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Generalization of skills between operant control and discrimination of EEG alpha

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ABSTRACT

While biofeedback is often said to increase self-control of physiological states by increasing awareness of their subjective correlates, relatively few studies have analyzed the relationship between control (standard biofeedback) and awareness (a discrimination paradigm). We hypothesized that the two skills would generalize and facilitate each other for 8–12 Hz EEG amplitude (alpha). Participants were given 7 sessions of training to either control or discriminate Pz alpha followed by 3 sessions of the other paradigm. Another group was given 7 sessions with time divided equally between the two types of training. The control-training first group showed significant generalization of skills to the discrimination task. However, the reverse was not true, and the combined task group did no better in either task than the other two groups. These results provide ambivalent support for the role of awareness in biofeedback, and suggest possible improvements in the discrimination paradigm.

1. Introduction

When information about a physiological response is represented externally to the person producing it, through a technique called biofeedback, it often becomes possible for the person to modify the response. Over time, people can learn to voluntarily control the response without the external display. It has long been understood that the mechanism of learning in biofeedback involves operant conditioning, where the external stimulus serves the role of a reinforcer (Black, Cott, & Pavloski, 1977; Strehl, 2014). It is also commonly argued that biofeedback increases awareness of the subjective correlates of the internal response, which then allows for their voluntary control (Brener, 1974; Congedo & Joffe, 2007; Frederick, 2016; Olson, 1987; Plotkin, 1981).

Brener (1974) argued that repeated pairing of external feedback with the physiological response resulted in awareness and learning of a "response image," a representation of the interoceptive sensory consequences or reafference produced by the response. Voluntary control of the response then depends upon our learning to compare our present sensory state to the stored response image of the desired state.

The importance of this comparison process for motor skill learning is seen in cases when afferent stimulation is lost. In patients with tabes dorsalis, there is loss of proprioceptive and kinesthetic innervation from the lower limbs (Bilodeau, 1969). These individuals are able to substitute exteroceptive (usually visual) feedback to maintain balance, but they cannot

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learn to maintain balance without it. By contrast, Brener argued, people who are born deaf can learn to speak through visual and tactile feedback because they have intact kinesthetic and proprioceptive reafference from the vocal apparatus. Biofeedback, then, is a like a form of sensory substitution that uses exteroceptive feedback to calibrate the relationship between internal afferents and effector processes.

One operational definition of awareness of a response is the ability to use the response as a discriminative stimulus for another response. For example, high versus low EEG alpha (8–12 Hz) amplitude can be used as a discriminative stimulus for a button-pressing response (Frederick, 2012; Kamiya, 1968, 2011). Human subjects can also discriminate differences in finger temperature (Lombardo & Violani, 1994), galvanic skin response (Dickoff, 1976; Stern, 1972), blood glucose levels (Cox, Carter, Gonder-Frederick, Clarke, & Pohl, 1988), gastric motility (Griggs & Stunkard, 1964), heart rate (Brener & Jones, 1974; Grigg & Ashton, 1986; Violani, Lombardo, De Gennaro, & Devoto, 1996), blood pressure (Greenstadt, Shapiro, & Whitehead, 1986), pulse transit time (Martin, Epstein, & Cinciripini, 1980), cephalic vasomotor activity (Fudge & Adams, 1985); stage 1 and stage 2 sleep (Antrobus & Antrobus, 1967), the sensorimotor rhythm (Cinciripini, 1984), P300 amplitude (Sommer & Matt, 1990), and slow cortical potentials (Kotchoubey, Kubler, Strehl, Flor, & Birbaumer, 2002).

