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Affect and Cognitive Control: Insights From Research on Effort Mobilization

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Abstract

We present theory and research on effort mobilization that is relevant for understanding the role of affect in cognitive control. We posit that cognitive control and effort are closely related and introduce motivational intensity theory and supporting empirical evidence mainly based on cardiovascular measures of effort. Most important, we discuss the role of affect in the context of effort mobilization and cognitive control from different perspectives. We first present theories predicting affective influences on effort, namely the mood-behavior-model and the implicit-affect-primes-effort model, and supporting empirical evidence. Second, we discuss further implications of the resource conservation principle highlighting the aversive aspect of effort and review evidence for the impact of value and its affective component on effort and cognitive control. Finally, we present a recent integration of the neural mechanisms underlying both effort and cognitive control. We conclude that affective processes are necessary and instrumental for both effort mobilization and cognitive control.

Keywords: effort, cognitive control, affect, value, resource conservation

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1. *Introduction*

"What is cognitive control without affect?" We understand the topic of this special issue as an attempt to determine whether cognitive control can exist without *any* affective processes, and if it can, what these affect-independent control processes are. From a traditional cognitivist perspective (e.g., Schneider & Shiffrin, 1977), the answer to the first question would be "yes". Applying a computer metaphor and conceptualizing humans as information processing agents does, at first, not leave much space for affective processes. Accordingly, cognitive control without affect would still be *cognitive* control. However, the reemergence of motivation psychology and the rise of affective psychology highlighted the importance of affect in human information processing and action (e.g., Geen, 1995; Sander & Scherer, 2009)—also in psychophysiology (Gendolla, 2017). Nevertheless, several psychological models have kept with the idea that cognition and emotion are parts of two relatively independent systems. As a prototypical example, Metcalfe and Mischel (1999) have proposed that cognitive control is part of a "cold" system that is related to basic information processing and works in an "emotionally neutral" way. By contrast, affect is associated with an independent "hot" system that can, however, interact with the cold system when individuals try to regulate their behavior. However, other models posit that cognitive and affective processes are so closely entangled that they are inseparably interrelated (e.g., Leventhal & Scherer, 1987). In this latter perspective, cognitive and affective processes might not exist on their own.

The topic of this special issue reminds us of the debate about affect – cognition primacy between Zajonc and Lazarus in the early 1980s (Lazarus, 1983, 1984; Zajonc, 1980, 1984). In that discussion it was argued whether affective processes could exist independently from cognition and whether cognitive processes precede affective experiences or not. Zajonc posited that basic affective reactions come first. Lazarus claimed that cognitive processes are necessary to elicit affective reactions. Leventhal and Scherer (1987) partly resolved this argument by considering definition issues associated with emotion and cognition. Accordingly, reflex-like basic affective reactions should be distinguished from emotions. Cognition and emotion are closely and inseparably intertwined, with the exception of innate reflex-like affective reactions at the very beginning of ontogenetic development.

In this article, we also consider definition issues to highlight the role of affect in cognitive control. According to dual-process models (Norman & Shallice, 1986; Posner & Snyder, 1975; Shiffrin & Schneider, 1977), cognitive control is by definition associated with effort, which represents the mobilization of resources to execute action (Gendolla & Wright, 2009). Therefore, one can expect research investigating affective impact on cognitive effort to be relevant for the question of this special issue and we aim to offer some answers by drawing on research on effort mobilization. As we will discuss below, effort is closely linked with controlled information processing and affective processes have systematic effects on effort mobilization and cognitive control.

In this article, we try to answer at least two related questions: First, are affective processes necessary for effort mobilization and intensity? Second, is there any aspect of effort mobilization that is independent from affective processes? We begin with a definition and discussing conceptual issues pertaining to effort. We then introduce motivational intensity theory (Brehm & Self, 1989), the theoretical framework we and several others have applied to make predictions about effort mobilization, and supporting empirical evidence mainly based on cardiovascular measures of effort. Most important, we discuss the role of affect in the context of effort mobilization and cognitive control from different perspectives. We first present theories predicting affective influences on effort, namely the mood-behavior-model (MBM) and the implicit-affect-primes-effort model (IAPE), and supporting empirical evidence. Second, we discuss further implications of the resource conservation principle highlighting the aversive aspect of effort and consequences for cognitive control. We then review evidence on the impact of value and its affective component on effort. Finally, we present a recent integration on the neural correlates and mechanisms underlying effort and cognitive control, which offers additional insights in the role of affective processes in both effort mobilization and cognitive control. We finish our discussion with a general summary and concluding remarks on the topic of this special issue.

2. Effort: Definition and Basic Conceptual Issues

As most psychological constructs, effort can be defined, conceptualized, and assessed in different ways (see Massin, 2017). As we discuss later, this can lead to theoretical divergences and confusion, making it necessary to clarify these definition issues at the first place. We define effort as the mobilization of resources to carry out instrumental behavior (Gendolla & Wright, 2009). This definition applies to physical as well as cognitive effort and refers to the intensity aspect of instrumental behavior—how much people strive to attain a goal—and calls for an operationalization that reflects the intensity of “striving” in general. The specific mobilized resources can be biochemical (e.g., adenosine triphosphate—ATP), psychological (e.g., attention), or physical (e.g., time) in nature. Thus, our definition of effort covers other ones—like the idea that effort is the intensity of attention (Kahneman, 1973) or the application of energetical resources (Hockey, 1997)—but it is distinct from the idea that effort refers to the set of intervening processes that determine which level of performance will in fact be attained (Shenhav et al., 2017) or the idea of associations between mobilized resources and performance (e.g., Hancock & Warm, 1989). We make a sharp distinction between effort (a behavioral input variable) and performance (a behavioral output variable).

In the context of information processing and self-regulation, effort is by definition associated with cognitive and behavioral control. According to early models, cognitive processes range from automatic/effortless to controlled/effortful (Norman & Shallice, 1986; Posner & Snyder, 1975; Shiffrin & Schneider, 1977). Automatic processes refer to direct responses to the environment, driven by bottom-up processes, and stimulus-response associations (Miller & Wallis, 2009). In contrast, controlled processes require the execution of cognitive control, which can be defined as the engagement of elementary cognitive processes when automatic or habitual responses are insufficient to sustain behavior (Shackman et al., 2011). These elementary processes typically refer to executive functions, a set of basic cognitive operations (e.g., response inhibition, task switching, and information updating) that are resource-dependent and at the core of all control processes (Jurado &

Rosselli, 2007; Miller & Cohen, 2001; Miyake et al., 2000; Niendam et al., 2012). That is, control is demanding (Koole, Jostmann, & Baumann, 2012) and effort mobilization should play a central role in control processes (e.g., Wright & Mlynski, 2019). Overall, it appears that cognitive control relies on effort. When automatic behaviors are insufficient for maintaining goal pursuit, individuals have to mobilize resources, i.e. exerting effort, through the engagement of additional cognitive and metabolic processes (Silvestrini, 2017). That is, cognitive control depends on (limited) resources and effort is the mobilization and allocation of these resources.

As stated above, our definition of effort refers to the general intensity of striving. However, other researchers debate about the precise nature of these resources people invest in effortful behavior (e.g., Kurzban, Duckworth, Kable, & Myers, 2013; Shenhav et al., 2017; Wickens, 2002). Whereas some authors claimed that the resource concept is too vague to be useful (e.g., Navon, 1984), others offer various propositions to conceptualize this term. Drawing on the work of Wickens (1984, 2002) and Kahneman (1973), Hockey conceptualized resources as “the availability of one or more pools of general processing units, capable of performing elementary operations across a wide range of tasks, and drawing upon common energy sources” (Hockey, 1997; p.75). Another proposition refers to metabolic resources such as oxygen supply and waste accumulation in relevant tissues (e.g., Newsholme, Blomstrand, & Ekblom, 1992). However, considering our definition of effort, this issue is beyond the scope of the present article. We do not doubt that there are biological bases of resources and effort or that psychological influences on the perception of the availability of these resources exist (see Silvestrini, Vuignier, Matthey, & Piguet, in press; Wright & Mlynski, 2019). But for the present analysis it is sufficient to draw on the assumption of a given limitation of these resources (e.g., Norman & Bobrow, 1975). As we discuss later, these actual or perceived limitations are expected to motivate individuals to preserve their resources following a resource conservation principle in which effort mobilization is basically grounded. But before going further, it is important to distinguish effort from other related concepts.

