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Redundancy analysis of autonomic and self-reported, responses to induced emotions☆

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ABSTRACT

The issue of concordance among the elements of emotional states has been prominent in the literature since Lang (1968) explored the topic in relation to therapy for anxiety. Since that time, a consensus has emerged that concordance among these components is relatively low. To address this issue, *redundancy analysis*, a technique for examining directional relationships between two sets of multivariate data, was applied to data from a previously published study (Stephens, Christie, & Friedman, 2010). Subjects in this study listened to emotion-inducing music and viewed affective films while a montage of autonomic variables, as well as self-reported affective responses, were recorded. Results indicated that approximately 27–28% of the variance in self-reported affect could be explained by autonomic variables, and vice-versa. When all of the constraints of this emotion research paradigm are considered, these levels of explained variance indicate substantial coherence between feelings and physiology during the emotion inductions. These results are considered vis-à-vis the low levels of coherence that have often been reported in the literature.

1. Redundancy analysis of autonomic and self-reported responses to induced emotions

Much of the current discussion of emotional concordance can be traced to anxiety research that emerged in the late 1960s, and has wielded an enduring influence on the study of emotion. In this research, concordance (or *synchrony*) among the various features of anxiety was considered in the context of its clinical and conceptual implications, which were viewed as interdependent. Various theoretical models and abundant empirical work ensued in this era, which have been particularly influential in guiding subsequent research on anxiety therapy.

Moreover, this line of work extends beyond the realm of anxiety into emotion theory in general. Mapping the relationship among the components of emotion, which are frequently characterized in terms of their physiological, behavioral, and experiential response patterns, has been a fundamental issue in psychology since seminal writings on emotion by William James (1884, 1890; see Friedman, 2010, for a review). Biopsychological research has generally been guided by this view of emotion as patterns of distinct response types, the interrelationships of which have been variously represented (Carlson, 2013).

Methodology bears heavily on the interpretation of data and its extrapolation to theory; the case of emotional concordance is no exception to this precept. Decisions on variable selection and analysis method can have a profound impact on inferences drawn from data, and the comparability of results across studies (Campbell & Fiske, 1959; Cone, 1998; Nesselroade & Jones, 1991). Studies employing univariate analyses are especially susceptible to such effects. In contrast, multivariate designs have distinct advantages in unpacking relationships between physiological variables and psychological constructs (Thayer & Friedman, 2000).

In reference to the topic at hand, we and others have applied these principles to emotion research utilizing multivariate *pattern classification analysis* of autonomic nervous system (ANS) and self-report variables (Christie & Friedman, 2004; Kreibig, Wilhelm, Roth, & Gross, 2007; Nyklicek, Thayer, & Van Doornen, 1997; Rainville, Bechara, Naqvi, & Damasio, 2006; Stephens et al., 2010). In this paper, *redundancy analysis*, another multivariate technique is applied to previously published data (Stephens et al., 2010) with the aim of addressing the issue of concordance among physiological and experiential aspects of emotion. Redundancy analysis is specifically used here to examine bi-directional relationships among autonomic and self-reported responses to laboratory induced emotional states.

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Toward this end, we begin with a historical review of the anxiety-concordance literature, using the influential work of Peter Lang and associates as a focal point. This body of work sets the context which is then related to emotion theory, particularly in reference to discrete emotion models based on evolutionary concepts. Next, we outline how multivariate analyses in general, and redundancy analysis in particular, are beneficial in assessing the interrelationships among various components of emotion. Finally, redundancy analysis of physiological and self-reported responses to affective stimuli is utilized to demonstrate how these areas collectively speak to the issue of emotional concordance.

2. Concordance among components of emotion: fear and avoidance

Clinical research in the 1960s on the development of cognitive-behavioral therapy was pivotal in launching the study of emotional concordance. A highly influential and oft-cited paper in this literature was an exposition on the role of the components of fear in systematic desensitization treatment of anxiety disorders (Lang, 1968). Three fundamental categories of fear responses were identified: verbal-cognitive, overt-motor, and somatic. Use of this schema was directed at objective fear assessment in anxiety therapy research, independent of theoretical orientation. These three fear response systems were observed to vary in terms of their synchrony and to dissociate under some conditions. Empirical examples were offered in which bivariate correlations among indices of these components were rather low. The implication for treatment was that therapy directed at one aspect of anxiety may not effect change in other aspects, and so clinical research should aim to identify techniques specific to each system that will be most effective at achieving the desired therapeutic change.

