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NEAR-INFRARED SPECTROMETRY FOR THE MEASUREMENT OF CENTRAL NERVOUS SYSTEM ACTIVATION: A BRIEF DEMONSTRATION OF AN EMERGING BEHAVIORAL ASSESSMENT TOOL

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Behavior analysts are familiar with the use of electrodermal activity as a dependent measure of central nervous system activation. In addition, behavior analysts have increasingly turned to direct measures of brain activation, such as electroencephalography and event-related potentials. Recent developments in the field of bioengineering, however, have produced a new and exciting brain-activation recording device known as near infrared spectrometry, or NIRS. The current paper reports a demonstration of its use in a traditional respondent conditioning paradigm. Specifically, a male volunteer was exposed to a conditioning paradigm designed to produce both an eliciting stimulus for fear and a relief stimulus. Conditioning effects were assessed using electrodermal activation as well as blood volume changes in the frontal lobe, recorded by NIRS. The results of the demonstration show that both electrodermal and NIRS measures can successfully identify conditioning effects without necessarily tracking each other on a trial-by-trial basis. It is suggested that NIRS is an inexpensive, non-invasive technique for the assessment of learning and behavior at the neural level.

Key words: central nervous system, NIRS, electrodermal activation, learning and behavior assessment

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Electrodermal activity (EDA; otherwise known as the Galvanic Skin Response) represents perhaps the most reliable index of general autonomic arousal (Dawson, Schell, & Fillon, 1990). The system was discovered by Féré (1888), who found that by passing a small current across two electrodes, through the body of a human subject, he could measure fluctuations in skin resistance in response to a variety of external stimuli. Thus, the EDA method was essentially a measure of potential electrical difference across any two points in the human body, measured in millivolts. The EDA method proved so reliable as a measure of sympathetic nervous system activity that such figures as C. G. Jung (1906) used it in assessing the emotional content of verbal stimuli for his patients. It has now been well established experimentally that EDA is an excellent index of physiological responses to discrete and tonic stimuli and a good correlate of most other psycho-physiological measures (see Cacioppo & Tassinory, 2000).

It is often thought that EDA is caused by the increased sweating that occurs during periods of autonomic activity. The truth is a little more complicated. Specifically, it has been known for almost a century that the EDA response occurs about 1 second before the appearance of sweat at the electrode placement site on the epidermis (Darrow, 1927). Early research also established that increased blood flow and blood pressure are not direct causes of EDA insofar as electrodermal responses can be shown to diverge from both of these measures under certain conditions (Darrow, 1927). Further complication is added by the fact that different types of sweat glands function in different ways to affect the EDA response. Specifically, eccrine glands respond largely to thermoregulatory stimuli, with the exception of those eccrine glands on the palm of the hands (Fowles, 1986). Appocrine glands, which are dense in the genital areas and armpits and less dense on the palms of the hands, are less well understood but are thought to respond largely to emotional stimuli. The stimuli that trigger apocrine sweating are still debated but are usually of emotional/psychological significance and do not usually occasion thermoregulatory activity (Shields, MacDowell, Fairchild, & Campbell, 1987).

While palmar sweating certainly contributes to the EDA response, it is now widely accepted that the sympathetic nervous system primarily controls EDA (rather than sweating itself). This view is supported by the strong correlation between sympathetic action potentials and skin conductance responses (SCRs) at normal room temperatures (Wallin, 1981). Thus, electrodermal activity is a complex function of the activity of the central and peripheral nervous systems and sweat gland activity.

