bandwidth. Another advantage of these technologies (compared to overt gesture recognition) is that they may be used privately in a public space. At the time of writing, BCI technologies (e.g. peripherals) are being marketed to gamers and entertainment software. This focus plays to a particular strength of BCI for healthy users, namely the novelty of the experience and satisfaction associated with mastery of this particular mode of input control in a competitive context.

In order for input control via physiological computing to be meaningful for a user, we must consider the motivational context for system use. In the case of hybrid systems (where BCI is used in conjunction with gesture or keyboards), use of BCI or equivalent is meaningful to the user to the extent to which it "fits" with alternative modes of input control.

The use of physiological signals as a proxy for input control occurs in two different situations. Certain types of BCI (Allison et al. 2007b) are operated by exposing the user to specific categories of stimulation at the interface and the response from the electroencephalogram (EEG) determines whether a selection is made. For example, one system (Krusienski et al. 2008) exposes the user to an array of letters that flash in sequence, the amplitude of the P300 evoked response potential (ERP) to each flashing letter determines whether the letter is selected, i.e. higher amplitude P300 response is related to greater processing, which serves as a proxy for intention. There is also a BCI protocol structured around Steady State Visual Evoked Potentials (SSVEPs); in this case, discrete areas on the screen are programmed to flicker at a specific frequency. These 'target' frequencies may be identified in the EEG data record at the visual cortex and the synchrony between the EEG and target frequencies used as a proxy for selection. Both cases adopt a similar strategy based upon experimental protocols whereby the user is exposed to 'probe' stimuli and the response of the EEG to these probes is the aspect of data analysis that determines response selection. From the perspective of the user, the only directive is to attend to that letter or area of the screen that is of interest, hence it is essential that the system successfully matches attention with the desired selection in order to imbue interaction with meaning for the user. The other dimension to this interaction is temporal synchrony. If the user attends to a particular point on the screen, in the case of a SSVEP-based BCI, how much time is required before the system makes a response? The correct identification of a desired command or selection represents the semantics of input control, but minimal time lag is equally important to ensure a sense of connection with the interface. The importance of the temporal dimension is particularly important when input control represents a continuous response, such as cursor movement in two-dimensional space, as opposed to the selection of discrete commands, i.e. using eye movement as a mode of cursor control. There are other categories of BCI that do not rely on external stimulation to trigger input control, these systems rely on motor imagery to produce distinct EEG patterns in the somatosensory cortex, which may be matched to discrete commands at the interface (Ramoser et al. 2000). For example, the user may be requested to think about the right hand or left hand or to imagine making specific categories of movement with each limb. This mode of input control originates from internal stimulation and capability of the user with respect to mental imagery. In terms of meaningful interaction, the same criteria of speed and accuracy are essential; the user looks to the system for a timely confirmation that mental imagery has been achieved, i.e. if I think of my right hand, I expect to see the button on the right side of the screen to activate.

The simplest case of input control via physiology is the use of eye tracking technology to enable cursor control. This system converts vertical and horizontal eye movement into x and y coordinates that are translated into cursor movement on the screen. In this case, the sense of connection between the actions/intentions of the user and event on screen is created when the cursor successfully mirrors the movement of the eyes as experienced by the user. The only real threats to continuity come from involuntary distraction (e.g. gaze being automatically oriented to an event outside the screen) and accuracy of second-order tracking. This latter factor is characterised as a sensitivity gradient, which describes the ratio of eye movement to cursor movement on the screen and may cause slow movement towards or overshooting of the desired target.