First, we consider that effort, defined as the mobilization of resources to carry out instrumental behavior, is not equivalent with the subjective feeling of effort. As William James had anticipated in one of his very first publication (James, 1880), the feeling of effort is surely important to investigate. However, we consider that the *feeling of effort*, as other self-related judgements, might be influenced by other factors than the *actual* mobilization of resources. Effort introspection can be difficult and the subjective feeling of effort is often dissociated from measures of actually mobilized effort (e.g., Bijleveld, 2018; Marcora, 2009). Moreover, people may underestimate their mobilized effort to protect their self-esteem by facilitating failure attributions to a lack of instable effort rather than a lack of stable ability, which would result in feelings of shame (Weiner, 2018). These issues highlight the limitations of self-report in assessing effort (see Gendolla & Richter, 2010) and suggest that the correspondence between the subjective feeling of effort and actual resource mobilization may vary as a function of contextual factors.

Second, one may wonder whether behavioral choices regarding effortless and effortful action alternatives (e.g., Inzlicht, Shenhav, & Olivola, 2018; Kool & Botvinick, 2018; Kurzban, Duckworth, Kable, & Myers, 2013) can inform about processes underlying actual resource mobilization. We acknowledge that the decision to engage in a given behavior, pursue this behavior, or disengage, may depend on the required or actual effort. Accordingly, effort mobilization and effort-based decision-making are expected to interact with each other and might be investigated in combination. However, investigating effort mechanisms using decision making tasks can also lead to different conclusions than directly assessing resource mobilization. Theoretically, choices refer to the *direction* of behavior, whereas effort refers to its *intensity* (see Geen, 1995). Consequently, it is important to distinguish between these different aspects of effort.

Third, it is important to reflect upon the relationship between effort and cognitive performance. One might consider that cognitive performance should reflect effort (e.g., Bijleveld, Custers, & Aarts, 2010; Roets, Van Hiel, Cornelis, & Soetens, 2008) and that thus more effort should lead to better performance. However, one should keep in mind that cognitive performance is influenced by more factors than only effort intensity—at least capacity, persistence, and strategy play additional and maybe more important roles (see Locke & Latham, 1990, 2019). Moreover, some authors consider effort to have a compensatory function (e.g., Hockey, 1997). For instance, due to ability differences, some people might engage a high level of effort, while others only mobilize little effort to attain a similar performance level (e.g., Smith & Hess, 2015). Moreover, one might engage high effort, but apply an inefficient cognitive strategy resulting in poor performance, or one may even apply an effortless strategy, like cheating, resulting in high performance. Therefore, whereas it seems intuitive that effort does enhance performance, there are many situations when this is not the case. We do not posit that effort and performance are always dissociated. But they refer to different aspects of action—input (effort) and outcome (performance)—and their relationship is not always simply linear and depends on moderators. Another, rather practical than conceptual problem is that measures of cognitive performance frequently require motor performance (e.g., reaction times of button presses or fluency in verbal responses). This confound makes it even more difficult to understand the relationship between effort and cognitive performance.

Considering the issues we have discussed so far provides good reasons for (1) assessing effort mobilization directly in accordance with its definition as the mobilization of resources for action and (2) to investigate effort in a theoretical framework that permits clear predictions about effort mobilization by clarifying how its central predictor variables function and interact. Motivational intensity theory and its integration with research and insights from psychophysiology has offered all this decades ago.

3. Motivational Intensity Theory

Motivational intensity theory (Brehm & Self, 1989; Brehm, Wright, Solomon, Silka, & Greenberg, 1983; Brehm, 1975) is grounded in the resource conservation principle (Gibson, 1900)—the idea that organisms do just the necessary, but not more for attaining their goals. Drawing further on the idea that effort has the function to cope with obstacles during goal pursuit, it was postulated that resource mobilization follows a “difficulty law of motivation” (e.g., Ach, 1935; Hillgruber, 1912). Accordingly, effort is mobilized proportionally to the experienced difficulty of instrumental behavior—the greater the obstacles encountered during goal pursuit, the more effort is mobilized.

Elaborating these basic principles, motivational intensity theory posits that *effort rises with subjective task difficulty as long as success is possible and the necessary effort is justified.* Accordingly, subjective difficulty—the extent of experienced demand—is the core variable determining effort within two specified limits: Effort proportionally increases with subjective demand until (1) a difficulty level exceeds a person's abilities, making success impossible, and until (2) the amount of necessary effort exceeds what is justified and a person is thus willing to mobilize. The level of justified effort depends on the value of success or success importance, which defines the level of *potential motivation*—the hypothetical maximum of the effort a person is willing to mobilize (see Wright, 2008). In compliance with the resource conservation principle, effort is predicted to sharply drop if one of the two limits of the difficulty-effort link is attained, because continuing engagement when success seems to be impossible or not justified would mean the waste of resources.

Importantly, according to motivational intensity theory, the importance of success has only an indirect effect on effort—it influences the maximally justified effort but does not directly determine the exerted effort—with one exception. This is unspecified difficulty, i.e. conditions under which subjective demand is unclear, because it randomly varies or is completely unknown. These predictions are graphically depicted in Figure 1.

3.1 Effort-Related Cardiovascular Response

Evidence that effort mobilization follows the principles of motivational intensity theory is abundant and strong, as reviewed elsewhere in detail (Gendolla, Wright, & Richter, 2012; in press; Richter, Gendolla, & Wright, 2016; Wright & Kirby, 2001). Most of the studies testing the theory have operationalized effort physiologically as responses in the cardiovascular system to monitor *activation*—which is by definition a key aspect of effort *mobilization*. The conceptual basis for this is Wright's (1996) integration of motivational intensity theory (Brehm & Self, 1989) with the active coping approach from psychophysiology (Obrist, 1981), which resulted in the important suggestion of an objective, physiological measure of effort mobilization. Accordingly, beta-adrenergic sympathetic nervous system impact (reflecting activation) on the heart is proportional to experienced task demand as long as success is possible and the necessary effort is justified. Beta-adrenergic sympathetic impact becomes especially manifest in cardiac pre-ejection period (PEP)—a cardiac contractility measure defined as the time interval between the onset of left ventricular cardiac excitation and the opening of the aortic valve in a cardiac cycle (Berntson, Lozano, Chen, & Cacioppo, 2004). This time interval, which takes about 100 ms during rest, becomes shorter when beta-adrenergic impact increases.

Cardiac contractility can also systematically influence other indices of cardiovascular activity, like systolic blood pressure (SBP)—the maximal arterial pressure between two heartbeats (Brownley, Hurwitz, & Schneiderman, 2000). Consequently, several studies have used SBP as index of effort (see Gendolla et al., 2012; Wright & Kirby, 2001 for reviews). However, although performance-related changes in SBP are a suitable quantification of effort mobilization, PEP directly reflects the beta-adrenergic sympathetic impact on the heart.

One may raise here that not only cardiovascular reactivity may reflect effort-related sympathetic activity. For instance, pupil dilation has been used to assess sympathetic activity and effort (Kahneman & Beatty, 1966; see van der Wel & van Steenbergen, 2018, for a review). Recent evidence indicates an association between activity of noradrenaline-containing neurons in the brainstem nucleus locus coeruleus and pupil dilation during cognitive performance (Joshi, Li, Kalwani, & Gold, 2016). In this context, recent neurocognitive models suggest that noradrenaline produced by the locus coeruleus energizes brain structures underlying cognitive effort (Silvetti, Vassena, Abrahamse, & Verguts, 2018). Whereas a comparison of various measures of effort-related sympathetic activity is beyond the scope of the present article, we consider cardiovascular reactivity to reflect such cognitive effortful processes as well (see Silvestrini, 2017). Therefore, it would not be surprising that PEP reactivity and pupil dilation respond in a similar way to challenging tasks—if it relies on sympathetic activation rather than parasympathetic deactivation—which may be investigated in future studies. However, most of the research presented in this article assessed effort as cardiovascular reactivity drawing on a firm theoretical background (Wright, 1996): Accordingly, effort should be most sensitively reflected by measures that best reflect sympathetic activation. PEP fulfills these criteria.