Despite the reliability and ease of use of the EDA system, behavior analysts interested in increasingly complex forms of human behavior, such as derived relational responding, have turned to more direct measures of nervous system activity. For example, Dickins, Singh, Roberts, Burns, Downes, Jimmieson, and Bentall (2001) employed functional magnetic resonance imaging (fMRI) to analyze brain activity during a stimulus equivalence

task. These researchers found that response accuracy on equivalence tests was correlated with left lateralization of the dorsolateral prefrontal cortex, an area of the brain associated with language. In addition, activity in the Broca's area, an area understood to be involved in naming (Pinel, 2000), was correlated only with verbal fluency and not with the derivation of stimulus relations.

fMRI offers the advantage of high spatial resolution but lacks the temporal resolution necessary to observe brain behavior on a moment-to-moment basis (Davidson, Jackson, & Larson, 2000). For this reason, several behavior analysts have turned to the use of Electroencephalography (EEG) in the analysis of the correlates of derived relational responding. EEG represents a direct and non-invasive measurement of electrical brain activation and has been correlated with both verbal (e.g., Elger, Grunwald, Lehnertz, Kutas, Helmstaedter, Brockhaus, Van Roost, & Heinze, 1997) and nonverbal (e.g., Fisch, 1999) indicators of body state.

DiFiore, Dube, Oross, Wilkinson, Deutsch, and McIlvane (2000) used measures of Event Related Potentials (ERPs; a modern development of EEG technology) to analyze brain wave functions during a stimulus equivalence task (see also Deutsch, Oross, S. III, DiFiore, & McIlvane, 2000). These researchers reported ERPs measures can be used to distinguish responses to equivalently related and unrelated pairs of stimuli presented simultaneously. In a more recent study, Roche, Linehan, Ward, Dymond, & Rehfeldt (2004) tracked trial-by-trial changes in EEG waveforms from the acquisition of contextually controlled conditional discriminations, to the derivation of the relational frames of Same and Opposite. These researchers found increase in alpha band activity (indicating a reduction in mental effort) during the acquisition phase and across the test for derived relational responding. These increases continued across the acquisition of a novel set of baseline training trials and the derivation of further Same and Opposite relations. The decreases in mental effort tracked attendant decreases in reaction time on each trial.

While EEG technology is certainly of some utility in the experimental analysis of behavior, the method is relatively time-consuming and technically challenging. Aside from mastering the EEG technology itself, the user must ensure that the experimental laboratory is free from all electrical interference and must often engage in complex forms of data analyses involving mathematical filtering techniques usually not familiar to the psychologist. Recent development in Near Infra-Red (NIR) technology, however, have made possible the measurement of location-specific brain activation with great ease and little expense.

DEVELOPING A NEW BEHAVIORAL MEASURE OF BRAIN ACTIVATION

Near infra-red spectrometry (NIRS) is an optical method that allows for the non-invasive measurement of changes in tissue oxygenation (Jobsis, 1977; Strangman, Boas, & Sutton, 2002; see also Coyle, Ward, Markham, & McDarby,, 2004). When applied to the brain such systems allow cerebral haemodynamic changes to be recorded. The principle of NIRS is based on the fact that light at a wavelength of between 650-900nm can penetrate the intact cranium to a depth of approximately 2cm, to reach the surface of the cerebral cortex. The cortical surface both scatters and absorbs the NIR beam, but a sufficient portion is backscattered for measurement at the super-cranial level. Changes in the volume of blood present at the NIR beam site will determine the amount of light reflect through the cranium. Thus, the optical response measured can be used to calculate changes in blood volume and other haemodynamic parameters. Moreover, the use of multiple wavelengths of illumination allows explicit separation of these parameters. In effect, a single wavelength/single site NIR system is essentially a brain photoplethysmograph, while a multiple wavelength system at a single site can be thought of as a cerebral pulse oximeter (Moyle, 1994). The extension of these techniques to multiple sites over the brain from which images of haemodynamic activity can be constructed is referred to as diffuse optical tomography and is part of the rapidly expanding filed of clinical biophotonics. Thus, the cerebral haemodynamic response detected using NIR techniques has potential use as a psycho-physiological measure and has the additional benefit of allowing for the extraction of multiple dependant measures of nervous system activity such as breathing, heart rate, cognitive and motor function.