As described earlier, BCI systems that operate on the basis of external stimulation or a trigger event are based upon voluntary acts of attention. The meaning of the interaction is derived from the accuracy of selection, or more specifically, the relationship between intention and selection. When the BCI is constructed around imagined movement or orienting attention to a specific part of the body, the sense of connection between mental activity and events at the interface is achieved via accurate and sensitive input control. In this sense, the mechanics of connecting imaginary movement to input control are similar to the recognition of overt gestures. One major distinction between actual and imagined movement is the presence of individual differences with respect to the latter. The inability of some people to produce consistent patterns in the EEG during motor imagery may account for the phenomenon of ‘BCI illiteracy’ (Kubler and Muller 2007). In this case, the sense of connection between user and system is undermined by variability inherent in self-regulation and the EEG signal. However, there is evidence that people can improve motor imagery and BCI communication via training in a neurofeedback regime (Hwang et al. 2009). It has also been suggested that playing certain types of videogame may lead to improved BCI control (Lotte et al. 2013) through stimulation of related cognitive processes e.g. mental rotation tasks.

The basic problem of BCI as input control for healthy users is that it remains relatively slow and inaccurate compared to the available alternatives. One response to this limitation is to select usage cases where a slow or inaccurate response are intuitive from the perspective of the user. It has been argued that computer games represent one test case where these limitations may be acceptable to the user (Nijholt et al. 2009). If we imagine a game where the player may enhance his chance to win by activating a special ability (e.g. flying), which confers great advantage but is also temperamental, this may add another dimension to game play (Fairclough 2008). This particular case exemplifies how matching the limitations of physiological computing to the usage case and expectations of the user may generate meaningful interaction.

Meaningful Interaction with Biocybernetic Adaptation

A biocybernetic adaptive system passively monitors psychophysiological changes in a user in order to inform real-time system adaptations. Physiological data is autonomously collected as the user performs a task, the biocybernetic system subsequently uses this information to activate software adaptation if certain triggering conditions are met. Biocybernetic systems operate outside the direct, intentional control of the user. These systems function on a control loop that is associated with a target state, therefore the system has a specific agenda (e.g. to achieve a specific target state in terms of human performance or psychological state) and is designed to influence the psychophysiology of the human operators in order to establish/sustain a target state. One of the earliest biocybernetic adaptive systems was developed by NASA for use in flight simulators (Pope et al. 1995); the psychophysiology of the pilot (spontaneous EEG) was monitored in order to manage the status of an auto-pilot facility during flight time. The agenda of the system was to sustain the level of alertness of the pilot at an optimal level via manipulation of the auto-pilot status i.e. alertness tended to decline during auto-pilot activation and to increase when the pilot manually controlled the craft.

Biocybernetic systems are designed to adapt the operating environment in order to optimise user experience. For example, computer games represent a category of technology that are designed for a particular skill set that may not accurately reflect the skill set of the individual player (Gilleade and Dix 2004). There are a multiple measures of cognitive workload e.g. frontal theta (Klimesch 1999), which can be used to infer the experience of difficulty during game play. A biocybernetic system can utilise these measures to dynamically adjust the level of difficulty in order to match the ability level of the player in real-time. Another popular agenda for this type of system is the mitigation of negative affective states, such as frustration, during computer use. This agenda has roots in the field of affective computing (Picard 1997) whereby computers are designed to understand their user's affective state and regulate undesirable states, in this case, the biocybernetic loop is designed for the personalisation and optimisation of player states (Pope and

Palsson 2001; Gilleade and Allanson 2003; Rani et al. 2005). Other biocybernetic agendas have been proposed for adapting gaming experiences (Gilleade et al. 2005) and information dissemination in social situations (Peck et al. 2011).

Biocybernetic adaptation operates in the background of the user experience, only intervening in the HCI when triggering conditions are met, as such the facilitation of a meaningful interaction can be problematic. A biocybernetic system must achieve an agenda in a manner that satisfies both user expectation of that agenda (e.g. this computer is designed to help me when I get frustrated) and their assessment of their self (e.g. self-perception of frustration). This directive necessitates a tricky proposition of providing the correct adaptation for a specific usage scenario at the right time. If the system fails to fulfil this requirement, biocybernetic adaption has the potential to cause enormous disruption to the user experience.

