Self-Adjusting Biofeedback with a Dynamic Feedback Signal Set (DyFSS)

Laurence I. Sugarman, Brian L. Garrison and Anna E. Hope
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*— A lack of control over their autonomic nervous system presents a major challenge for many children with Autism Spectrum Disorder (ASD). Autonomic biofeedback training is a promising treatment for managing anxiety and ASD symptoms more generally. We describe software that tunes four autonomic measurements to the best abilities and needs of each individual patient. Using this dynamic feedback signal set (DyFSS), a strength-based, self-customizing algorithm, we aim to address the autonomic heterogeneity of youth with ASD. The DyFSS may improve autonomic biofeedback training for the user by making it more understandable and easier to accomplish. Because it is self-adjusting, it may also ease the integration of autonomic biofeedback training into clinical work. Initial feasibility testing of this algorithm in youth with ASD with a five-session autonomic biofeedback training protocol showed improved behavior in relation to ASD symptoms Initial reactions show that youth with ASD are readily engaged through technological interventions such as autonomic biofeedback.**

Keywords— autism spectrum disorder; autonomic regulation, emotional regulation, biofeedback, sympathetic nervous system, access technology

I. Autonomic Regulation

The autonomic nervous system (ANS), consists of the sympathetic (SNS) and parasympathetic (PS, predominately vagus nerve or vagal) systems. It provides a foundation for higher processes including emotional regulation, social adaptation and cognition. Originally conceived by Bernard as the "mileu intérior" [1], Cannon developed the notion of the ANS as opposing anatomic and functional structures – "fight or flight" versus "rest and digest" – that maintain homeostasis [2]. While the role of SNS in the stress response and Selye's "General Adaptation Syndrome" [3] predominated during the past 60 years, research in the past two decades has focused increasingly on the role of the PS component. Notably, Porges' "Polyvagal Theory" [4] crystallizes a new understanding of the function of the vagal nerve nuclei, emphasizing their mediating role in somatic awareness (interoception), emotional attunement and social engagement. Porges' contribution shifts away from Cannon's classification by dividing the ANS into externally (SNS) and internally (PS) focused branches; the SNS devoted primarily to threats and defense and the PS, or "vagal system," fostering both homeostatic processes and social adaptation.

Autonomic regulation refers to a person's ability to balance these components: to adapt psychophysiologically to one's changing internal and external milieu. Because of the bidirectional nature of all brain-body systems, this capacity plays a crucial role in health. Autonomic regulation affects inflammation, gastrointestinal motility and absorption, pain experience and mental health [4]. Evidence shows that training in autonomic regulation is an effective primary and adjunctive therapy for anxiety, sleep disturbance, pain syndromes, irritable bowel syndrome, and elimination disorders in adults and children [5].

II. Biofeedback and Autonomic Reguation Training

A variety of therapeutic methods will improve voluntary (i.e., self-initiated) autonomic regulation including abdominal breathing, progressive muscle relaxation, guided and unguided mindfulness meditation, self-hypnosis and yoga. While effective and available, they share drawbacks. They are indirect. While they encourage behaviors that can result subjectively in a change in autonomic state, there is no real-time, objective evidence provided that they do so. Also, social influence and prescription of behavior are essential to these practices, so they depend on therapeutic relationships with either clinicians or teachers.

Biofeedback training differs fundamentally from these strategies in that it primarily provides information, enabling the participant to determine how best to use it. 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. [6]

Simply put, biofeedback works as a physiological mirror. The utility of the biofeedback system – the mirror – to promote learning hinges on (1) how rapidly and accurately information is presented to the user; (2) whether the information is associated with a relevant physiological process (i.e., the mirror is reflecting what the user needs to see); and (3) how understandable the presented information is for the user. While the first criterion is universal – immediate, real-time feedback is best – the latter criteria depend on the proclivities and abilities of the user. Which physiological proxies and which audiovisual presentation options best suit a given user's learning abilities? This question underlies and guides our work, described below, with young people with autism spectrum disorder. The best physiological mirrors utilize the most adaptive hardware and software, capable of adapting to users' differing needs.

