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Using a false biofeedback methodology to explore relationships between learners' affect, metacognition, and performance

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ABSTRACT

We used a false-biofeedback methodology to manipulate physiological arousal in order to induce affective states that would influence learners' metacognitive judgments and learning performance. False-biofeedback is a method used to induce physiological arousal (and resultant affective states) by presenting learners with audio stimuli of false heart beats. Learners were presented with accelerated, baseline, or no heart beat (control) while they completed a challenging learning task. We tested four hypotheses about the effect of false-biofeedback. The *alarm* vs. *alert hypothesis* predicted that false biofeedback would be appraised as either a signal of distress and would impair learning (alarm), or as a signal of engagement and would facilitate learning (alert). The *differential biofeedback hypothesis* predicted that the alarm and alert effects would be dependent on the type of biofeedback (accelerated vs. baseline). The *question depth hypothesis* predicted that these effects would be more pronounced for challenging inference questions. Lastly, the *self* vs. *recording hypothesis* predicted that effects would only occur if participants believed that false biofeedback was indicative of their own physiological arousal. In general, learners experienced more positive/activating affective states, made more confident metacognitive judgments, and achieved higher learning when they received accelerated or baseline biofeedback while answering a challenging inference question, irrespective of the perceived source of the biofeedback. Thus, our findings supported the alert and question depth hypotheses, but not the differential biofeedback or self vs. recording hypotheses. Implications of the findings for the integration of affective processes into models of cognitive and metacognitive processes during learning are discussed.

1. Introduction

Beginning in middle school and continuing through high school and beyond, students have to learn about difficult and conceptually-rich topics in mathematics, physics, ecology, chemistry, and biology. It is in these domains that adolescents and young adults face the greatest challenges to learning (PISA, 2009) because they are confronted with novel and unfamiliar terms, abstract concepts, and the necessity for construction and reconstruction of mental models (Newcombe et al., 2009). Fortunately, research has shown that learning can improve through the deployment of key cognitive and metacognitive processes such as planning, monitoring, and through the use of appropriate learning strategies (Azevedo, 2009; Dunosky & Metcalfe, 2009; Hacker, Dunlosky, & Graesser, 2009; Pintrich, 2000; Winne, 2011; Winne & Hadwin, 2008; Zimmerman & Schunk, 2011). These processes, also called self-regulated learning (SRL) processes, are based on the assumption that learners actively monitor and control their learning to aid in deeper processing of the material (Azevedo & Witherspoon, 2009).

Self-regulated learning is an active and constructive process that involves learners' ability to build on their understanding of a topic by using planning, monitoring, and learning strategies, and by regulating key aspects of cognition, behavior, motivation, and affect in order to achieve some desired learning goal (Azevedo & Witherspoon, 2009; Boekaerts, Pintrich, & Zeidner, 2000; Koriat, Ma'ayan, & Nussinson, 2006; Pintrich, 2000; Zimmerman & Schunk, 2011). More specifically, learning of complex science topics necessitates learners to effectively self-regulate their learning by *metacognitively monitoring* their emerging understanding of a given topic (Burkett & Azevedo, 2012; Graesser et al., 2007; Shapiro, 2008). Most research on the topic of metacognitive monitoring focuses primarily on *metacognitive judgments* (see Dunosky and Metcalfe (2009) for a recent review), which occur before, during, and after learning has taken place, as learners continually assess their emerging understanding of the material.

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There are three metacognitive judgments that are most commonly examined in SRL research. These include ease of learning (EOL), judgments of learning (JOL), and retrospective confidence judgments (RCJs) (Dunosky & Metcalfe, 2009; Leonesio & Nelson, 1990; Nelson & Narens, 1990). Ease of learning judgments occur *before* learning and involve preemptively determining how easily a given topic can be learned. They occur in the prospective phase of learning and are assumed to help learners establish goals, subgoals, and allocation of study-time, and can be used as a baseline comparison for future metacognitive judgments. Judgments of learning occur *during* learning when learners attempt to assess their emerging understanding of the topic, and are predictive of subsequent learning performance (Jang & Nelson, 2005). Retrospective confidence judgments occur *after* learning has taken place when learners predict how likely it is that their responses to evaluative items were correct.

Examining the use of metacognitive monitoring processes can provide several insights into how learners regulate their learning. However, an equally important component that is gaining attention in the domain of SRL is the role of affect (Brosch, Pourtios, & Sander, 2010; Frijda, 2009; Izard, 2007; Schwarz, 2011; Stein, Hernandez, & Trabasso, 2008). There are many terms that are used to describe learners' affective experiences, such as basic emotions (Ekman, 1992), moods (Bless, 2000; Bower & Forgas; 2000; Isen, 2001, 2010; Schwarz & Clore, 1983), affective states (D'Mello & Graesser, 2011a, 2012) and academic emotions (Pekrun, 2010). Within the category of academic emotions, there are various other terms such as acheivement emotions, topic emotions, social emotions, and epistimic emotions (Pekrun, 2010). Although each of these terms are distinct and important in their own way, this article uses the term *affect* or *affective states* broadly to encapsulate the feelings and emotions that arise during brief learning episodes (30 min to 2-h). This consists of reactions to specific learning events that vary in intensity but are relatively brief, lasting for a few seconds to a few minutes (D'Mello & Graesser, 2011a; Rosenberg, 1998). What is not meant by *affect*, however, are moods (longer term affective experiences that are not directed at any particular event), affective traits (predispositions in affective responding), or motivational states. Previously published papers offer justification for this conceptualizaton of affect (Baker, D'Mello, Rodrigo, & Graesser, 2010; Calvo & D'Mello, 2011; Conati & Maclaren, 2009; Rosenberg, 1998; Woolf et al., 2009).