The design of a biocybernetic system that delivers adaptations that are both timely and intuitive is a complex challenge. Implementing an agenda for the system requires the selection of appropriate physiological measures for the task environment, deciding which type and magnitude of physiological change will trigger an adaptation and what type of adaptation will be triggered with respect to the frequency of intervention and magnitude of change. There are no ideal solutions or generic design rules for meaningful interaction at the present time; the desired effect of the system will differ according to the task, agenda and user. The most pressing issue in biocybernetic system design is accurate diagnosis of the user state based upon the psycho-physiological inference (Cacioppo and Tassinary 1990). Interpreting psychophysiology using real-time analysis in a physiological computing paradigm is problematic as measures can be easily influenced by a range of confounds e.g. movement; therefore, the system is unlikely to be working with a perfect (one-to-one) representation of psychological state. When the biocybernetic loop decides to manipulate the system state there is no guarantee that the resulting intervention will be appropriate and deemed meaningful by the user. If the adaptation is overt and obvious to the user, any conflict between the assumed and actual user state are obvious. For example, if a system is designed to intervene when the user becomes frustrated, e.g. appearance of a virtual agent asking "Would you like assistance?" and does so in the absence of frustration as perceived by the user, it is liable to both annoy the user (ironically creating the emotional state it set out to avoid) and negatively affect the perceptions of biocybernetic control as a technological advancement. By comparison, conflict during covert adaptation, e.g. making minor cumulatively or indirect environmental changes, are unlikely to be perceived by the user, provided that the trajectory of the adaptations over a long time frame is in the correct direction. Implementing a meaningful interaction with biocybernetic control is a design trade-off between sustaining a connection between user experience and the system response and the ability of the system to push user experience in the desired direction. A case study in the design of a biocybernetic loop has been provided by Fairclough and Gilleade (2012) that outlines a process-based approach to these problems.

Meaningful Interaction with Body Blogging

Physiological data provides intimate information about a person with respect to affective, cognitive and physical states. As physiological sensors have become affordable, the general public has the opportunity to quantify, visualise and log their own physiological processes and share these data with family and friends or medical professionals. There is a trend towards automating the data collection process and to integrate the resulting data into Internet applications for a personalised physiological log, e.g. tracking fitness performance. Sharing this information with others provides opportunities to improve health and lifestyle choices, e.g. evaluation of fitness performance by experts. For example, a pedometer can be used to track an individual's daily physical activity in order to generate a database; once uploaded to the Internet, this data may be reviewed by other individuals who can provide feedback to both inform and motivate the user, e.g. Philips Direct Life (Philips 2011). This process of collecting and sharing physiological data is known as Body Blogging (Gilleade and Fairclough 2010) and is defined as the act of logging physiological data using web technology.

Body blogs can be applied in a wide range of domains including the tracking of psychological/physical health, sports performance and self-quantification. In work by Ståhl et al. (2008), physiological information was incorporated into a digital diary. Operating through a mobile phone, the system not only collected a user's normal phone activity e.g. SMS, but it also collected skin conductance and motion data. These data were used to create what is known as an affective diary which could be used by a diarist to view both their subjective experience of their day (via phone activity) and the physical sensations that co-occurred with them. This visualisation allows the diarist to access a more complete picture of their experiences and learn how they may be affected by their environment, e.g. identifying stress triggers, as well as being used for memory recall. While physiological information can potentially be a powerful tool for the purposes of introspective, presenting information in an informative manner that conveys meaning can be problematic. As noted during the development of the affective diary (Lindström et al. 2006), the authors felt visualising physiological information as a standard time series graph would risk creating a disconnect between the data and the diarist. In other words the diarist wouldn't be able to associate their experiences with the format in which the data was presented. During user trials (Ståhl et al. 2008), these data were presented as a series of amorphous body postures, with activity represented by posture and skin conductance by colour. While this interface was designed to resonate with the experience of the person, user opinions were divided on the matter and depended much on users being able to connect their subjective experience with the data representations (e.g. during the trial one user, not being able to understand the data representations being provided by the system, exported the raw physiological data to another program to interpret them). This can be difficult to facilitate as such connections are made on an individual basis.