Biofeedback training commonly subdivides into two categories based on the specific physiological signals recorded. Neurofeedback primarily uses electroencephalograph signals from scalp surface electrodes to access and feed back a variety of emotional and cognitive states. Peripheral biofeedback collects input from other body systems (e.g., cardiovascular, electrodermal, musculoskeletal, respiratory) to focuses the user's learning on motor (through electromyography) and autonomic control. The proxies most commonly chosen for peripheral autonomic biofeedback (PAB) are eccrine sweat gland activity (as skin conductance level, SCL), breathing rate and depth (by chest or abdominal strain-gauge belt, Rsp), peripheral skin blood flow (as skin temperature by thermistor, Tmp) and the percentage of low-frequency band (0.05-0.15 Hz) heart rate variability which correlates with vagal tone (calculated from blood volume pulse via photoplethysmograph or electrocardiographically via chest surface electrodes, HRV). Our work exclusively uses PAB, because (1) our aim is to facilitating autonomic regulation, and (2) we posit that experiencing the body's responses to emotional and cognitive changes enhances learning about both brain-body integration and skills that maintain wellbeing.

Learning in biofeedback training has been described as a three-step process: "discern-control-generalize" [7].

- *Discern* relates to 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 practicing and mastering the skill of voluntarily directing that signal so it can be done without feedback, e.g., *not* increasing skin conductance in response to a stressor, without viewing the screen.
- *Generalize* refers to associating that mastered skill in other useful contexts, e.g., test taking, performance, challenging social settings.

Essentially, this approach combines experiential and associative learning to integrate a psychophysiological self-regulation skill (e.g., reducing SNS arousal as measured by skin conductance) into daily life.

III. Autonomic Regulation in Autism Spectrum Disorder

Autism spectrum disorder (ASD) is a group of neurodevelopmental conditions with core symptoms of persistent (1) impairments in social communication and interaction and (2) restrictive, repetitive patterns of behavior, interests, or activities [8]. Common co-morbid symptoms collectively affect at least 60% of young people with ASD and include gastrointestinal dysfunction, sleep disorders, sensory sensitivity and anxiety [9, 10, 11, 12]. ASD is estimated to affect 1:68 young people in the US with boys affected about five times more than girls [13]. The most salient feature of ASD appears to be its heterogeneity.

The wide range of phenotypic variation in ASD has not yet been explained by a unified theory of causation. A possible explanation comes from looking at the extensive evidence that both core and co-morbid symptoms of ASD are associated with impaired autonomic regulation as characterized by chronic SNS hyper-arousal and decreased vagal influence [4, 14, 15]. Most therapeutic strategies have focused primarily on changing specific core symptoms without considering that they may represent this common, and possibly fundamental impairment, and that the self-involved behaviors are a reach for homeostasis to compensate for autonomic dysregualtion [14]. Therefore, it is compelling to investigate the role of PAB-based autonomic regulation training (ART) to determine if young people with ASD can replace their maladaptive, compensatory behaviors with more productive ones.

IV. Developing and Testing a DyFSS for Autonomic Regulation Training in Autism Spectrum Disorder

Counseling and other behavioral training approaches for ART in ASD may be limited by their primary reliance on therapeutic rapport and language [14]. Computer-based peripheral biofeedback is an ideal method for ART in young people with ASD because it provides direct user-focused information on autonomic function without primary reliance on relationship or language [14, 16]. The authors (LIS, AEH) have observed that individuals with ASD demonstrate varied patterns of autonomic control: their autonomic proxies do not reliably co-vary in the expected ways. For example, skin conductance reactivity to stressors may be blunted, medications may modulate heart rate variability and slowed breathing may be difficult to coordinate. This "autonomic dyspraxia," perhaps symptomatic of underlying autonomic dysregulation, presents challenges to clinicians engaging in ART with this population. Relying on commonly-used biofeedback software for ART can be unfeasible, ineffective, or, at the very least, require additional vigilance and awareness (i.e., sensor choice, feedback form) by the clinician to present a person-centered, adaptive and accessible learning experience.