Part of the challenge of learning about conceptually-rich domains such as science, technology, engineering, and mathematics is that these domains are rife with affect-eliciting factors such as complexity of the learning materials, uncertainty about how to proceed when faced with obstacles to learning, and the fear of performing poorly on subsequent evaluations. These negative factors can interfere with learners' ability to effectively regulate their learning. Although many conceptual models of SRL focus on learners' use of metacognitive monitoring and control processes to regulate their learning (Azevedo, Moos, Johnson, & Chauncey, 2010; Dunlosky & Theide, 2004; Dunosky & Metcalfe, 2009; Metcalfe, 2002; Zimmerman & Schunk, 2011), the role of affect during learning has, until recently, received somewhat less attention. Existing models that address learners' affect tend to focus primarily on how affect broadly impacts motivational, metacognitive, and cognitive processes. For example, increases in self-satisfaction (a positively valenced affective state) are correlated with enhanced motivation and effort, while decreases are associated with diminished effort (Schunk, 2001). Self-efficacy is also associated with the use of varied study methods in order to discover new avenues for self-improvement (Zimmerman, 2002), and is related to learners' use of SRL strategies (Braten, Samuelstuen, & Stromso, 2004). Other models of SRL explore the role of affective processes on motivation (Boekaerts, 2009; Pintrich, 2000), goal orientation (Harachiewicz, Barron, Pintrich, Elliot, & Thrash, 2002), interest (Pintrich & Schunk, 2002; Wigfield, Eccles, Schiefele, Roesner, & Davis-Kean, 2006), and the relationship between products (i.e., learning outcomes) and standards (i.e., learners' evaluations of optimal end states) (Winne & Hadwin, 2008).

While these models focus primarily on broad effects of affect on a number of outcome variables, the present research diverges from, but builds upon, these models by attempting to uncover the intricate relationship between affect, SRL (specifically metacognitive components of SRL), and learning outcomes. Investigation into the relationship among these processes is essential, because there is a complex interplay between cognitive and affective processes during learning and problem solving (Craig, Graesser, Sullins, & Gholson, 2004; D'Mello & Graesser, 2011b; Daniels, Stupnisky, et al., 2009; Daniels, Pekrun, et al., 2009; Linnenbrink, 2006; Meyer & Turner, 2006; Pekrun, 2010; Schutz & Pekrun, 2007; Zeidner, 2007). Affect operates throughout cognitive processes such as causal reasoning, deliberation, goal appraisal, and planning. Flexibility, creative thinking, efficient decision-making, and conceptually-driven relational thinking have been linked to positive affect, while negative affect has been associated with localized attention and stimulus-driven processing (Clore & Huntsinger, 2007; Fielder, 2001; Fredrickson & Branigan, 2005; Isen, 2008; Schwarz, 2011). Affect can also have a serious impact on learners' comprehension and performance on evaluative measures (Zeidner, 2007).

Importantly, it is perhaps not the affective states themselves, but the cognitive and metacognitive activities that accompany their experience that are predictive of learning. This leads to the critical question of how affect influences these metacognitive and cognitive processes, a question that motivated the present research.

2. Theoretical framework, hypotheses, and present research

The current research adopts an appraisal theoretic framework to describe the antecedents of learners' affective states. Contemporary theories of affect posit that cognitive appraisals of physiological changes are one prominent way that affective states arise (Barrett, Mesquita, Ochsner, & Gross, 2007; Lazarus, 1991; Mandler, 1975, 1999; Ortony, Clore, & Collins, 1988; Russell, 2003; Schachter & Singer, 1962; Stein & Levine, 1991). The specific affective states that arise depend on an individual's unconscious or conscious appraisals (i.e., evaluations) of the situation that presumably caused the physiological change along dimensions such as novelty, goal-alignment, agency, coping potential, and availability of a plan (Cacioppo, Klein, Berntson, & Hatfield, 1993; Duffy, 1962; Karsdorp, Kindt, Rietveld, Everaerd, & Mulder, 2009; Ortony et al., 1988; Schachter & Singer, 1962; Valins, 1966).

Building on this research foundation, the fundamental question addressed in this article is how affect influences learners' metacognitive judgments and performance. We conducted an experiment that used a false-biofeedback methodology (Kirsch & Lynn, 1999; Schachter & Singer, 1962; Valins, 1966) to induce physiological arousal (and resultant affective states) by presenting learners with audio stimuli of false heart beats that were either baseline, like those that would be experienced if an individual was in a neutral state, and accelerated, like those that would be experienced in a moment of excitement or fear. In some trials we presented learners with no auditory stimulus; these trials served as the control trials.

One key concept related to false biofeedback is the occurrence of physiological alignment with the presented auditory stimulus. Previous research has demonstrated that participants' physiological responses will align with false heart rate biofeedback and false skin conductance biofeedback (Ehlers, Margraf, Roth, Taylor, & Birbaumer, 1988; Holroyd et al., 1984; Lichstein & Hoelscher, 1989). That is, when participants hear an accelerated heart rate, their own heart