3.2 Evidence for the Principles of Motivational Intensity Theory

Research on motivational intensity theory (Brehm & Self, 1989) has primarily focused on variables that systematically influence experienced task demand. Examples are fixed performance standards (e.g., Wright, Contrada, & Patane, 1986), ability beliefs (see Wright, 1998), implementation intentions (Freydefont, Gollwitzer, & Oettingen, 2016), biological aging (e.g., Smith & Hess, 2015), the activation of aging stereotypes (Zafeiriou & Gendolla, 2017), and—most relevant in the present context—affective variables like experienced fatigue (see Wright & Stewart, 2012), mood states (see Gendolla, Brinkmann, & Silvestrini, 2012), pain (Silvestrini, 2015, 2018), and depressive symptoms (e.g., Brinkmann & Gendolla, 2007, 2008). All of these variables have been found to systematically influence the experience of task demand and the strength of effort-related cardiovascular response during cognitive performance, as long as success was possible and the necessary effort was justified.

4. The Role of Affect

The concept of affect is strongly associated with valence, which refers to a continuum from negative/unpleasant to positive/pleasant aspects of subjective experiences or events (Frijda & Scherer, 2009). According to Schwarz and Clore (1996), affective experiences include moods, emotions, as well as cognitive experiences such as familiarity, boredom, or difficulty, and bodily experiences such as hunger or pain.

As discussed above, the question whether affect requires cognitive processes was a heavily debated one (Lazarus, 1983, 1984; Leventhal & Scherer, 1987; Zajonc, 1980, 1984). By contrast, with the exception of early purely cognitive theories, the idea that affect can influence cognition has been more consensual and received strong empirical support (e.g., Bower, 1981; Forgas, 1995; Isen, 1984; Schwarz & Clore, 1988; Wyer, Clore, & Isbell, 1999). Such links between affect and cognitive processes and the principles of motivational intensity theory (Brehm & Self, 1989) were at the core of a fruitful line of research investigating how affect influences effort mobilization during cognitive performance.

4.1 Affective Influences on Effort

Gendolla has elaborated the role of affect in effort mobilization focusing on two types of affective influences with two second order theories within the general framework of motivational intensity theory. First, the mood-behavior-model (Gendolla, 2000) posits that experienced moods can influence effort mobilization because of their informational impact—people use their mood as a piece of diagnostic information and integrate it with all other available information into their behavior-related judgments (Abele & Petzold, 1994). By default, this leads to a mood congruency effect: Individuals in a negative mood judge task difficulty as higher than individuals in a positive mood. Second, the implicit-affect-primes-effort model (Gendolla, 2012) postulates that the mere activation of affect knowledge leads to similar effects. The implicit-affect-primes-effort model applies to stimuli (primes) that activate affect-related knowledge, which then implicitly influences subjective demand. Due to learning that it is easier or more difficult to perform cognitive tasks in different affective states, ease becomes a feature of people's mental representations of happiness and anger, while difficulty should become a feature of their representations of sadness and fear. Implicitly processed emotional cues (affect primes) that activate these mental representations should thus render the ease and difficulty features accessible, resulting in lower or higher subjective task demand and effort during performance.

The main difference between the mood-behavior-model and the implicit-affect primes-effort model lies in the type and origin of affect-related information that influence subjective task demand. The mood-behavior-model applies to *experienced feelings* and predicts that mood is directly used as information for difficulty judgments. The implicit-affect-primes-effort model applies to emotion knowledge and posits that implicitly processed affective stimuli can influence effort by rendering the ease or difficulty concepts accessible. However, independent of the type and origin of affect-related information, both models rely on the principles of motivational intensity theory to predict effort mobilization. Effort should be a direct function of subjective task difficulty—which is systematically influenced by experienced mood or activated affect-related knowledge—as long as success is possible and the required effort is justified.[1]

Several studies have tested and supported the predictions of the mood-behavior-model and the implicit-affect-primes-effort model (see Gendolla, 2012, 2015, in press; Gendolla, Brinkmann, et al., 2012 for reviews). In summary, in easy or moderately difficult tasks individuals engage more effort in a negative mood than in a happy mood (e.g., Gendolla, Abele, & Krüsken, 2001); moreover, they engage more effort when suffering from depressive symptoms than when not suffering from such symptoms (e.g., Brinkmann & Gendolla, 2007); finally, they engage more effort when the concepts of sadness or fear are implicitly activated compared to the implicit activation of the happiness or anger concepts (e.g., Chatelain & Gendolla, 2015; Gendolla & Silvestrini, 2011). This happens in objectively easy or moderately difficult tasks because subjective demand is low (positive mood, weak depressive symptoms, implicit happiness or anger) versus high but feasible (negative mood, depressive symptoms, implicit sadness or fear). However, when participants perform objectively difficult tasks, this pattern turns around, as depicted in Figure 2. In objectively difficult tasks experiencing a positive mood leads to higher effort than a negative mood (e.g., Gendolla & Krüsken, 2001); weak or no depressive symptoms leads to higher effort than strong depressive symptoms (e.g., Brinkmann & Gendolla, 2008); the implicit activation of the happiness or anger concepts leads to higher effort than implicitly activated sadness or fear concepts (e.g., Chatelain, Silvestrini, & Gendolla, 2016; Silvestrini & Gendolla, 2011). The same applies to the effect of implicitly processed pain primes on effort (Silvestrini, 2018). This happens in objectively easy tasks because subjective demand is high but feasible (positive mood, weak depressive symptoms, implicit happiness or anger) versus excessively high (negative mood, depressive symptoms, implicit sadness or fear).

4.2. More Lessons From the Resource Conservation Principle

As discussed now, the resource conservation principle, which is at the core of motivational intensity theory, has received ample empirical support. Accordingly, people avoid wasting resources and only mobilize the amount of effort that is required for goal attainment. In an evolutionary perspective, it is intuitive to preserve resources that are important for survival. But what prevents individuals from wasting resources? How do people know how to adapt their behavior to conserve their resources? We argue that people rely on affective processes to guide their behavior according to the resource conservation principle—as evident in the above discussed research on the systematic impact of experienced affective states and their mental representations on effort mobilization. Available resources should increase the probability of efficient coping with obstacles during goal pursuit and thus facilitate survival and adaptation (see Silvestrini et al., in press). By contrast, little available resources represent a critical situation with the potential of negative—maybe even severely negative—consequences. Consequently, individuals should perceive and evaluate such conditions on the negative side of the valence continuum. That is, resource mobilization should basically be aversive.

Supporting this view, empirical evidence shows that people perceive difficulties and effort as rather unpleasant and costly (Kool, McGuire, Rosen, & Botvinick, 2010; Kool, McGuire, Wang, & Botvinick, 2013; van der Linden, Frese, & Meijman, 2003) and ease as pleasant (e.g., Winkielman & Cacioppo, 2001)—even on the implicit level, as shown by implicit associations between ease/happiness and difficulty/sadness (Lasauskaite, Gendolla, Bolmont, & Freydefont, 2017). This is in line with the laws of least work or minimal effort (Hull, 1943; Tolman, 1932), stipulating that, if two or more actions allow attaining a similar outcome, individuals tend to choose the least effortful option. Initially inspired by the physical law of least action (Ferrero, 1894; Gibson, 1900), empirical evidence has strongly supported this idea in different species, such as humans and rats (Hull, 1943; Kool et al., 2010), and in different domains, such as cognitive performance or linguistics (Zipf, 1949). For instance, rats tend, after some learning trials, to use the shortest and easiest way in a maze to get food (Hull, 1943). Similarly, to get a similar reward, humans prefer and chose a less demanding compared with a more demanding cognitive task (Kool et al., 2010). We interpret this evidence as supporting the idea that effortful action options have an aversive affective component, leading individuals to prefer the least effortful options for attaining comparable outcomes. This “effort-aversion” principle helps people to preserve their resources.