NIRS has not been used by psychologists as a research tool. In our research we have begun to explore its potential as a psychophysiological recording method. As a demonstration of its utility in assessing temporally discrete changes in brain activation and as a measure of general autonomic arousal, we exposed one subject to a respondent conditioning paradigm during which both EDA and NIRS measures were taken for comparison.

METHOD

Subject

An adult male volunteer was employed as a subject. He was briefed on the general nature of the study but not informed of the functions of the conditioned stimuli and

was ignorant of respondent conditioning processes.

Apparatus

Silver silver chloride (NaNaCl) metal electrodes (5cm2) were attached to the distal phalanges of the index and middle finger of the non-dominant hand using Velcro® straps. EDA was recorded using Biobench® (Layfayette® Instruments) software running on a Pentium® III Dell® PC at 200 samples per second. The EDA readings were acquired by a Datalab® polygraph system interfaced to the PC with a National Instruments® acquisition card. The Biobench® software recorded skin resistance as the index of EDA.

The NIRS technology was constructed by the researchers for the purpose of this demonstration. The system consisted of a single channel, continuous wave near infra-red beam. To create this beam, a near infrared LED (880nm, output power 5mW) modulated at 5kHz for lock-in detection, was connected directly to the subject's forehead using a nylon headband. The detector, an avalanche photodiode, made contact with the subject's head via a fibre optic bundle, placed 4cm away from the source position. Lock-in detection was used and the signal was sampled at a rate of 100Hz using a 16-bit A/D data acquisition card.

All conditioned and unconditioned stimuli were presented to the subject via a Macintosh Power PC computer using the PsyScope (Cohen, MacWhinney, Flatt, & Provost, 1993) experiment generation software. PsyScope also controlled the presentation of event markers on the EDA and NIR recordings simultaneously with the presentation of CS+ and CS- stimuli.

Procedure

The subject was seated comfortably in an 'easy-chair' 20 cm from a 14' colour computer monitor and fitted with headphones that were connected to the Macintosh computer. EDA and NIRS devices were attached to the subject as described. The respondent conditioning phase consisted of 10 presentations to each of a CS+ and CS- in a quasi-random order with random inter-trial intervals of 10-40 seconds. . The CS+ and CS- stimuli were the nonsense syllables "CUG" and "JOM", respectively. On any one conditioning trial the CS+ or CS- was presented in the centre of the computer monitor in size 36 Times font for 5 s. On 75% of the CS+ trials, the screen cleared for 2s before the onset of the unconditioned stimulus, which was a loud burst of white noise (80db) of 5s duration delivered to the subject via the headphones. The screen remained black during the presentation of the US. The remaining 25% of CS+ trials were followed only by the usual intertrial interval. All presentations of the CS- were followed only by the intertribal interval.

EDA and NIRS responses were recorded from the onset of the CS+ and CS- for five seconds. Thus, responses to the conditioned stimuli were not contaminated by responses to the noise burst. In effect, a conditioned response to the CS+ could be examined from the onset of conditioning as each conditioning trial also served as a probe trial.

RESULTS

A phasic EDA response was defined as the maximum decrease in skin resistance (i.e., inversely related to autonomic arousal) from the level of skin resistance at the time of stimulus presentation for the subsequent 5s (i.e., up to the point of presentation of the unconditioned stimulus; see Roche & Barnes, 1997). For the purpose of analysis, and to reduce the spread, skew and kurtosis in the data, all EDA recordings were transformed according to a log10 (EDA+1) function, as is common in psycho-physiological studies.