A. What is a DyFSS?

To overcome this barrier, the authors and colleagues developed a novel algorithm that dynamically weights and sums four autonomic proxies (SCL, Rsp, Tmp and HRV) based on their movement toward minimum SNS and

maximum vagal tone. The graphical user interface presents a stacked, four-color bar graph that goes up in proportion to increasing vagal tone. Optional line graphs show values over time in their standard units of measurement. A particularly useful feature of the algorithm is that it calculates a score on a linear scale representing the sum of the sensor inputs moving toward increased "comfort" (decreased SNS arousal relative to recent state) thereby simplifying a user's progress to a number on a linear scale, e.g., 0-10.

We designed this dynamic feedback signal set (DyFSS, pronounced "*diff*-iss") to meet the aforementioned utility criteria by rapidly and accurately presenting relevant physiological process in an understandable way. Notably the DyFSS adapts to the evolving proclivities and abilities of the user, reducing reliance on the clinician over time. It provides rapid differential reinforcement to facilitate control of multiple biofeedback signals. To reuse the metaphor: the mirror's reflection emphasizes what the user does best.

The inputs into the DyFSS algorithm come from FDA-approved medical hardware manufactured by MindMedia [17]. Four sensors plug into a transducer (NeXus MK-10™) that wirelessly transmits signals to the computer thereby allowing freedom of movement for the user.

B. Piloting the DyFSS

ASD-affected youth used the DyFSS during two feasibility studies. In the first, a community-diagnosed sample of teens (ages 12-18, n = 8) participated in 5 weekly, 30-45 minute ART sessions. During this training they learned about the nature of biofeedback and autonomic self-regulation. Then, using the discern-control-generalize model, they (1) practiced increasing vagal tone with the DyFSS, (2) practiced without observing the feedback, and (3) practiced these skills between sessions and in anticipation of stressors. Practice without feedback during training sessions started at five minutes duration and increased, optionally, to ten minutes during the five-week course. Parents used a Daily Observation Scale for Autism (DOSA), to measure five categories of ASD core-symptom-related behaviors (tantrums, repetitive behaviors, rigidity, language and social engagement). Results showed a trend toward improved behaviors overall (Fig. 1) and in DOSA sub-scales (Fig. 2).

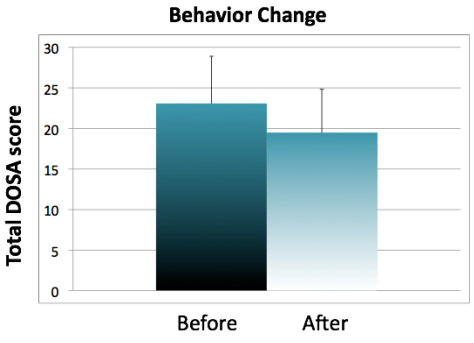

Fig. 1. Results of intial DyFSS feasibility trial comparing change in DOSA score from first to fifth ART session. Lower DOSA scores indicate better behavior. A one-tailed, paired t-test indicates a trend toward lower DOSA scores, $t(7) = -1.7$, $p < .10$.

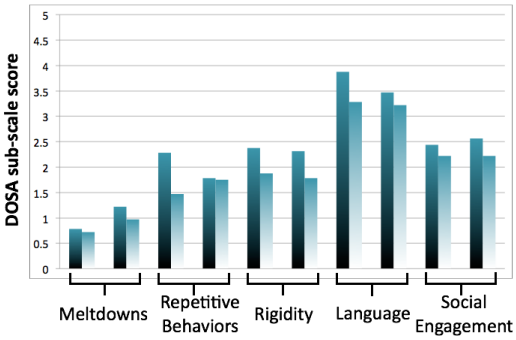

Fig. 2. Results of intial DyFSS feasibility trial comparing change in DOSA subscale scores from first to fifth ART session. Lower DOSA scores indicate better behavior.