Another independent line of research suggesting that effort is experienced as unpleasant stems from studies on effort justification. Drawing on cognitive dissonance theory (Festinger, 1957), it was found that attitudes about objects become more positive if people expect those objects to be associated with effort (e.g., Wicklund, Cooper, & Linder, 1967). Accordingly, attitude change reflects an attempt to reduce the dissonance induced by the costly and therefore unpleasant aspect of expected effort. Dissonance theory predicts a similar mechanism for any kind of costs (monetary, cognitive, or social) that can be associated with a given action. For instance, after having paid a high price for a computer, people should develop a positive attitude toward this computer to reduce the dissonance induced by the high price—losing money is aversive. Therefore, positive attitude change associated with high effort offers additional support to the idea that effort is perceived as costly and unpleasant. This reasoning has been particularly supported by early studies in the context of motivational intensity theory showing that goal valence (i.e. attractiveness) is a direct function of the effort people have to mobilize for attaining that goal (Brehm, Wright, Solomon, Silka, & Greenberg, 1983): High effort for difficult goals results in highly positive goal valence, while low effort for easy or impossible goals results in less positive goal valence (see Wright & Brehm, 1989 for a review).

In summary, there is good evidence that effort itself has an affective value, which is rather negative—effort is basically experienced as aversive. We acknowledge that there may be special circumstances under which effort can also be positively valued (see Inzlicht et al., 2018). Moreover, we recognize that the fundamental mechanism by which effort is associated with aversiveness remains to be determined—e.g. whether the aversiveness of effort is rather learned or innate. But in any case, it seems that the affective component of effort is essential for allowing individuals to adapt their behavior in an optimal way. Without affect, people would have difficulties to preserve their resources. That is, affective associations of effort facilitate the compliance with the resource conservation principle, which means that they foster adaptation. Therefore, we conclude that affect is a central component of the processes underlying effort adjustment and cognitive control.

4.3. Value and Effort

As discussed so far, it seems that effort has an inherent affective component—it is basically aversive. Additionally, several studies have investigated how variables associated with positive affect—incentives and rewards—influence effort. As a basic principle, it seems that positive incentive can justify and thus outweigh the aversive aspect of effort. Again, research on motivational intensity theory is instructive here.

Several studies have investigated the impact of performance-contingent benefit—i.e. variables influencing the level of potential motivation—the amount of maximally *justified* effort for goal attainment (Brehm & Self, 1989; Wright, 2008). Examples are monetary incentive of success (e.g., Eubanks, Wright, & Williams, 2002; Richter & Gendolla, 2009), instrumentality of success for obtaining a desired outcome (e.g., Silvestrini & Gendolla, 2009; Wright & Gregorich, 1989), or the extent to which performance has positive consequences for performers' self-esteem (see Gendolla & Richter, 2010)—for example because performance is observed (Gendolla & Richter, 2006) or evaluated by others (e.g., Wright, Dill, Geen, & Anderson, 1998) or oneself (Gendolla, Richter, & Silvia, 2008). These studies have focused on both tasks with manipulated fixed difficulty levels and tasks where difficulty was unspecified. As outlined above, motivational intensity theory predicts that high benefit (i.e. potential motivation) justifies the high effort that is necessary to cope with highly difficult demands, while low benefit does not, resulting in disengagement on lower difficulty levels. Moreover, effort intensity should be proportional to potential motivation when task difficulty is unspecified or unknown.

Evidence for such a direct incentive effect on effort-related cardiovascular response was reported by Richter and Gendolla (2006). Attractive incentives resulted in stronger cardiovascular responses during a memory task than unattractive incentives, when task difficulty was not known. By contrast, when difficulty was known, task difficulty determined effort-related cardiovascular reactivity up to the level of performance-contingent benefit: Attractive incentive only resulted in high effort for a difficult task, but not for an easy task. Other studies found that effort-related cardiovascular responses increased proportionally to the extent of monetary success incentive when task difficulty was unknown (Richter & Gendolla, 2007, 2009). That is, high incentive justifies the high and aversive necessary effort for (1) difficult tasks and (2) under conditions under which task difficulty is not known. This casts doubt on approaches positing that benefit always directly determines effort (see Kool & Botvinick, 2018 for an overview).

Although we have made a clear distinction between effort and performance and think that conclusions about the role of effort based on performance measures should be avoided, it is worth looking at performance studies to better understand the role of affect in cognitive control. However, enlarging the focus and looking at the effect of incentive on performance in tasks requiring controlled cognitive processing reveals that evidence is mixed. Some studies found that reward can foster controlled processing, others found that it decreases cognitive control, and still others suggest that reward effects are moderated by further task context variables.

On the one hand, there is evidence that reward stimuli that are processed during the trials of an effortful tasks can augment individuals' cognitive performance (e.g, Custers & Aarts, 2007; Marien, Aarts, & Custers, 2015). This can be interpreted as showing that reward-related positive affect can foster controlled cognitive performance. However, on the other hand, van Steenbergen, Band, and Hommel (2009) found that reward can also reduce cognitive conflict adaptation in a Flanker task—a classical paradigm to study cognitive control. A possible explanation for this latter effect is that reward-related positive affect reduced participants' effort, because it made the task appearing easier than it actually was, resulting in control difficulties. This reasoning is compatible with research by van Steenbergen, Band, and Hommel (2010) in which manipulations of negative affect (anxiety and sadness) fostered conflict adaptation—presumably, because negative affect signals high demand resulting in the allocation of high resources (see also Chatelain & Gendolla, 2015; Framorando & Gendolla, 2018).

However, following up on a study by Pessiglione and colleagues (2007) on implicit monetary incentive cues on the exertion of physical force, Bijleveld, Custers, and Aarts (2009) found that the effect of masked pictures of low vs. high monetary incentive during a digit-retention task was moderated by task difficulty. Measures of pupil dilation during task performance (which is related to sympathetic arousal and has been suggested to mirror mental effort; see van der Wel & van Steenbergen, 2018), found higher arousal when task trials were difficulty and participants were flashed with pictures of valuable coins than when the trials were difficult and associated with low reward, or when the trials were easy. This finding complies with the principles of motivational intensity theory. Accordingly, reward-related positive affect could augment potential motivation and justify the necessary effort for difficult trials (see also Vassena, Deraeve, & Alexander, 2019). However, this positive effect of benefit on effort and performance seems to especially apply to conditions of implicitly processed reward cues (see Bijleveld, Custers, & Aarts, 2012; Zedelius et al., 2014). This suggests that the conscious awareness of benefit can interfere with controlled cognitive processing because the reward cues capture attention and thus reduce the necessary cognitive resources for efficient controlled processing of and responding to the primary cognitive task stimuli. This interpretation is compatible with the above-discussed finding that reward can reduce cognitive conflict adaptation (van Steenbergen et al., 2009). That is, again the principles of motivational intensity theory are instructive for understanding the role of affect in cognitive control and allow to make sense of apparently contradictory findings.

