Improving the Graphical User Interface (GUI) for the Dynamic Feedback Signal Set (DyFSS): Increasing Accessibility for the Neurodiverse

Daniel M. Hicks, Eric T. Hunt, Lindsay M. Alvut, Anna E. Hope and Laurence I. Sugarman

Center for Applied Psychophysiology and Self-regulation
Institute of Health Sciences and Technology
Rochester Institute of Technology
Rochester, New York, USA
Laurence.Sugarman@RIT.edu

Abstract—Peripheral biofeedback is an explicit learning tool that allows for real-time evaluation and control of physiological proxies by means of computerized signals. Its integration into health practice allows users to calibrate self-awareness and self-regulation then apply these skills to everyday life. People with neurodevelopmental differences encounter limitations when using commercially available clinical biofeedback due to variation in their autonomic response. Principles of Universal Design dictate that biofeedback inputs and displays allow effective access and benefit for as many individuals as possible.

Our Dynamic Feedback Signal Set (DyFSS, nonprovisional patent-in-process) algorithm adjusts signal processing by dynamically weighting feedback signals to the best abilities of the user, increasing the efficacy of biofeedback for the neurodiverse. The software includes an interactive graphical tutorial and quiz, a variety of graphical user interfaces to honor individual preferences and abilities, and a game that can be played by blind and hard of hearing individuals alike.

Keywords—neurodiversity; applied psychophysiology; autonomic regulation training; peripheral biofeedback; universal design; access technology

I. APPLIED PSYCHOPHYSIOLOGY AND SELF-REGULATION USING PERIPHERAL BIOFEEDBACK

Applied psychophysiology involves the study and practice of mind and body integration. Tied closely to behavioral medicine and psychosomatics, applied psychophysiology synthesizes psychological, behavioral and cognitive understandings of health and wellness [1].

Psychophysiological self-regulation entails purposefully using one’s innate abilities to alter physiological processes in order to benefit health and adaptation. Strategies such as biofeedback, self-hypnosis, meditation, and other contemplative practices are commonly employed for building skills in psychophysiological self-regulation. Clinical hypnosis and biofeedback in particular integrate easily into conventional healthcare encounters.

A variety of therapeutic strategies improve voluntary (i.e., self-initiated) regulation of the autonomic nervous system (ANS), which includes both the sympathetic (SNS) and parasympathetic (PS) systems. Specific examples of other contemplative strategies for autonomic self-regulation include abdominal breathing, progressive muscle relaxation, guided and unguided meditation, mindfulness practices, self-hypnosis and yoga. While often effective and accessible, they are indirect and share drawbacks. There is usually no real-time, objective evidence demonstrating a change or shift in autonomic functioning associated with these practices. Since social influence and prescription of behavior can be fundamental to learning these practices, they often rely on therapeutic relationships with clinicians or teachers.

Biofeedback training differs fundamentally from these strategies in that it primarily provides information, encouraging self-awareness in real-time and enabling the participant to determine how best to use the information. The Association of Applied Psychophysiology and Biofeedback defines biofeedback training as:

…a process that enables an individual to learn how to change physiological activity…precise instruments measure physiological activity…and rapidly and accurately “feed back” information to the user. The presentation of this information—often in conjunction with changes in thinking, emotions and behavior—supports desired physiological changes. Over time, these changes can endure without continued use of an instrument. [2]

Biofeedback functions primarily as a biological mirror. We claim that the usefulness of the biofeedback system—the mirror—in promoting learning depends upon (1) how quickly and accurately the information is presented to the user; (2) how relevant the information is to the user and (3) how easily the user understands the presented information. While the first criterion is universal—immediate, real-time feedback is best—the latter criteria depend on the tendencies and abilities of the user and may prove more challenging for the neurodiverse. In order to improve the second and third criteria, we have dedicated a majority of our work to exploring and creating a biofeedback system that can be easily used by the neurodiverse, including those individuals diagnosed with autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), dyslexia, anxiety and Tourette syndrome. To create the most adaptive physiological mirror, we utilize the most flexible hardware and software, altering them to meet the widest variety of users’ differing needs.