Body blogs are not simply meant for introspective purposes, e.g. personal reviews of past activity, but provide avenues for in-depth analysis e.g. identify health problems from real-world physiological data, and recommendations for behaviour modification e.g. expert analysis of current sports performance. A variety of interested stakeholders can access the data facilitating new application paradigms using the Internet as a platform for data sharing. For example, in an experiment with public bodying blogging, The Body Blogger (Gilleade and Fairclough 2010), a single user's real-time physiological information was streamed continuously for over a year across a range of online websites e.g. Twitter, allowing the public to informally interpret the physiological and psychological state of the data's owner (Gilleade 2010). Interested stakeholders ranged from the owner, friends of the owner and the public at large. Depending on the stakeholder each accessed the data with a different agenda and found a different meaning from the dataset. The data owner learned how their physiology responded to different life events which are not normally observed e.g. impact of a major holiday on physical health (Gilleade 2011), and friends learned to remotely interpret affective states e.g. work stress (Gilleade 2010). In addition, as physiological data can be interpreted differently within different contexts of measurement, a singular physiological measure can have multiple applications; data collected by a wearable electrocardiogram monitor can be used to provide medical information about the individual's heart performance to a cardiologist and fitness information to a personal trainer.

A body blog must be capable of processing and presenting large data sets in a meaningful way for a variety of interested stakeholders. For example, heartbeat rate sampled over the course of a few minutes or hours can be appropriately presented as a time series graph. From the graph, stakeholders obtain an understanding of how heart activity is affected over time e.g. during sports performance. This begs a question regarding the representation of this kind of data over the course of days, months or even years. This eventuality poses two related questions: (1) is there any meaningful information to be had from such vast data sets, and (2) how is this information to be represented or visualised? In the case of long-term heart activity, Fig. 1.1 illustrates how heart rate activity collected as part of The Body Blogger experiment was condensed into a heat map to allow stakeholders identify meta trends that occurred over the course of a month such as their sleep cycle (shaded blue) and evening exercise regime (shaded orange–yellow).

For each measure in a body blog, the designer must consider how to represent information in a manner that relates to the stakeholder, especially the data owner whose sense of self is embodied within that data. As illustrated during the development of the affective diary, this is a difficult process as the meaning the designer wishes to convey must also align with the expectations the user brings to the data. This is likely to be easier for more objective bodily states e.g. posture, where the user can readily confirm the interpretation of the data (e.g. the sensor reported me as standing up, and I remember standing up at this time, therefore the interpretation is correct). However for more subjective bodily states e.g. emotions, where the associated physiological signals are more open to interpretation, then the

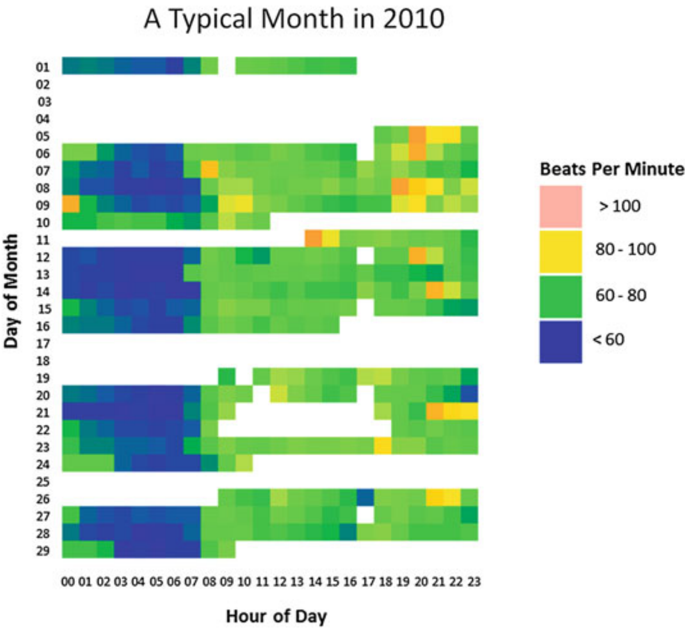

Fig. 1.1 Heat map of user's heartbeat rate over the course of a month

conveyance of meaning at the interface will be more difficult. In a biocybernetic system, poor psychophysiological inferences lead to poor adaptations and can thereby lead to user mistrust, similarly here, if the user is not able to associate their body blog data with their experiences there are more likely to be mistrustful of its interpretation. A potential way to build trust in body blogs would be to allow the user access to the different stages in creating a visualisation e.g. from raw signal to display, so they can create a dialog with the data and their own understanding of how these signals represent their own experiences.