4.4. Effort, Cognitive Control, and the Dorsal Anterior Cingulate Cortex

So far, we have focused on sympathetic nervous system measures of effort—especially responses in the cardiovascular system. As outlined at the beginning of this article, the reason for this has been that effort mobilization is by definition related to activation. However, given that cognitive processing happens in the brain, it is crucial to investigate and understand the links between the central and autonomic nervous systems in cognitive control. Surprisingly, only few studies directly investigated the neural correlates of effort-related autonomic activity (e.g., Critchley et al., 2003; Critchley, Tang, Glaser, Butterworth, & Dolan, 2005). But the cognitive control literature offers a large body of research related to the central neural correlates of control processes (Botvinick, Cohen, & Carter, 2004; Fox, Corbetta, Snyder, Vincent, & Raichle, 2006; Miller & Cohen, 2001; Pessoa, 2009; Seeley et al., 2007; Shackman et al., 2011; Shenhav, Botvinick, & Cohen, 2013). A recent integrative theoretical approach by Silvestrini (2017) aimed at bridging the gap between these two domains. In the context of this special issue and in line with the evidence presented in the preceding sections, this integration suggests that central mechanisms determining effort strongly rely on affective information.

Silvestrini's integration draws on ample evidence indicating that especially one brain region, the dorsal anterior cingulate cortex (dACC), is highly active during demanding cognitive tasks (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Botvinick et al., 2004; Gehring, Goss, Coles, Meyer, & Donchin, 1993; Paus, Koski, Caramanos, & Westbury, 1998; Verguts, Vassena, & Silvetti, 2015). Importantly, studies by Critchley and colleagues (2003, 2005) found that dACC activity is linked to cardiovascular activity during effortful cognitive processes. This suggests that dACC activity at least participates in the regulation of autonomic activity during cognitive performance and contributes to governing effort-related cardiovascular activity. However, it remained unclear how the dACC processes task-related information leading to effort adjustments.

4.4.1. Effort and Conflict Monitoring

To address this issue, Silvestrini's integration referred in a second step to the conflict-monitoring theory and its recent extension as a theoretical and computational background to explain dACC function (Botvinick et al., 2001, 2004; Shenhav et al., 2013; Shenhav, Cohen, & Botvinick, 2016). According to this framework, the dACC monitors the occurrence of conflict, defined as the co-occurrence of competing representations in a given situation. The conflict-monitoring hypothesis predicts that conflict detection should lead in turn to the initiation and modulation of cognitive control, which underlies further behavioral adjustments.

Several experimental and computational modeling studies have lent support to this idea (Botvinick et al., 2001, 2004).

Further research has distinguished between conflict monitoring in the dACC and control implementation in more lateral prefrontal areas, such as the dorso-lateral prefrontal cortex (Egner & Hirsch, 2005; Kerns et al., 2004; MacDonald, Cohen, Stenger, & Carter, 2000; Matsumoto & Tanaka, 2004). Here, implementation of control refers to the engagement of basic cognitive capacities, such as the executive functions, that allow adaptation. However, it is first necessary that the dACC detects a conflict to drive control implementation by engaging the executive functions. In other words, conflict detection is required for any behavioral adjustments that call for effortful control behaviors.

Regarding the influence of affect on these mechanisms, converging evidence supports the idea that conflict—from low-level cognitive conflict to high-level goal conflict—is aversive and produces negative affect (Botvinick, 2007; Dreisbach & Fischer, 2012; Fritz & Dreisbach, 2013). Most important, some authors suggest that conflict-related affect actually drives cognitive control (e.g., Botvinick, 2007; Inzlicht, Bartholow, & Hirsh, 2015). According to Inzlicht et al. (2015), goal conflict leads to negative affect, which motivates individuals refocusing on goal-directed behavior and recruiting control if necessary (see Dignath et al., in press). In contrast, the reduction of conflict would induce positive affect and lead to a reduction of control and effort. Already previous motivation research drawing on cybernetic models conceptualized affect as signaling progress toward goal attainment and driving further behavioral adjustments (e.g., Carver, 2004; Carver & Scheier, 1990, 2017). Overall, this suggests that conflict-related affect contributes to behavioral adjustments and effort.

4.4.2. Effort and the Expected Value of Control Theory

Silvestrini's integration also draws on the expected value of control (EVC) theory, which is considered by its authors as an extension of the conflict monitoring theory (Shenhav et al., 2013, 2016)—although the EVC theory does not make specific predictions about dACC BOLD signal. The EVC theory aims to provide a more comprehensive account of dACC function including additional motivational factors, such as value and costs associated with an action. According to this approach, distinct brain areas process information about value (e.g., the insula, the striatum or the amygdala) and costs (e.g., lateral regions of the prefrontal cortex; McGuire & Botvinick, 2010). The expected value of control model proposes that the dACC integrates value-related and cost-related information by estimating the net value associated with allocating control to a given task and selects the action that offers the highest expected value. Importantly, this selection also applies to the intensity of the signal, which should determine the intensity of a given action and which is close to the concept of effort—the intensity aspect of behavior.

This later extension offers additional support for the role of affect in cognitive control and effort. It proposes that the dACC integrates information about value and costs, which have both a strong affective component. As discussed in detail in the previous sections, value is fundamentally related to valence and affect, and costs by themselves are typically considered as aversive (Kool et al., 2010). This suggests that affective information is relevant for the integration of value and costs to determine further behavioral adjustments. Actually, conflict and conflict-related affect may reflect competing affective information related to value and costs associated with a given situation.

While it is important to keep in mind that other models ascribe different functions to the dACC (e.g., Alexander & Brown, 2011; Holroyd & McClure, 2014; Kolling, Behrens, Mars, & Rushworth, 2012; Vassena, Holroyd, & Alexander, 2017), the integration of the conflict monitoring theory and the EVC theory in the context of effort research offers interesting perspectives (Silvestrini, 2017). First, it reveals an additional rational for assessing cardiovascular reactivity to monitor effort mobilization by suggesting that dACC output drives control implementation together with proportional sympathetic impact on the heart during cognitive tasks. Second, it indicates a distinction between processes that determine how much effort should be engaged, and processes that implement control processes. This is an important point. As presented earlier, control implementation relies on executive functions—the cognitive tools that allow adaptation when automatic cognitive processing is not sufficient. However, it appears that those tools require a mechanism indicating when they have to work. Similarly, one cannot explain effort mobilization without a mechanism that determines when and how much effort should be mobilized. Altogether, the present section indicates that this mechanism is grounded in the dACC and strongly relies on affective information to determine cognitive control and effort. Finally, future research might further investigate the integration between neurocomputational approaches, motivational intensity theory, and effort-related physiological activity to better determine the underlying mechanisms of effortful behavior and performance.

5. Conclusions

Summing up, effort research offers, according to our view, interesting insights for the question of the role of affect in control processes. As discussed in this article, several lines of research have revealed affective influences on effortful processes. A large body of evidence has shown that experienced affective states and their cognitive representations systematically influence effort mobilization in cognitive tasks. This suggests that affect is highly relevant information for effort-related appraisals, such as the subjective difficulty of actions. Further evidence related to the resource conservation principle highlights the aversive aspect of effort itself, which appears instrumental for allowing individuals to adapt their behavior in an optimal way. Accordingly, research on the impact of value on effort indicates that positive incentive has to justify and thus outweigh the aversive aspect of effortful actions. In line with these previous findings, research on the neural substrates and mechanisms underlying effort and cognitive control suggests as well that affect is an important information for behavioral adjustment. Accordingly, affect is related to conflict detection, value processing, and cost processing, which in turn altogether contribute to determine optimal control and effort mobilization.

To conclude, we would like to go back to the two questions we have raised at the beginning of this article. The first question asked whether affective processes are necessary for effort mobilization and intensity. The above-discussed evidence speaks in favor of a “yes” answer. The second question asked whether there could be any aspect of effort mobilization and cognitive control that is independent from affective processes. As discussed in the last section of this article, one may argue that the functions related to the execution or implementation of control, namely what is often referred to as the executive functions, might be considered as “emotionally neutral”. However, the evidence and arguments presented in this article indicate that the initiation, modulation, and withdrawal of these functions draw on affective information. Otherwise, these functions would remain unemployed. Therefore, we consider that affect is necessary and instrumental for the processes that drive control and effort and answer our second question with “no”. Without affect, individuals would probably not engage in any effortful cognitive control.