It was subsequently argued that the de-coupling of fear and avoidance behavior has specific implications for therapy (Rachman & Hodgson, 1974). "Concordance" was inferred in the presence of high correlations among cognitive, behavioral, and somatic aspects of fear; "discordance" was defined by inverse or independent relations among these components ("synchrony" and "desynchrony" more specifically referred to *changes* in these components that vary together, independently, or inversely). Three types of phobia treatments were used as examples of distinct temporal covariance patterns between fear feelings and avoidance. In desensitization, fear reduction was thought to precede the decline of avoidance; the opposite pattern was observed in flooding. Fear and avoidance were said to decrease synchronously in participant modeling. Ultimately, all three therapies led to similar reductions in fear and avoidance, but did so by different synchrony-desynchrony pathways. These examples demonstrated the fluid relationship between fear and avoidance, which can situationally uncouple. However, the authors remarked in closing that ". . .most often, fear and avoidance are in fact closely linked" (p. 318).

Inspired by influential cognitive models of the 1970s, Lang (1979) expanded his concept of the structure of fear and emotion in proposing *bio-informational theory*. This conception of emotion, with specific reference to imagery, integrates psychophysiology with information processing theories that were prominent in this era of cognitive psychology. Such models represented information as networks of constructs that are logically related by *propositions* (Anderson & Bower, 1973; Kieras, 1978; Kintsch, 1974; Paivio, 1971; Plyshyn, 1973). Bio-informational theory depicts emotional images as propositional networks that include both stimulus and response information. The nodes of these networks are not necessarily activated uniformly; therein lies the potential for varying degrees of concordance among the observed responses to emotional stimuli, which in this case, are images. It is worth noting that these models were advanced prior to the widespread use and publication of brain imaging studies and concomitant emergence of the cognitive neuroscience paradigm; as such, little or no attempt was made to match the models with workings of the brain.

Bio-informational theory holds that the propositional structure of an emotional image includes efferent output matched to that image. This output includes motor actions and their supporting autonomic changes. Also included are subjective feelings and perceptual qualities of the stimulus context. This model is also derived from the aforementioned research on behavior therapy, and so was specifically related to anxiety hierarchies used in systematic desensitization. Such hierarchies may employ scripts in which the client is instructed to imagine participating in anxiety-provoking scenes. So, for example, in the case of snake phobia, the script may describe a chance encounter with a long snake that evokes heart palpitations plus feelings of fear and the need to flee. If one can vividly imagine being in this scene, the various components of the propositional network for that image will be collectively activated, leading to high concordance. Reports of substantial positive correlations between heart rate increases and both self-reported fear and image vividness support this view of high concordance between emotional experience and physiology under such conditions (Grossberg & Wilson, 1968; Lang, Melamed, & Hart, 1970; Marks & Huson, 1973; Van Egeren, Feather, & Hein, 1971).

Lang (1979) further argued, with supportive data, that image scripts containing response propositions (e.g., run away, heart pounding) increase concordance between physiological changes and other fear indices. Priming the response propositions acts to ". . .increase the magnitude of those responses which are *part of an affective reaction to which the subject is already predisposed*" (p. 506; italics added). This comment appears to refer to phobic individuals who are predisposed to respond to specific stimuli with feelings of fear, sympathetic nervous system activation, and behavioral avoidance. However, such phobias are more likely to be of stimuli that have evolutionary significance (e.g., threatening animals; Ohman, 1986). As such, these tendencies and their associated propositional networks are part of the human evolutionary heritage, and are present in varying degrees across individuals. Of course, these networks can be modified by individual experience; successful therapy for phobias attests to this. Indeed, Lang proposed that chances for successful therapy for phobias are enhanced by the ability to vividly imagine the phobic stimulus and activate the full propositional network, particularly the visceral and motor response propositions. In other words, initial concordance among fear components predicts successful outcome in anxiety therapy.

Lang and his colleagues shifted gears in the 1980s in a number of ways that advanced theoretical development (Lang, 1995; Lang & Bradley, 2010). Focus moved away from behavior therapy for anxiety disorders in particular toward a broader purview of emotion theory. Concurrent with this change was the usurpation of mental imagery as the primary emotion-elicitor by affective pictures, typically in conjunction with startle probe methodology. These standardized pictures (the *International Affective Picture System*), grounded in a two-factor valence-activation model of emotion, remain widely in use in contemporary emotion research (Center for the Psychophysiological Study of Emotion & Attention, 1994). Another development was the de-emphasis of cognitive models based on information-processing views in favor of a neuroscientific perspective based on animal models and brain imaging data.

Of relevance to concordance is the view that emotions are primarily driven by two motivational tendencies that map onto distinct neural systems: appetitive and aversive. These systems have been shaped by evolutionary forces that link them with survival of the individual; furthermore the species' emotions are viewed as "action tendencies" driven by these motives. Consistent with bio-informational theory's tripartite construction, human emotions