The NIR signal, being photoplethysmographic in nature, is characterized by light intensity changes due to fluctuations in blood pressure and cerebral blood flow. This signal consists of a number of components on different time scales including a pulsatile signal due to the cardiac cycle and a number of slowly varying components at timescales ranging from 5 to 60s. The origins of some of these components such as the Meyer wave are not fully understood while others, such as blood pressure fluctuations, local vascular dynamics, and breathing-modulated heart rate changes have been more thoroughly investigated by other researchers (Elwell, Springett, Hillman, & Delpy, 1999; Obrig, Neufang, Wenzel, Kohl, Steinbrink, Einhaupl, & Villringer, 2000). Two of these components were chosen based on visual inspection of the data for analysis in this experiment: Short fluctuations at frequencies below 0.75Hz. and a heart-rate variability (HRV) signal as calculated from the cardiac component. Given that the current study was a demonstrative comparison of two physiological recordings, NIR responses were also defined as the maximum decrease in the signal from the level at the time of stimulus presentation for the subsequent 5s. This was used for both signals examined.

In order to extract the HRV signal from the NIR data, the optical signal was linearly de-trended and low-pass filtered at a cut-off frequency of 0.75Hz to observe the underlying slow vascular response. In order to isolate the heart-rate variability (HRV) signal, the de-trended optical signal was also band-pass filtered between 0.75Hz

Table 1.

Response after transformation to log10 (Response+1), where Response denotes the response in raw units as recorded on the NIRS or EDA system. Each number represents successive phasic response to CS+ and CS- across the conditioning phase, from top to bottom.

EDA		NIR		Heart Rate	
CS+	CS-	CS+	CS-	CS+	CS-
3.385	3.385	.153	.199	1.197	0.7
3.051	2.471	.224	.124	1.248	.512
3.303	2.25	.122	.065	1.021	.505
3.027	2.076	0	.061	1.198	0
3.29	2.676	.086	0	1.08	.796
2.618	2.076	.231	0	.875	.849
3.114	2.25	.064	.005	1.149	.669
2.076	0	0	0	.961	.539
3.003	1.778	.113	.002	1.106	0
3.073	2.076	.119	0	0	.598

and 1.5Hz to accentuate heart rate, and the time interval between each pulse was determined using a simple threshold. A phasic HRV response was defined as the maximum increase in heart rate from the point of stimulus presentation for the subsequent 5s. For the sake of consistency, NIR and HRV data were transformed according to a log10 (X+1) function. The transformed data can be seen in Table 1.

Table 1 shows that response differentials to the CS+ and CS- were observed across conditioning trials/probes for all three measures. A paired (one-tailed) t-test revealed that the CS+/CS- response differential recorded by EDA was significant at p=0.0003 (t=5.193). The same test showed that the response differential recorded by NIR was significant at p=0.0198 (t=2.403). Finally, the response differential recorded by HRV was significant at p=0.0093 (t=2.868). In effect, the NIR and HRV measures were successful in identifying the CS+/CS- differential that is usually assessed physiologically by behavior analysts using EDA as a dependent measure.

Figure 1 shows that the NIR and HRV measures did not appear to track the EDA recordings on a trial-by-trial basis. More specifically, increases or decreases in EDA responses from trial-to-trial did not accompany proportionate increases or decreases in NIR and HRV. A correlation analysis of all EDA responses (i.e., to both the CS+ and CS-) revealed an EDA-NIR covariance of 0.007 and a correlation value of 0.243 (R-squared = 0.059). Similarly, EDA-HRV covariance was calculated at 0.017, with a correlation value of 0.119 (R-squared = 0.014). In effect, the phasic NIR and HRV measures appear to be relatively independent of EDA on individual trials and yet follow the same general pattern in distinguishing between responses to the CS+ and CS-.

DISCUSSION

The current findings suggest that NIR and derivative HRV measures are sensitive to psychological conditioning effects as measured in a common psycho-physiological research paradigm. In particular, it would appear that the NIR system may be useful in research preparations that attempt to assess the psychological significance of ranges of discrete stimuli presented in rapid succession.