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References

Abele, A., & Petzold, P. (1994). How does mood operate in an impression formation task? An information integration approach. *European Journal of Social Psychology*, *24*(1), 173‐187. doi: 10.1002/ejsp.2420240113

Ach, N. (1935). *Analyse des Willens [Analysis of the will]*. Berlin, Germany: Urban Schwarzenberg.

Alexander, W. H., & Brown, J. W. (2011). Medial prefrontal cortex as an action-outcome predictor. *Nature Neuroscience*, *14*(10), 1338–1344. doi: 10.1038/nn.2921

Berntson, G. G., Lozano, D. L., Chen, Y.-J., & Cacioppo, J. T. (2004). Where to Q in PEP. *Psychophysiology*, *41*(2), 333–337. doi: 10.1111/j.1469-8986.2004.00156.x

Bijleveld, E., Custers, R., & Aarts, H. (2009). The Unconscious Eye Opener Pupil Dilation Reveals Strategic Recruitment of Resources Upon Presentation of Subliminal Reward Cues. *Psychological Science*, *20*(11), 1313–1315. doi: 10.1111/j.1467-9280.2009.02443.x

Bijleveld, E, Custers, R., & Aarts, H. (2012). Adaptive reward pursuit: How effort requirements affect unconscious reward responses and conscious reward decisions. *Journal of Experimental Psychology: General*, *141*(4), 728–742. doi: 10.1037/a0027615

Bijleveld, E. (2018). The feeling of effort during mental activity. *Consciousness and Cognition*, *63*, 218–227. doi: 10.1016/j.concog.2018.05.013

Bijleveld, E., Custers, R., & Aarts, H. (2010). Unconscious reward cues increase invested effort, but do not change speed-accuracy tradeoffs. *Cognition*, *115*(2), 330–335. doi: https://doi.org/10.1016/j.cognition.2009.12.012

Botvinick, M. M. (2007). Conflict monitoring and decision making: Reconciling two perspectives on anterior cingulate function. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(4), 356–366. doi: 10.3758/CABN.7.4.356

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652. doi: 10.1037/0033-295X.108.3.624

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: an update. *Trends in Cognitive Sciences*, *8*(12), 539–546. doi: 10.1016/j.tics.2004.10.003

Bower, G. H. (1981). Mood and memory. *American Psychologist*, *36*(2), 129–148. doi: 10.1037/0003-066X.36.2.129

Brehm, J. W., & Self, E. A. (1989). The Intensity of Motivation. *Annual Review of Psychology*, *40*(1), 109–131. doi: 10.1146/annurev.ps.40.020189.000545

Brehm, J. W., Wright, R. A., Solomon, S., Silka, L., & Greenberg, J. (1983). Perceived difficulty, energization, and the magnitude of goal valence. *Journal of Experimental Social Psychology*, *19*(1), 21–48. doi: 10.1016/0022-1031(83)90003-3

Brehm, J. W. (1975). *Research on motivational suppression*. Research Proposal submitted to the National Science Foundation. Department of Psychology, University of Kansas.

Brehm, J. W., Wright, R. A., Solomon, S., Silka, L., & Greenberg, J. (1983). Perceived difficulty, energization, and the magnitude of goal valence. *Journal of Experimental Social Psychology*, *19*(1), 21–48. doi: 10.1016/0022-1031(83)90003-3

Brinkmann, K., & Gendolla, G. H. E. (2007). Dysphoria and mobilization of mental effort: Effects on cardiovascular reactivity. *Motivation and Emotion*, *31*(1), 71–82. doi: 10.1007/s11031-007-9054-0

Brinkmann, K., & Gendolla, G. H. E. (2008). Does depression interfere with effort mobilization? Effects of dysphoria and task difficulty on cardiovascular response. *Journal of Personality and Social Psychology*, *94*(1), 146–157. doi: 10.1037/0022-3514.94.1.146

Brownley, K. A., Hurwitz, B. E., & Schneiderman, N. (2000). Cardiovascular psychophysiology. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of Psychophysiology* (pp. 224–264). New York, NY, US: Cambridge University Press.

Carver, C. S. (2004). Negative affects deriving from the behavioral approach system. *Emotion*, *4*(1), 3–22. doi: 10.1037/1528-3542.4.1.3

Carver, C. S., & Scheier, M. F. (1990). Origins and functions of positive and negative affect: A control-process view. *Psychological Review*, *97*(1), 19. doi: 10.1037/0033-295X.97.1.19

Carver, C. S., & Scheier, M. F. (2017). Self-regulatory functions supporting motivated action. In A. J. Elliot (Ed.), *Advances in motivation science* (Vol. 4, pp. 1–37). doi: 10.1016/bs.adms.2017.02.002

Chatelain, M., & Gendolla, G. H. E. (2015). Implicit fear and effort-related cardiac response. *Biological Psychology*, *111*, 73–82. doi: 10.1016/j.biopsycho.2015.08.009

Chatelain, M., Silvestrini, N., & Gendolla, G. H. E. (2016). Task difficulty moderates implicit fear and anger effects on effort-related cardiac response. *Biological Psychology*, *115*, 94–100. doi: 10.1016/j.biopsycho.2016.01.014

Critchley, H. D., Mathias, C. J., Josephs, O., O'Doherty, J., Zanini, S., Dewar, B.-K., … Dolan, R. J. (2003). Human cingulate cortex and autonomic control: converging neuroimaging and clinical evidence. *Brain*, *126*(10), 2139–2152. doi: 10.1093/brain/awg216

Critchley, H. D., Tang, J., Glaser, D., Butterworth, B., & Dolan, R. J. (2005). Anterior cingulate activity during error and autonomic response. *NeuroImage*, *27*(4), 885–895. doi: 10.1016/j.neuroimage.2005.05.047

Custers, R., & Aarts, H. (2007). In search of the nonconscious sources of goal pursuit: Accessibility and positive affective valence of the goal state. *Journal of Experimental Social Psychology*, *43*(2), 312–318. doi: 10.1016/j.jesp.2006.02.005

Dignath, D., Wirth, R., Kühnhausen, J., Gawrilow, C., Kunde, W., & Kiesel, A. (in press). Motivation drives conflict adaptation. *Motivation Science*.

Dreisbach, G., & Fischer, R. (2012). Conflicts as aversive signals. *Brain and Cognition*, *78*(2), 94–98. doi: 10.1016/j.bandc.2011.12.003

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience*, *8*(12), 1784–1790. doi: 10.1038/nn1594

Eubanks, L., Wright, R. A., & Williams, B. J. (2002). Reward influence on the heart: Cardiovascular response as a function of incentive value at five levels of task demand. *Motivation and Emotion*, *26*(2), 139–152. doi: 10.1023/A:1019863318803

Ferrero, G. (1894). L'inertie mental et la loi du moindre effort [Mental inertia and the law of least effort]. *Revue Philosophique de La France et de l'Étranger*, *37*, 169–182.

Festinger, L. (1957). *A theory of cognitive dissonance*. Stanford, CA: Stanford University Press.

Forgas, J. P. (1995). Mood and judgment: The affect infusion model (AIM). *Psychological Bulletin*, *117*(1), 39–66. doi: 10.1037/0033-2909.117.1.39

Fox, M. D., Corbetta, M., Snyder, A. Z., Vincent, J. L., & Raichle, M. E. (2006). Spontaneous neuronal activity distinguishes human dorsal and ventral attention systems. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(26), 10046–10051. doi: 10.1073/pnas.0604187103

Framorando, D., & Gendolla, G. H. E. (2018). Prime visibility moderates implicit anger and sadness effects on effort-related cardiac response. *Biological Psychology*, *135*, 204–210. doi: 10.1016/j.biopsycho.2018.04.007

Freydefont, L., Gollwitzer, P. M., & Oettingen, G. (2016). Goal striving strategies and effort mobilization: When implementation intentions reduce effort-related cardiac activity during task performance. *International Journal of Psychophysiology*, *107*, 44–53. doi: 10.1016/j.ijpsycho.2016.06.013

Frijda, N. H., & Scherer, K. R. (2009). Affect (Psychological Perspectives). In D. Sander & K. R. Scherer (Eds.), *The Oxford Companion to Emotion and the Affective Sciences* (p. 10). Oxford University Press.

