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Interpretation of physiological indicators of motivation: Caveats and recommendations

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ABSTRACT

Motivation scientists employing physiological measures to gather information about motivation-related states are at risk of committing two fundamental errors: overstating the inferences that can be drawn from their physiological measures and circular reasoning. We critically discuss two complementary approaches, Cacioppo and colleagues' model of psychophysiological relations and construct validation theory, to highlight the conditions under which these errors are committed and provide guidance on how to avoid them. In particular, we demonstrate that the direct inference from changes in a physiological measure to changes in a motivation-related state requires the demonstration that the measure is not related to other relevant psychological states. We also point out that circular reasoning can be avoided by separating the definition of the motivation-related state from the hypotheses that are empirically tested.

1. Introduction

Most psychological professional bodies and associations, like the British Psychological Society (BPS), the German Psychological Society (DGPs), the American Psychological Association (APA), or the Association for Psychological Science (APS), emphasize the importance of sound method-related knowledge and skills for all psychologists independent of the specific field they are working in. It is therefore no wonder that classes on quantitative and qualitative methods, test and questionnaire construction, and philosophy of science are crucial features of many undergraduate and postgraduate psychology programs. Most psychologists underwent rigorous training in scientific methodology during their studies and this in-depth formation crystallizes in many research fields where psychologists conduct carefully designed, scientifically sound empirical research. Surprisingly, psychologists seem to struggle with applying their methodological expertise when it comes to employing physiological measures to study psychological phenomena like motivation.

Many psychologists using physiological measures to study motivation-related topics seem to be unaware of two major pitfalls and are consequently unable to avoid them. First, motivation scientists need to avoid interpreting changes in physiological measures as reflecting changes in motivation-related states if this conclusion is not warranted.[1] Second, they need to avoid circular reasoning when justifying the assessment of their physiological measures. Failing to avoid these pitfalls leads to inaccurate conclusions and decreases the scientific quality of the conducted research. However, many motivation scientists seem to be unaware of these potential problems and lack the knowledge to avoid them. This article aims at providing them with the required knowledge by discussing two theoretical frameworks on the link between physiological measures and psychological states—Cacioppo, Tassinary, and Berntson's model of psychophysiological relations (Cacioppo and Tassinary, 1990; Cacioppo et al., 2000a) and classical construct validity theory (e.g., Campbell and Fiske, 1959; Cronbach and Meehl, 1955; Strauss and Smith, 2009; Trochim, 2016)—that illustrate the two pitfalls and their consequences. Referring to these frameworks, we will also provide guidance on how to avoid the pitfalls.

2. Pitfall 1: inferring psychological states from physiological measures

As noted in the preceding section, motivation scientists often interpret changes in physiological measures as reflecting changes in motivation-related states. Examples include suggestions that the error-related negativity of event-related brain potentials indicates defensive reactivity (Weinberg et al., 2012), that heart rate measures affective

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[1] Psychologists are of course not only interested in motivation-related states. They examine all kinds of psychological states and they are also interested in any type of psychological variable (like processes or properties). Given the focus of this special issue and for the sake of readability, we will use 'motivation-related state' throughout this article as placeholder for any psychological variable that a psychologist might be interested in.

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Table 1
Psychophysiological relations, possible inferences, and validation.

	Outcome	Concomitant	Marker	Invariant
Psychophysiological relation	Context-limited one-to-many relationship	General one-to-many relationship	Context-limited one-to-one relationship	General one-to-one relationship
Application				
Test of hypotheses	Possible	Possible	Possible	Possible
Comparison of theories	Possible	Possible	Possible	Possible
Inferences to changes in the psychological state	Not possible	Not possible	Possible	Possible
Validation				
Demonstration that the psychological state of interest influences the psychological measure	Required	Required	Required	Required
Demonstration that other psychological states do not influence the psychological measure	Not required	Not required	Required	Required
Demonstration that the relationship is context-independent	Not required	Required	Not required	Required

arousal (Sideridis et al., 2014), or that the combination of EEG activity, pupillometric response, and skin conductance change provides information about the level of task engagement (Gergelyfi et al., 2015). It is understandable that motivation scientists are interested in using physiological measures to gather information about motivation-related states. It is, however, important to acknowledge that the existing empirical research on most physiological measures does not warrant such a strong inference (e.g., Cacioppo et al., 2000a).