The fact that HRV and NIR measures did not co-vary

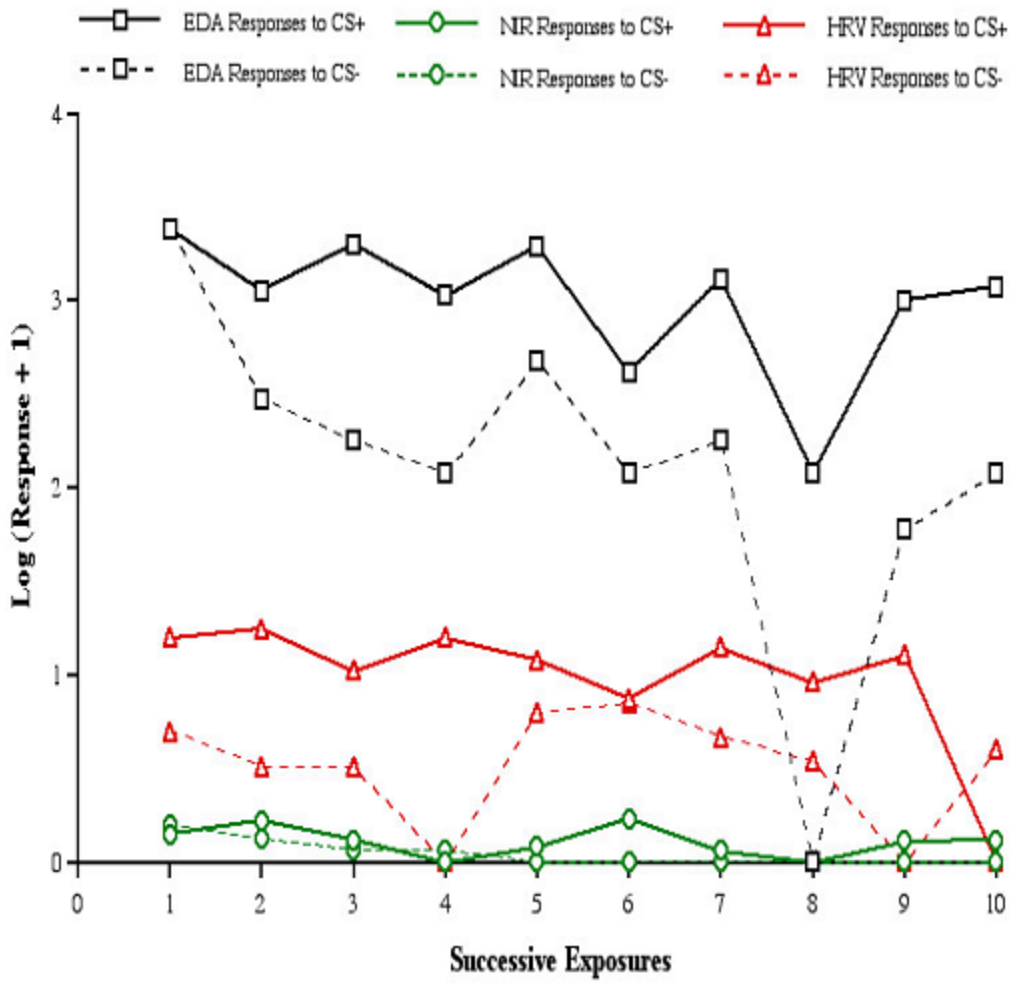

Figure 1: EDA, NIR and HRV responses on successive exposures to the CS+ and CS-. Successive responses to either stimulus have been extracted and grouped for representation as a single line graph. The actual order of trial types was quasi-random.

with EDA measures raises several sophisticated conceptual and methodological issues. Firstly, the lack of co-variance does not necessarily indicate that NIR and HRV measures are invalid. Several psycho-physiological measures fail to co-vary and others bear inverse relations with each other under specific conditions (e.g., heart rate and respiration). Rather than attempt to correlate measures, psycho-physiologists have simply assumed fundamental differences in the relevant processes and have employed different measures for different research purposes. Thus, NIR and HRV may be useful for the assessment of conditioning effects, while at the same time failing to co-vary with other common measures. Only further research will determine the contexts in which NIR will be of most use to psychologists.