Fritz, J., & Dreisbach, G. (2013). Conflicts as aversive signals: Conflict priming increases negative judgments for neutral stimuli. *Cognitive, Affective, & Behavioral Neuroscience*, *13*(2), 311–317. doi: 10.3758/s13415-012-0147-1

Gable, P., & Harmon-Jones, E. (2010). The motivational dimensional model of affect: Implications for breadth of attention, memory, and cognitive categorisation. *Cognition and Emotion*, *24*(2), 322–337. doi: 10.1080/02699930903378305

Geen, R. G. (1995). *Human motivation: A social psychological approach*. Belmont, CA, US: Thomson Brooks/Cole Publishing Co.

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science (0956-7976)*, *4*(6), 385–390. doi: https://doi.org/10.1111/j.1467-9280.1993.tb00586.x

Gendolla, G. H. E. (in press). Effort mobilization in self-regulation: The impact of experienced and implicit affect. In J. Shaw (Ed.), *Self-regulation: Context, capacity, and challenge*. New York, NY: Psychology Press.

Gendolla, G. H. E. (2000). On the impact of mood on behavior: An integrative theory and a review. *Review of General Psychology*, *4*(4), 378–408. doi: 10.1037/1089-2680.4.4.378

Gendolla, G. H. E. (2012). Implicit affect primes effort: A theory and research on cardiovascular response. *International Journal of Psychophysiology*, *86*(2), 123–135. doi: 10.1016/j.ijpsycho.2012.05.003

Gendolla, G. H. E. (2015). Implicit affect primes effort: basic processes, moderators, and boundary conditions. *Social and Personality Psychology Compass*, *9*(11), 606–619. doi: 10.1111/spc3.12208

Gendolla, G. H. E. (2017). The psychophysiology of motivation: Body and brain in action. *International Journal of Psychophysiology*, *119*, 1–3. doi: 10.1016/j.ijpsycho.2017.05.010

Gendolla, G. H. E., Abele, A. E., & Krüsken, J. (2001). The informational impact of mood on effort mobilization: A study of cardiovascular and electrodermal responses. *Emotion*, *1*(1), 12–24. doi: 10.1037/1528-3542.1.1.12

Gendolla, G. H. E., Brinkmann, K., & Silvestrini, N. (2012). Gloomy and lazy? On the impact of mood and depressive symptoms on effort-related cardiovascular response. In R. A. Wright & G. H. E. Gendolla (Eds.), *How motivation affects cardiovascular response: Mechanisms and applications* (pp. 139–155). doi: 10.1037/13090-007

Gendolla, G. H. E., & Krüsken, J. (2001). The joint impact of mood state and task difficulty on cardiovascular and electrodermal reactivity in active coping. *Psychophysiology*, *38*(3), 548–556. doi: 10.1017/S0048577201000622

Gendolla, G. H. E., & Richter, M. (2006). Ego-involvement and the difficulty law of motivation: Effects on performance-related cardiovascular response. *Personality and Social Psychology Bulletin*, *32*(9), 1188–1203. doi: 10.1177/0146167206288945

Gendolla, G. H. E., & Richter, M. (2010). Effort mobilization when the self is involved: Some lessons from the cardiovascular system. *Review of General Psychology*, *14*(3), 212–226. doi: 10.1037/a0019742

Gendolla, G. H. E., Richter, M., & Silvia, P. J. (2008). Self-focus and task difficulty effects on effort-related cardiovascular reactivity. *Psychophysiology*, *45*(4), 653–662. doi: 10.1111/j.1469-8986.2008.00655.x

Gendolla, G. H. E., & Silvestrini, N. (2011). Smiles make it easier and so do frowns: Masked affective stimuli influence mental effort. *Emotion*, *11*(2), 320. doi: 10.1037/a0022593

Gendolla, G. H. E., & Wright, R. A. (2009). Effort. In D. Sander & K. R. Scherer (Eds.), *The Oxford companion to emotion and the affective science* (pp. 134–135). New York, NY: Oxford University Press.

Gendolla, G. H. E., Wright, R. A., & Richter, M. (in press). Advancing issues in motivation intensity research: Updated insights from the cardiovascular system. In R. M. Ryan (Ed.), *The Oxford handbook of human motivation (2nd ed)*. New York, NY: Oxford University Press.

Gendolla, G. H. E., Wright, R. A., & Richter, M. (2012). Effort intensity: Some insights from the cardiovascular system. In R. M. Ryan (Ed.), *The Oxford handbook of human motivation* (pp. 420–438). New York, NY: Oxford University Press. Scopus.

Gibson, W. R. B. (1900). The Principle of Least Action as a Psychological Principle. *Mind*, *9*(36), 469–495.

Hancock, P. A., & Warm, J. S. (1989). A Dynamic Model of Stress and Sustained Attention. *Human Factors*, *31*(5), 519–537. doi: 10.1177/001872088903100503

Harmon-Jones, E., Price, T. F., & Gable, P. A. (2012). The Influence of Affective States on Cognitive Broadening/Narrowing: Considering the Importance of Motivational Intensity. *Social and Personality Psychology Compass*, *6*(4), 314–327. doi: 10.1111/j.1751-9004.2012.00432.x

Hillgruber, A. (1912). *Fortlaufende Arbeit und Willensbetätigung. [Continuous work and the will]*. Leipzig, Germany: Quelle und Meyer.

Hockey, G. R. J. (1997). Compensatory control in the regulation of human performance under stress and high workload: A cognitive-energetical framework. *Biological Psychology*, *45*(1–3), 73–93. doi: 10.1016/S0301-0511(96)05223-4

Holroyd, C. B., & McClure, S. M. (2014). Hierarchical Control Over Effortful Behavior by Rodent Medial Frontal Cortex: A Computational Model. *Psychological Review*, No Pagination Specified. doi: 10.1037/a0038339

Hull, C. L. (1943). *Principles of behavior*. New York, NY: Appleton- Century.

Inzlicht, M., Bartholow, B. D., & Hirsh, J. B. (2015). Emotional foundations of cognitive control. *Trends in Cognitive Sciences*, *19*(3), 126–132. doi: 10.1016/j.tics.2015.01.004

Inzlicht, M., Shenhav, A., & Olivola, C. (2018). The effort paradox: Effort is both costly and valued. *Trends in Cognitive Sciences*. doi: 10.17605/OSF.IO/B5A2M

Isen, A. M. (1984). Toward understanding the role of affect in cognition. In *Handbook of social cognition, Vol 3.* (pp. 179–236). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

James, W. (1880). The feeling of effort. *Mind*, *5*(20), 582.

Joshi, S., Li, Y., Kalwani, R. M., & Gold, J. I. (2016). Relationships between Pupil Diameter and Neuronal Activity in the Locus Coeruleus, Colliculi, and Cingulate Cortex. *Neuron*, *89*(1), 221–234. doi: 10.1016/j.neuron.2015.11.028

Jurado, M. B., & Rosselli, M. (2007). The elusive nature of executive functions: A review of our current understanding. *Neuropsychology Review*, *17*(3), 213–233. doi: 10.1007/s11065-007-9040-z

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice-Hall.

