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Physiophenomenology in retrospect: Memory reliably reflects physiological arousal during a prior threatening experience

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ABSTRACT

Psychologists have long studied links between physiology and subjective feelings, but little is known about how those links are preserved in memory. Here we examine this question via arousal, a subjective feeling with strong physiological correlates. Using virtual reality, we immersed participants in a threatening scene (Room 101) where they confronted a variety of disturbing events. Later, participants watched the scene on a desktop computer while continuously rating how aroused they remembered feeling. Analyses of those time series revealed that retrospective reports were coherent with participants' unique patterns in physiological arousal (skin conductance and heart rate) during the original events. Analyses further revealed that coherence did not depend on simulating physiological arousal and that it was particularly strong among individuals high in interoceptive accuracy. These data demonstrate that memory encodes physiological information during emotional episodes such that individuals' recall of arousal reliably reflects physiological signals as they unfolded over time.

1. Introduction

Human beings spend a great deal of time thinking and talking about how past experiences made them feel. Whether we recall relaxing on a beach or careening down a ski slope, memory seems to encode visceral qualities. But is this the case? Although research has both explored the accuracy of memory for subjective feelings (e.g. Berntsen & Rubin, 2006; Parkinson, Briner, Reynolds, & Totterdell, 1995) and has examined the online relationships between subjective feelings and physiology (e.g. Golland, Keissar, & Levit-Binnun, 2014; Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005; Sze, Gyurak, Yuan, & Levenson, 2010), little is known about how those relationships between mind and body are preserved in memory. Here we explore this question by focusing on arousal, a feeling state with known physiological correlates.

Arousal is central to human affective experience (e.g. Duffy, 1957; Schachter & Singer, 1962; Wundt & Pintner, 1912). In subjective terms, arousal refers to the feeling of being activated versus relaxed or sleepy (Russell & Barrett, 1999; Thayer, 1967). This feeling emerges consistently as a primary dimension in the words people use to describe their own moods, feelings, or emotions (e.g. Mayer & Gaschke, 1988), as well those we use to describe affective states of others (e.g. Kuppens, Tuerlinckx, Russell, & Barrett, 2013; Russell & Bullock, 1986). This pattern holds across cultures (Russell, 1991) and age groups (Russell & Bullock, 1986). Not surprisingly, arousal is important to many psychological and neural models of affect (e.g. Russell & Barrett, 1999; Wundt & Pintner, 1912) and contemporary affective research relies heavily on explicit self-

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reports of arousal or activity (e.g. Bradley & Lang, 1994; Russell, Weiss, & Mendelsohn, 1989). Whether responding to stimuli in the laboratory (Bradley & Lang, 1994), or reporting on everyday experiences outside of the lab (e.g. Kuppens, Oravecz, & Tuerlinckx, 2010), people easily and frequently use arousal-related terms to describe their affective state.

The subjective experience of arousal correlates with measures of both central (e.g. Wilson-Mendenhall, Barrett, & Barsalou, 2013) and peripheral(Lang, Greenwald, Bradley, & Hamm, 1993) physiological activity (Mauss & Robinson, 2009). Physiological arousal typically refers to activation of the sympathetic branch of the autonomic nervous system, which is responsible for triggering a cascade of processes that facilitate bodily action (e.g., by increasing cardiac output to the musculature) (Cannon, 1929; Critchley, 2005). Although sympathetic activity originates in the brainstem, it appears to be partly controlled by cortical regions responsible for higher order processing such as the dorsal anterior cingulate cortex and ventrolateral prefrontal/subgenual cortex (Critchley, Nagai, Gray, & Mathias, 2011). Sympathetic activity directly effects electrodermal activity such that at the peripheral level, skin conductance provides a uniquely continuous gauge of physiological arousal (Dawson, Schell, & Filion, 2007). Skin conductance is higher when individuals look at pictures that they find arousing (Lang et al., 1993), when they are exposed to fear-conditioned stimuli (LeDoux, 1992) or when they listen to emotionally powerful music (Rickard, 2004). Heart rate also changes during arousing experiences, but this relationship is more complex. For example, heart rate generally increases during threatening experiences such as frightening films (Kreibig, Wilhelm, Roth, & Gross, 2007) or public speaking (Croft, Gonsalvez, Gander, Lechem, & Barry, 2004), but this response may be preceded by a deceleration immediately after the onset of a threat (Lang, Bradley, & Cuthbert, 1997). Regardless, heart rate changes can influence emotional appraisal (Gray et al., 2012) and the subjective experience of arousal (Dunn et al., 2010).