Black et al. (1977) disputed the importance of awareness of reafference for learning to control a physiological response. While deafferentation substantially impairs motor performance (Mott & Sherrington, 1895; Taub, Bacon, & Berman, 1965), operant conditioning of voluntary actions is still possible in the absence of sensory feedback (Taub & Berman, 1963). There are also abundant examples where learning occurs without awareness. In sequential learning experiments, participants learn to respond with faster reaction time when stimuli are presented in an orderly sequence of locations, even when they cannot verbally report the knowledge that they are using (Lewicki, Hill, & Czyzewska, 1992; Nissen & Bullemer, 1987). In another study, subjects were asked to control the simulated production of sugar in a game by controlling variables such as financial incentives and the size of the workforce. Performance improved over the course of days, but subjects' explicit knowledge and confidence in their judgments was unrelated to their performance (Berry & Broadbent, 1984). Other examples include mild emotional and priming effects that can be produced by subliminal stimuli (Gibbons, 2009), or the ability of patients to complete paired associates learned during anesthesia (Kihlstrom, Schacter, Cork, Hurt, & Behr, 1990). All conscious processes are constructed from unconscious ones (Eagleman, 2011), so it is likely that the mechanism of learning of physiological self-regulation involves implicit processing at many levels.

Lacroix (1981) argued that while successful discrimination of a physiological response could indicate awareness of the sensory consequences of the response, it could also result from subjects actively manipulating the response and reporting their volitional or *efferent* state. Indeed, participants reported manipulating their state while discriminating electrodermal activity (Lacroix, 1977) and heart rate (Brener, Ross, Baker, & Clemens, 1979). However, the relationship between a behavior and the experience of consciously controlling that behavior is not simple and straightforward (Castiello, Paulignan, & Jeannerod, 1991; Libet, 1985; Milner & Goodale, 1995), and verbal reports on mental processes are often confabulations based on assumptions about what seems plausible (Nisbett & Wilson, 1977). The interpretation that participants are merely reporting their volitional state also begs the question of how they discriminate this volitional state (given that overt skeletal motor manipulations are not allowed). The effort or intention to control a physiological response may involve diverse subjective and neurophysiological causes, correlates, or consequences, all of which may serve as discriminative stimuli. For EEG responses, the distinction between afferent and efferent loses meaning because the brain has intrinsic activity even in the absence of input or output (Musso, Brinkmeyer, Mobascher, Warbrick, & Winterer, 2010).

While it is of considerable interest how a subject becomes aware of their volitional state, awareness may still play the same role in comparing the immediate state to a response image of the desired state—regardless of whether the response image is efferent or afferent. While Black et al. (1977) disputed that awareness was necessary for physiological self-control, they acknowledged that awareness of the response can *facilitate* learning of the response. The facilitation of learning by increasing awareness has been demonstrated in studies where subjects are asked to make judgments about their performance. For instance, when asked to make a judgment about a sequential finger movement performance after each trial, participants showed more effective learning of the movement (Boutin, Blandin, Massen, Heuer, & Badets, 2014). Self-monitoring has been shown to improve learning of dart throwing skills (Kolovelonis, Goudas, & Dermitzaki, 2011; Zimmerman & Kitsantas, 1996), to improve academic learning (Bercher, 2012; Chang, 2013; Lan, 1996), and to reduce off-task behavior (Coughlin, McCoy, Kenzer, Mathur, & Zucker, 2012). Careful attention to the success of one's performance is especially important during the early stages of learning a skill, when trial and error is used identify the correct behavior (Fitts & Posner, 1967). By contrast, after a skill is well-learned and highly practiced, conscious awareness of the details can disrupt performance (Beilock & Carr, 2001).

While subliminal stimuli can produce above-chance effects on behavior and limited activity in the brain, conscious awareness dramatically increases the influence of a stimulus. Conscious processing results in more distributed activity and connectivity in the brain, providing access to more flexible serial processing of novel tasks (Dehaene, Charles, King, & Marti, 2014). Consciously processed stimuli have the advantage that they are maintained in working memory so that executive processes—problem-solving, decision-making, and action planning—can operate on them, allowing the solution of conflicts among competing motor plans (Boutin et al., 2014; Morsella, 2005; Ramachandran & Hirstein, 1997). While "blindsight" patients with occipital lobe damage can correctly rotate an envelope to insert it through a slot of any arbitrary angle, despite having no visual awareness of the scene, this skilled sensorimotor performance has no short-term memory. If the lights are turned out just before inserting the envelope, the performance goes to chance levels (Milner & Goodale, 1995; Rossetti, 1998).