Biofeedback training currently subdivides into neurofeedback and peripheral biofeedback, two categories
based on the types of physiological signals being recorded. Neurofeedback primarily uses electroencephalograph (EEG) signals from scalp surface electrodes, while peripheral biofeedback collects input from other body systems (e.g., cardiovascular, electrodermal, musculoskeletal, respiratory). The proxies most commonly chosen for peripheral autonomic biofeedback are eccrine sweat gland activity (skin conductance level, SCL), breathing rate and depth (by chest or abdominal strain-gauge belt, RSP), peripheral skin blood flow (as skin temperature by thermostor, TMP) and heart rate variability within the percentage of low-frequency band of 0.05-0.15 Hz (%LF-HRV). Low frequency heart rate variability correlates with vagal tone (calculated from blood volume pulse via photoplethysmograph or electrocardiographically via chest surface electrodes). This work uses peripheral biofeedback exclusively, because (1) the aim is to facilitate autonomic regulation, and (2) we posit that experiencing effects of emotional and cognitive changes peripherally and somatically can enhance learning about brain-body integration skills that maintain wellbeing.

We often describe learning in biofeedback training by using a three-step “discern-control-generalize” model [3].

- **Discern** refers to a person noticing or becoming aware of the ability to move a given signal in an intentional direction, e.g., to increase skin conductance in response to a stressor.
- **Control** pertains to a person practicing and mastering the skill of voluntarily directing a signal so it can be done without feedback, e.g., intentionally changing a signal in a given direction without viewing the screen.
- **Generalize** signifies a person associating a mastered skill in other useful contexts, e.g., intentionally lowering skin conductance level while taking a test at school.

This three-step process combines experiential and associative learning to integrate psychophysiological self-regulation skills into daily life.

II. DEVELOPING THE DyFSS FOR AUTONOMIC REGULATION TRAINING

Counseling and other behavioral training approaches to building skills in psychophysiological self-regulation may be limited by their primary reliance on therapeutic rapport and language [4]. Computer-based peripheral biofeedback provides an alternative for the neurodiverse because it provides direct user-focused information on autonomic function without a heavy reliance on relationship or language [4, 5]. Within a neurodiverse population, individuals will demonstrate varied patterns of autonomic control: their autonomic proxies may co-vary in unpredicted directions. For example, skin conductance reactivity to expected stressors may be slow or absent. Medications can modulate heart rate variability. Some individuals find abdominal breathing challenging and stressful. These individual differences present challenges to clinicians engaging in autonomic regulation training with proprietary peripheral biofeedback systems. In these instances, relying on commonly used biofeedback software could be unfeasible, ineffective, or at least can require additional vigilance and awareness by the clinician (i.e., sensor choice, feedback form) in order to provide a person-centered, adaptive and accessible learning experience.

A. What is a DyFSS?

To improve accessibility for users, one of the authors (LIS) and colleagues developed an algorithm and method which dynamically weights and sums a collection of signals that can be applied, in this case, to four autonomic proxies (SCL, RSP, TMP and %LF-HRV) based on their movement toward minimum sympathetic nervous system arousal and maximum vagal tone [8]. The primary reference graphical user interface (GUI) presents a stacked, four-color bar graph that rises in proportion to increasing vagal tone.

The dynamic feedback signal set (DyFSS, pronounced “diff-iss”) was designed to meet the aforementioned utility criteria of rapidly and accurately presenting relevant physiological process to neurodiverse users in a practical way. By dynamically changing the relative weights of signals, the DyFSS adapts to the varied and evolving abilities of the user thereby providing rapid differential reinforcement to facilitate control of multiple biofeedback signals. The DyFSS adapts to the physiological processes to the user, magnifying what the user already does best.