A second trial alternately assigned a community-diagnosed sample of ASD-affected youth (ages 8-15, n = 20) to equally sized groups using the DyFSS or a non-customizing display of the four signals as individual bar graphs over a similar five-week protocol of ART to that used in the first study. Both groups improved in core-symptom-related behaviors (Fig. 3), though the sample size was too small to appreciate any difference between the two conditions. Notably there was a strong correlation ($r = 0.56$) between DOSA decrease (improved behaviors) and physiological control (ability to increase vagal tone) as shown in Fig. 4.

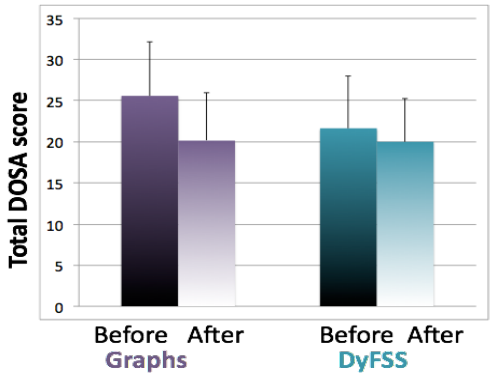

Fig. 3. DyFSS *vs.* Graphs Comparison

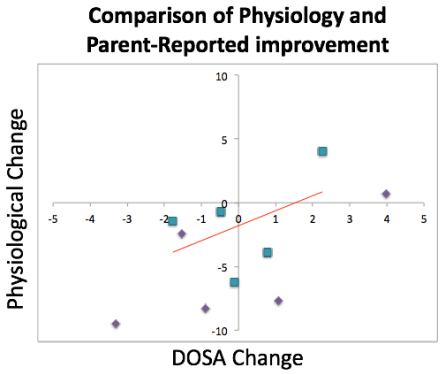

Fig. 4. DOSA change with physiological change, $r = 0.56$.

Though the small sample size of these pilot studies precludes conclusions regarding the effectiveness of this ART protocol, the measured improvement is promising. The young people with ASD in our trials readily engaged with the computerized intervention, and additional reporting from participants indicates that they used what they learned during the sessions at home and school We are designing a comparative effectiveness trial of DyFSS-based ART measured against cognitive and behavioral relaxation training with more rigorous sample characterization and a combination of standardized behavioral and biological outcome measures.

V. Future Directions for DyFSS

We are currently engaged in creating a palette of graphical interfaces for the DyFSS so that users can choose from several intuitive and engaging format options. An animated interactive tutorial is also being developed, both to decrease reliance on the clinician during sessions and facilitate autonomy in the user. These refinements aim at increasing the utility of the DyFSS and so will be critiqued by a focus group of young people with ASD who have participated in previous trials.

The DyFSS was also developed with applications for interactive games and media in mind. Because it adapts to the user's abilities without adjustments by a clinician it can function readily as a controller in video games with mechanics that link increasing autonomic regulation to success. If a game environment is constructed to present virtual challenges from the player's life, then integrating the DyFSS as a controller creates an engaging opportunity to enhance learning and conditioning of autonomic control in the face of adversity.

We developed the DyFSS to refine and tune our ART intervention, and to address the difficulties involved with making ART accessible and testable for this population of youth with ASD. However, autonomic regulation is elemental to many other conditions including chronic and recurrent pain, anxiety, depressive disorders, post-traumatic stress disorder, irritable bowel syndrome, and a number of inflammatory and immune conditions. So, by developing this relatively autonomous media and computer-based intervention, we can improve access to ART for an increasing range of health challenges and populations. Ultimately, the DyFSS increases access to the user's own psychophysiological resources for autonomic self- regulation.