The sharing of physiological data online raises a variety of privacy and ethical dilemmas (Gilleade and Lee 2011). The presentation and analysis of physiological data has been predominately the domain of health and fitness professionals. When these data are provided to new stakeholders, it is likely that they will require training in order to interpret this information. For example an individual sharing medical information online such as blood pressure opens the data for interpretation by medical amateurs. This may lead to an informal misdiagnosis causing the individual and their data's followers undue stress. Therefore in such instances a meaningful interface is not just about conveying relevant information, but to convey that data at a suitable level for the given audience and application context (Gilleade and Lee 2011).

Summary and Conclusions

The concept of meaningful interaction with physiological computing systems has been defined with respect to extending the body schema and the body image. Meaningful input control is enhanced when the system offers an equivalent level of speed and accuracy relative to existing peripheral devices. If input control via physiology cannot compete with this standard, interaction design must accommodate this limitation via the creation of hybrid systems (i.e. where physiological computing and conventional input control are used together) or by deriving an appropriate context for usage. The use of technology to extend body awareness is a complicated design challenge as self-perception of psychological states tends to be nebulous and ephemeral. In this case, modes of interaction must be designed with caution as the physiological data record may be seen to contradict the direct experience of the person. In addition, an adaptive response from software may be misinterpreted unless the goal of that response is clearly apparent to the user. The body blogging system represents a quantification of physiology that may be related to physical activity, health or psychological wellbeing. In this case, the meaning of the data is open to idiosyncratic interpretation from the source of the data or their friends and family members.

We have claimed that interaction with a physiological computing system is rendered meaningful when events at the interface conform to the expectations or experience of the user. This is logical but we believe it is also crucial to the adoption of this technology. The primary barriers to acceptance of physiological computing system are: (1) usage is perceived to be synonymous with an invasion of privacy (2) an emphasis on physiological data is seen to be potentially threatening as methods and measures are associated with medical procedures, and (3) biocybernetic adaptation represents a new mode of HCI where the computer has a greater degree of autonomy. Most nascent technologies are viewed with a mixture of apprehension and suspicion (often with good reason) and it is likely that the requirement for physiological monitoring will increase the trepidation of the user in this particular case. It is intended that meaningful interaction should promote greater understanding of this technology by enhancing a sense of connection between person and machine. This connection may be achieved by promoting the bootstrapping potential of the technology as tool to increase communication bandwidth (with other people as well as computers) and to enhance the self-awareness of the individual. It is especially important for users to understand the meaning of physiological interactions in order to develop a sense of trust in the technology. With respect to the latter, lessons may be learned from human factors work on trust in automation (Lee and See 2004). The user trusts a system when they understand the mechanism by which the system produces its behaviour. This analytic mode of trust development may be contrasted with an analogic route where systems are trusted based upon membership of a particular group or context, i.e. I’ve read great reviews about this BCI system, therefore I am positively disposed towards it.

The development of trust is particularly important in the case of biocybernetic adaptation. These systems possess a degree of autonomy and for a user faced with the novelty of a semi-autonomous system, a degree of vulnerability is to be expected on the part of the user. The design of meaningful interaction will enhance understanding in order to promote trust in the technology. Sustained exposure to meaningful interaction allows the user to make broad inferences about the connection between body and machine in order to reduce apprehension and uncertainty. In short, meaningful interaction is a means of maintaining the primacy of the user as we learn to communicate with a new category of technology via the body and the brain.

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