Nevertheless, subjective and physiological arousal are distinct phenomena (Barrett, Quigley, Bliss-Moreau, & Aronson, 2004; Blascovich, 1990; Blascovich & Kelsey, 1990). Although correlations between them may emerge on the group level, individuals differ in the degree to which physiological signals cohere with self-report. One key determinant of this coherence is interoceptive accuracy, the degree to which individuals have conscious access to their physiological states (Dunn et al., 2010; Schandry, 1981). The notion here is that physiological signals should have a stronger influence on subjective experience when individuals are better able to detect them (Blascovich, 1990; Critchley, Wiens, Rotshtein, Öhman, & Dolan, 2004; Sze et al., 2010). Accordingly, people high in interoceptive accuracy describe their states with more arousal-related terms (Barrett et al., 2004) and show a stronger link between heart rate and arousal ratings (Dunn et al., 2010; Pollatos, Herbert, Matthias, & Schandry, 2007).

Together these findings suggest that subjectively experienced arousal depends on both physiological arousal and the degree to which one interocepts about it. However, when time passes and the physiological state has changed, does memory retain this relationship between the mind and the body?

On the one hand, memory for arousal and other feeling states serves obvious functions, helping us plan future actions and allowing us to share our experiences with others and feel empathy for people in similar circumstances (Alea & Bluck, 2003; Bluck, Baron, Ainsworth, Gesselman, & Gold, 2013; Levine, Lench, & Safer, 2009). On the other hand, all memory is fallible. We forget and distort when we recall the past and this is no less the case when we recall feeling states (e.g. Levine & Safer, 2002; Schwarz, 1999). Recollection of feelings can be biased by one's current mood, the desire to regulate emotion, the vantage point from which one remembers, and individual differences such as neuroticism and extraversion (Berntsen & Rubin, 2006; Parkinson et al., 1995). Even for an experience as salient as physical pain, recall is partly determined by the present condition of the body (Marty et al., 2009) and is biased by peak and final levels of pain intensity (Kahneman, Fredrickson, Schreiber, & Redelmeier, 1993).

Biases in memory for feelings are more likely to emerge when one cannot remember, or misremembers, details of the actual events that triggered those feelings (Robinson & Clore, 2002). Given this fact, researchers from a variety of backgrounds have devised ways to cue recall. On the qualitative end are guided interviews that probe experience in order to produce highly detailed accounts of past events (Petitmengin, Navarro, & Le Van Quyen, 2007). In more quantitative research, the literature on empathic accuracy provides clever methods (e.g. Ickes, Stinson, Bissonnette, & Garcia, 1990; Levenson & Ruef, 1992). Participants are recorded during a social interaction and later watch the recording while reporting how they felt. This method allows participants to report feelings continuously. Because continuous reports do not require participants to summarize an entire experience, they are more likely to be accurate (e.g. Kahneman et al., 1993; Sze et al., 2010). Moreover, continuous data are ideal for examining dynamic coherence between subjective and physiological measures (e.g. Mauss et al., 2005). Along these lines, when participants re-watch a film while continuously reporting their original emotional response to it, those reports cohere with physiological signals during the first viewing of the film (Mauss et al., 2005) although it is not clear whether subjective reports depend upon memory or the re-experiencing of feelings upon the second or third viewing of the film.

In sum, one stream of research has investigated memory for subjective feeling states while another has examined the correlation between subjective feeling states and physiological signals but research has not adequately explored if and how those physiological signals are preserved in memory. Here we do using Room 101, an immersive virtual environment named after the torture chamber in George Orwell's novel *Nineteen Eighty-Four* (Orwell, 1949). In Orwell's Room 101, individuals were forced to confront their version of "the worst thing in the world". In our Room 101, participants encountered a series of potentially arousing stimuli which ranged from explosions to gunshots to spiders to a collapsing floor. Participants spent five minutes in Room 101, during which time we measured their skin conductance and heart rate. After the task, participants watched the scene again on a desktop computer while continuously rating their remembered arousal. In addition, we gathered behavioral and self-reports of trait interoceptive sensitivity.