Such questions notwithstanding, the NIR and HRV certainly appear to be useful in assessing one of the most central features of human learning; the ability to show differential autonomic responding to arbitrary stimuli based on their history of association with other psychologically significant stimuli. This single feature suggests the utility of NIR measures over any degree of co-variance with common polygraph measures.

Secondly, the lack of co-variance between NIR, HRV and EDA recordings may reflect differences in physiological processes underlying these measures. Indeed, it is important to consider that the definitions of EDA, NIR and HRV responding employed in the current study may have exacerbated natural deviances between them. More specifically, it took the best part of a century for psycho-physiologists to agree on such matters as the “rise-time” of an electrodermal response, and the natural cycle of phasic skin conductance or resistance changes in response to psychological stimuli. It is likely that NIR measures must also undergo a period of research and scrutiny in which definitions of responding are arrived at through a range of methodological and conceptual considerations. In the current study, differing definitions of NIR based on 10s rather than 5s cycles, for instance, may have identified tighter correlations between NIR and EDA mea-

sures. Indeed, functional activation studies have begun to report a modulation effect of the length of the resting period between the presentation of stimuli (Elwell, Springett, Hillman, & Delpy, 1999). The optimum rest period for consistent NIR data appears to vary for each preparation tested, and the phenomenon has yet to be explained.

Thirdly, spontaneous low frequency oscillations in the NIR signal can distort the phasic response as we defined it. Indeed, it has been found that the effects of this oscillation must be taken into consideration (Obrig, Hirth, Junge-Hulsing, Doge, Wenzel, Wolf, Dirnagl, & Villringer, 1997). In our future research, we will employ an adaptive filter, based on the NIR signal acquired during a basleine "resting" phase or at a remote body site. This filter will aloow us to remove the effects of this physiological "noise". It should also be noted that further studies will help to clarify the relationship between NIR and the EDA and to this end the authors are currently devising models to account for the relationships that have been observed.

EDA is thought to provide a simple index of the level of sympathetic activity at any given time in response to psychologically significant stimuli. The results of this demonstration show that the cerebral haemodynamic response found using NIR techniques could also be used as a psycho-physiological measure for the same general purposes. Further applications of the method may include biofeedback and relaxation training. NIR technology also has the benefit of being non-invasive, portable, and not requiring the use of electrode gels, and allowing for the extraction of multiple dependant measures of nervous system activity (such as oxygenation, breathing rate, blood pressure) of interest to neuroscientists, physiologists and psychologists. Perhaps, most importantly, NIRS allows for the direct measurement of general brain activation levels in specific regions and does so with an acceptable level of temporal resolution for most experimental purposes. Moreover, it is not a complicated matter to take NIRS measures at multiple brain sites simultaneously, thereby providing similar representations of overall brain activation as those provided by EEG recordings. While much work remains to be done in perfecting the NIRS technique, we are committed to ensuring an input from the experimental analysis of behavior to its ongoing development.

REFERENCES

Bryan, J. M. J. (1990). Cerebral blood flow and energy metabolism during stress. *American Journal of Physiology, 259*, 269-280.

Cacioppo, J. & Tassinory, L.G. (2000). *Principles of psychophysiology. Physical, social, and inferential elements*. New York: Cambridge University Press.

Cohen, J.D., MacWhinney, B., Flatt, M., & Provost, J. (1993). Psyscope: A new graphic interactive environment for designing psychology experiments. Behavioral Research Methods, Instruments and Computers, 25, 257-271.

Coyle, S., Ward, T., Markham, C., & McDarby, G. (2004). On the suitability of near-infrared (NIR) systems for next-generation brain-computer interfaces. *Physiological Measurement, 25*, 815-822.