2.1. Psychophysiological relations

Cacioppo and colleagues provided a classification of the relationships between physiological measures and psychological states (Cacioppo and Tassinary, 1990; Cacioppo et al., 2000a; see also Allanson and Fairclough, 2004; Fairclough, 2009) which highlights the characteristics that a physiological measure needs to possess to enable inferences about a psychological (motivation-related) state. They distinguished four classes of relations between physiological measures and psychological states according to the level of specificity and generality. Table 1 provides an overview of these relations, the inferences that they enable, and the required validation.

A physiological measure that changes as a function of the manipulation of a psychological state is considered an *outcome*. An outcome is characterized by a *one-to-many relation* between the physiological measure and psychological states. It has been demonstrated that a specific psychological state affects the physiological measure in a certain context but there might be other psychological states that also influence the measure or the relation might not hold in other contexts.[2] This applies probably to most physiological measures used in the motivation-related literature and these measures thus constitute physiological outcomes of motivation-related states. For instance, de Morree and Marcora's (2010) observation that corrugator supercilii amplitude increased as a function of increasing difficulty of a leg extension task demonstrated that corrugator supercilii amplitude is an outcome of effort (assuming that leg extension difficulty manipulates effort).

If additional research demonstrates that the physiological measure responds similarly in many different contexts to variations in the psychological state, the physiological measure is called a *concomitant*. Physiological concomitants have a general one-to-many relation with psychological states. They are affected by many psychological states but the relations are independent of the specific context. In the case of the corrugator supercilii example, research would need to demonstrate that corrugator supercilii amplitude responds in general—in many different contexts—to variations in effort.

If one can demonstrate that a physiological measure is only affected by a single psychological state, one has evidence for a *one-to-one relationship*. If this relationship only holds in a certain context, the physiological measure is called a *marker* of the psychological state. If the relationship is general, the physiological measure is called an *invariant*.[3] To warrant the conclusion that corrugator supercilii amplitude is a marker of effort, one would need to show that it is—in a certain context—only affected by changes in effort and not by changes in any other psychological state. To conclude that it is an invariant, one would have to demonstrate the one-to-one relationship in every context. Empirical evidence revealing that corrugator supercilii amplitude is also affected by other psychological states—like Cacioppo et al.'s (2000b) demonstration that it changes as a function of mood—disqualifies the measure as an invariant of effort and would also disqualify it as a marker of effort if the empirical evidence had been gathered in a context similar to the context of de Morree and Marcora's study.

Outcomes, concomitants, markers, and invariants differ considerably regarding the inferences that they enable. Invariants enable the type of conclusion that most motivation scientists are probably looking for. Given that the physiological measure and the motivation-related state have a general one-to-one relationship, one can directly infer the motivation-related state from the physiological measure. Any change in the measure reflects a change in the state. If corrugator supercilii amplitude were an invariant of effort, any change in its amplitude would announce a change in effort. When psychologists use physiological measures to find out whether drivers are in an optimal state for driving (Brookhuis and de Waard, 2010), to design ambulatory devices that monitor mental stress (Choi et al., 2012), or to predict whether athletes feel challenged or threatened in a competition (Jones et al., 2009), they are keen on having a physiological invariant of the psychological state that they are interested in. In cognitive neuroscience this desire to infer psychological states from physiological (neurological) activity has been labeled reverse inference (e.g., Poldrack, 2011). Examples include the inference of reward processing from ventral striatum activity (Takahashi et al., 2009) and valuation from orbitofrontal cortex activation (Padoa-Schioppia and Assad, 2006).

As pointed out in the preceding paragraphs, an invariant is a physiological measure that is exclusively related to a single psycholo-

[2] Cacioppo and colleagues' framework uses the term context in a broad sense. It refers to any aspect that can differ between two situations and does include the specific stimulus configuration present in a certain context. Psychophysiological studies on stimulus specificity (e.g., Brenner et al., 2005; Edelberg and Wright, 1964) thus constitute specific demonstrations of context-dependent relationships.

[3] Cacioppo and colleagues' distinction between context-independent invariants and concomitants and context-dependent outcomes and markers resembles the distinction between endophenotypes, intermediate phenotypes, and biomarkers in psychopathology (Beauchaine, 2009; Lenzenweger, 2013a, 2013b; Puntmann, 2009). Endophenotypes and intermediate phenotypes are supposed to be context-independent because of their genetic underpinnings, whereas biomarkers are measures that correlate with some aspects of a disease but not necessarily in all contexts.