Acknowledgment

The authors gratefully acknowledge all of the RIT students who joined us in developing the DyFSS and its applications, our supportive colleagues and faculty, the Office of the Vice-President of Research at RIT and, most importantly, the young people who participated in our initial trials and their parents who got them there.

References

[1] Bernard, C. (1974). *Lectures on the phenomena common to animals and plants.* Translated by Hoff, H.E. Guillemin, L., Guilleman, R. Sprngfield, IL: Charles C. Thomas.

[2] Cannon, W.B. (1915). *Bodily Changes in Pain, Hunger, Fear and Rage: An Account of Recent Researches into the Function of Emotional Excitement*. New York, NY:Appleton

[3] Selye, H.H.B. (1956). *The stress of life*. New York: McGraw-Hill, 1956

[4] Porges, S.W. (2011) *The Polyvagal Theory: Neurophysiological foundations of emotions, attachment, communication, and self-regulation*. New York, NY: W.W. Norton & Company, Inc.

[5] Association for Applied Psychophysiology and Biofeedback. (2011). *Efficacy Information: List of Disorders and Performance Related Issues.* From: http://www.aapb.org/i4a/pages/index .cfm?pageID=3404.

[6] Association for Applied Psychophysiology and Biofeedback (2008). What is biofeedback? www.aapb.org/i4a/pages/index.cfm?pageid=3285

[7] Culbert, T.P. & Banez, G.A. (2003). Pedaitric applications other than headache. In Schwartz, M.S. & Andrasik, F. *Biofeedback: A Practitioner's guide*. New York, NY: Guilford, p. 700.

[8] American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.; *DSM-5*). Washington, DC: Author.

[9] Mazurek, M.O., Vasa, R.A., Kalb, L.G., et al. (2012) Anxiety, Sensory Over- Responsivity, and Gastrointestinal Problems in Children with Autism Spectrum Disorders. Journal of Abnormal Child Psychology, Aug 1: 1-12.

[10] Adams, J.B., Johansen, L.J., Powell, L.D., et al. (2011) Gastrointestinal flora and gastrointestinal status in children with autism--comparisons to typical children and correlation with autism severity. BMC gastroenterology, 11: (1): 22.

[11] Chandler, S., Carcani-Rathwell, I., Charman, T., et al. (2013) Parent-Reported Gastro-intestinal Symptoms in Children with Autism Spectrum Disorders. Journal of Autism and Developmental Disorders.

[12] Hoshino, Y.,Watanabe, H., Yashima, Y., Kaneko, M., & Kumashiro, H. (1984). An investigation on sleep disturbance of autistic children. *Folia Psychiatrica et Neurologica Japonica*, *38*, 45–51.

[13] Centers for Disease Control (2014). Retrived from www.cdc.gov/ncbddd/autism/facts.html

[14] Sugarman, L.I., Garrison, B.L., Williford, K.L. (2013). Symptoms as solutions: Hypnosis and biofeedback for autonomic regulation in autism spectrum disorders. *American Journal of Clinical Hypnosis*, 56: 152–173.

[15] Kinsbourne, M. (2011). Repetitive movements and arousal. In DA Fein (ed.), *Neuropsychology of autism*, 367-394. New York, NY: Oxford University Press.

[16] Hileman, C. (1996). *Computer technology with autistic children*. In: Autism Society of America National Conference, Milwaukee, WI.

[17] Mind Media BV, Louis Eijssenweg 2B, 6049CD Herten, The Netherlands. www.mindmedia.info.

[18] Sugarman, L.I., Garrison, B.L., Hope, A.E., Jacobs, S., Glade, A., Wezalis, M.R., & Williford, K.L. (2014). Self-adjusting biofeedback with a dynamic feedback signal set (dyfss). Technology demonstration and poster presented at the International Meeting for Autism Research. Atlanta, GA.