Davidson, R.J., Jackson, D.C., & Larson, C.L. (2000). Human electroencephalography. In J.T. Cacioppo, L.G. Tassinary, G.G. Berntson (Eds.), *Handbook of Psychophysiology* (2nd Ed.). Cambridge University Press: New York.

Dawson, M.E., Schell, A.M., & Filion, D. L. (1990). The electrodermal system. In J. Cacioppo & L. Tassinory (Eds.), *Principles of psychophysiology. Physical, social, and inferential elements* (pp. 295-324). New York, Cambridge University Press.

DiFiore, A., Dube, W. V., Oross, S. III, Wilkinson, K., Deutsch, C. K., & McIlvane, W. J. (2000). Studies of brain activity correlates of behaviour in individuals with and without developmental disabilities. *Experimental Analysis of Human Behaviour Bulletin, 18*, 33-35.

Elger, C.E., Grunwald, T., Lehnertz, K, Kutas, M., Helmstaedter, C., Brockhaus, A., Van Roost, D., & Heinze, H.J. (1997). Human temporal lobe potentials in verbal learning and memory processes. *Neuropsychologia, 35*, 657-667.

Elwell, C.E., Springett, R., Hillman, E., & Delpy, D.T. (1999). Oscilllations in cerebral haemodynamics. In A. Eke & D. T. Delpy (Eds.), *Oxygen transport to tissue xxi (*pp. pp. 57-65). New York: Kluwer Academic/Plenum Publishers.

Fisch, B.J. (1999). *Fisch and Spehlmanns EEG primer: Basic principles of digital and analog EEG* (3rd ed.). Amsterdam: Elservier Science.

Fowles, D. G. (1986). The eccrine system and electrodermal activity. In M. G. H. Coles, B. Donchin & S. W. Porges (Eds.), *Psychophysiology: Systems, processes, and applications* (pp. 51-96). New York: Guilford Press.

Jimmieson, P.& Bentall, R.P. (2001). An fMRI study of stimulus equivalence. *NeuroReport, 1,* 2-7.

Jobsis, F.F. (1977). Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. *Science, 198*, 1264-1267.

Moyle, J.T.B. (1994). *Pulse oximetry*. London: BMJ Publishing.

Obrig, H., Hirth C., Junge-Hulsing, J. G., Doge, C., Wenzel, R., Wolf, T., Dirnagl, U., & Villringer, A. (1997). Length of resting period between stimulation cycles modulates hemodynamic response to a motor stimulus. *Advances in Experimental Medical Biology, 411*, 471-80.

Obrig, H., Neufang, M., Wenzel, R., Kohl, M., Steinbrink, J., Einhaupl, K., &

Villringer, A. (2000). Spontaneous low frequency oscillations of cerebral hemodynamics and metabolism in human adults. *Neuroimage, 12*, 623-639.

Pinel, J.P.J. (2000). Biopsychology. Allyn & Bacon: Boston.

Roche, B. & Barnes, D. (1997). A transformation of respondently conditioned stimulus function in accordance with arbitrarily applicable relations. *Journal of the Experimental Analysis of Behavior, 67*, 275-301.

Roche, B., Linhehan, C., Ward, T., Dymond, S., & Rehfeldt, R. (2004). The unfolding of the relational operant: A real-time analysis using electroencephalography and reaction time measures. *International Journal of Psychology and Psychological Therapy, 4*, 587-603.

Shields, S. A., MacDowell, K. A., Fairchild, S. B, & Campbell, M. L. (1987). Is mediation of sweating cholernergic, adrenergic, or both?

A comment on the literature. *Psychophysiology, 24*, 312-319.

Strangman, G., Boas, D. A., Sutton, J. P. (2002). Non-invasive neuroimaging using near-infrared light. *Biological Psychiatry, 52*, 679-693.

Wallin, B. G. (1981). Sympathetic nerve activity underlying electrodermal and cardiovascular reactions in man. Psychophysiology,30, 279-286.

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