The DyFSS algorithm was first used with pre-existing FDA-approved medical hardware manufactured by MindMedia [6]. Four sensors plug into the NeXus MK-10™ transducer that wirelessly transmits the signals to the computer, allowing some freedom of movement for the user.

B. Initial Piloting of the DyFSS

Two small pilot studies were conducted regarding the effectiveness and feasibility of an autonomic training protocol with the DyFSS in children diagnosed with autism [7]. The young people with ASD in those trials readily engaged with the computerized intervention, and used what they learned during sessions both at home and at school.

III. DyFSS GUI REFINEMENTS AND ADDITIONS

Having developed, implemented and tested the DyFSS, we turned to improving two aspects of the GUI: the therapeutic interface and the report functions. The therapeutic GUI developments include (1) an interactive comic-book-themed tutorial and quiz; (2) multiple switchable graphical displays; (3) icon cues for physiological processes to improve; and a game-based display using characters from the tutorial and quiz. The report functions include (1) statistical analysis; (2) isolation of specific session epochs for evaluation; (3) magnification of specific signals; and (4) a session overview screen.

The opening tutorial and quiz have been developed in accordance with input from focus groups and clinical encounters with young individuals diagnosed with ASD and their family members. Both the tutorial and quiz feature a young boy and girl learning how to develop their “superpowers” or skills in self-regulation while emphasizing...
autonomy and mastery. The “stress monster” acts as the antagonist upon whom they can focus while practicing their skills and abilities (Fig. 1). The tutorial and quiz provide an engaging and consistent platform independent of the relationship with clinician.

Fig. 1. The comic-book themed quiz involves the user answering basic questions about peripheral biofeedback and each of its four sensors in aims of defeating the “stress monster.”

Three different GUIs have been created: a “hand,” a “brain,” and a “stress destroyer game” (Fig. 2). Each of the new GUIs can be used to improve self-regulation skills and includes icon cues upon which the user can focus in order to make the most physiological improvement. The icon cues are represented as a heart, a thermometer, a pair of lungs and a drop of sweat with a lightning bolt, which symbolize %LF-HRV, TMP, RSP and SCL respectively. Each of the three GUIs include a visual representation of the DyFSS on the left hand side as a four-color stacked bar representing total physiological comfort.

The game GUI includes graphics and animation that match the comic-book themed quiz and tutorial. The game itself has three difficulty levels that can easily be adjusted by the user – affecting the speed, quantity and color of the paint bombs being thrown at the user as representations of stressors.

Sound effects have been added, so that blind students could use the software and still be aware of the experiences. Music and positive audiovisual reinforcements or “quips” have also been added. The sound effects, music and quips can easily be switched on and off by the user. Users can choose their own gender and can play the game until they feel finished.

The report functions were initially added for statistical analysis, so that large periods of time could be selected, isolated and evaluated. The current software allows for flexible selection of any segment of time that was previously recorded during a session. This allows for statistical analysis of any individual physiological signal or all four signals combined. The report functions also play an instrumental role in explaining the DyFSS and its utility to new users. A user can press the space bar on the keyboard at any point during a session to create a marker on the report screen that can then be labeled (i.e. sneeze, 2 minute baseline, thinking about homework). These markers record and emphasize important autonomic shifts. The DyFSS now includes a full report screen (Fig. 3) that displays the data generated by each of the four signals individually, as well as the total DyFSS number. The report screen also includes all of the markers and labels that are personally added by the user, allowing for a more person-centered experience.

IV. FUTURE DIRECTIONS FOR THE DYFSS

The authors currently use the DyFSS with college students in the Minding Anxiety Project (MAP) at the Rochester Institute of Technology where it was developed, as well as with children and families in the community at a local Diagnostic and Treatment Center.

Future applications will include feasibility and comparison trials. We are currently developing a comparison trial to be implemented by select middle school counseling centers in the region, to measure the effectiveness of this type of treatment compared to standard treatment methods in these settings.
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