Kahneman, D., & Beatty, J. (1966). Pupil Diameter and Load on Memory. *Science*, *154*(3756), 1583–1585. doi: 10.1126/science.154.3756.1583

Kerns, J. G., Cohen, J. D., MacDonald, A. W., Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulate conflict monitoring and adjustments in control. *Science*, *303*(5660), 1023–1026. doi: 10.1126/science.1089910

Kolling, N., Behrens, T. E. J., Mars, R. B., & Rushworth, M. F. S. (2012). Neural Mechanisms of Foraging. *Science*, *336*(6077), 95–98. doi: 10.1126/science.1216930

Kool, W., & Botvinick, M. (2018). Mental labour. *Nature Human Behaviour*, *2*(12), 899–908. doi: 10.1038/s41562-018-0401-9

Kool, W., McGuire, J. T., Rosen, Z. B., & Botvinick, M. M. (2010). Decision making and the avoidance of cognitive demand. *Journal of Experimental Psychology: General*, *139*(4), 665–682. doi: 10.1037/a0020198

Kool, W., McGuire, J. T., Wang, G. J., & Botvinick, M. M. (2013). Neural and Behavioral Evidence for an Intrinsic Cost of Self-Control. *PLOS ONE*, *8*(8), e72626. doi: 10.1371/journal.pone.0072626

Koole, S. L., Jostmann, N. B., & Baumann, N. (2012). Do demanding conditions help or hurt self-regulation? *Social and Personality Psychology Compass*, *6*(4), 328–346. doi: 10.1111/j.1751-9004.2012.00425.x

Kurzban, R., Duckworth, A., Kable, J. W., & Myers, J. (2013). An opportunity cost model of subjective effort and task performance. *Behavioral and Brain Sciences*, *36*(6), 661–679. doi: 10.1017/S0140525X12003196

Lasauskaite, R., Gendolla, G. H. E., Bolmont, M., & Freydefont, L. (2017). Implicit happiness and sadness are associated with ease and difficulty: evidence from sequential priming. *Psychological Research*, *81*(1), 321–331. doi: 10.1007/s00426-015-0732-3

Lazarus, R. S. (1983). Thoughts on the relations between emotion and cognition. *American Psychologist*, *37*(9), 1019. doi: 10.1037/0003-066X.37.9.1019

Lazarus, R. S. (1984). On the primacy of cognition. *American Psychologist*, *39*(2), 124. doi: 10.1037/0003-066X.39.2.124

Leventhal, H., & Scherer, K. R. (1987). The relationship of emotion to cognition: A functional approach to a semantic controversy. *Cognition and Emotion*, *1*(1), 3–28.

Locke, E. A., & Latham, G. P. (1990). *A theory of goal setting and task performance*. Upper Saddle River, NJ: Prentice-Hall.

Locke, E. A., & Latham, G. P. (2019). The development of goal setting theory: A half century retrospective. *Motivation Science*. doi: 10.1037/mot0000127

MacDonald, A. W., Cohen, J. D., Stenger, V. A., & Carter, C. S. (2000). Dissociating the role of the dorsolateral prefrontal and anterior cingulate cortex in cognitive control. *Science*, *288*(5472), 1835–1838. doi: 10.1126/science.288.5472.1835

Marcora, S. (2009). Perception of effort during exercise is independent of afferent feedback from skeletal muscles, heart, and lungs. *Journal of Applied Physiology*, *106*(6), 2060–2062. doi: 10.1152/japplphysiol.90378.2008

Marien, H., Aarts, H., & Custers, R. (2015). The interactive role of action-outcome learning and positive affective information in motivating human goal-directed behavior. *Motivation Science*, *1*(3), 165–183. doi: 10.1037/mot0000021

Massin, O. (2017). Towards a definition of efforts. *Motivation Science*, *3*(3), 230–259. doi: 10.1037/mot0000066

Matsumoto, K., & Tanaka, K. (2004). Conflict and cognitive control. *Science*, *303*(5660), 969–970. doi: 10.1126/science.1094733

McGuire, J. T., & Botvinick, M. M. (2010). Prefrontal cortex, cognitive control, and the registration of decision costs. *Proceedings of the National Academy of Sciences*, *107*(17), 7922–7926. doi: 10.1073/pnas.0910662107

Metcalfe, J., & Mischel, W. (1999). A hot/cool-system analysis of delay of gratification: Dynamics of willpower. *Psychological Review*, *106*(1), 3–19. doi: 10.1037/0033-295X.106.1.3

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience*, *24*(1), 167–202. doi: 10.1146/annurev.neuro.24.1.167

Miller, E. K., & Wallis, J. D. (2009). Executive function and higher-order cognition: definition and neural substrates. In L. R. Squire (Ed.), *Encyclopedia of neuroscience* (Vol. 4, pp. 99–104). Oxford: Academic Press.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive function and their contributions to complex" frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. doi: 10.1006/cogp.1999.0734

Navon, D. (1984). Resources—a theoretical soup stone? *Psychological Review*, *91*(2), 216–234. doi: 10.1037/0033-295X.91.2.216

Newsholme, E. A., Blomstrand, E., & Ekblom, B. (1992). Physical and mental fatigue: Metabolic mechanisms and importance of plasma amino acids. *British Medical Bulletin*, *48*(3), 477–495. doi: 10.1093/oxfordjournals.bmb.a072558

Niendam, T. A., Laird, A. R., Ray, K. L., Dean, Y. M., Glahn, D. C., & Carter, C. S. (2012). Meta-analytic evidence for a superordinate cognitive control network subserving diverse executive functions. *Cognitive, Affective, & Behavioral Neuroscience*, *12*(2), 241–268. doi: 10.3758/s13415-011-0083-5

Norman, D. A., & Bobrow, D. G. (1975). On data-limited and resource-limited processes. *Cognitive Psychology*, *7*(1), 44–64. doi: 10.1016/0010-0285(75)90004-3

Norman, D. A., & Shallice, T. (1986). Attention to action. In R. J. Davidson, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation: Advances in research and theory* (pp. 1–18). Boston, MA: Springer US.

Obrist, P. A. (1981). *Cardiovascular psychophysiology: A perspective*. New York, NY: Plenum Press.

Paus, T., Koski, L., Caramanos, Z., & Westbury, C. (1998). Regional differences in the effects of task difficulty and motor output on blood flow response in the human anterior cingulate cortex: a review of 107 PET activation studies. *Neuroreport*, *9*(9), R37–R47.

Pessiglione, M., Schmidt, L., Draganski, B., Kalisch, R., Lau, H., Dolan, R. J., & Frith, C. D. (2007). How the brain translates money into force: A neuroimaging study of subliminal motivation. *Science*, *316*(5826), 904–906. doi: 10.1126/science.1140459

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences*, *13*(4), 160–166. doi: 10.1016/j.tics.2009.01.006

Posner, M. I., & Snyder, C. R. R. (1975). Attention and cognitive control. In R. L. Solso (Ed.), *Information processing and cognition* (pp. 55–85). Hillsdale, NJ: Erlbaum.

Richter, M., & Gendolla, G. H. E. (2006). Incentive effects on cardiovascular reactivity in active coping with unclear task difficulty. *International Journal of Psychophysiology*, *61*(2), 216–225. doi: 10.1016/j.ijpsycho.2005.10.003

Richter, M., & Gendolla, G. H. E. (2007). Incentive value, unclear task difficulty, and cardiovascular reactivity in active coping. *International Journal of Psychophysiology*, *63*(3), 294–301. doi: 10.1016/j.ijpsycho.2006.12.002

Richter, M., & Gendolla, G. H. E. (2009). The heart contracts to reward: Monetary incentives and preejection period. *Psychophysiology*, *46*(3), 451–457. doi: 10.1111/j.1469-8986.2009.00795.x

Richter, M., Gendolla, G. H. E., & Wright, R. A. (2016). Three decades of research on motivational intensity theory: What we have learned about effort and what we still don't know. *Advances in Motivation Science*, *3*, 149–168. doi: http://dx.doi.org/10.1016/bs.adms.2016.02.001

Roets, A., Van Hiel, A., Cornelis, I., & Soetens, B. (2008). Determinants of task performance and invested effort: A need for closure by relative cognitive capacity interaction analysis. *Personality and Social Psychology Bulletin*, *34*(6), 779–792. doi: 10.1177/0146167208315554

Sander, D., & Scherer, K. R. (2009). *The Oxford companion to emotion and the affective sciences*. New York, NY: Oxford University Press.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review*, *84*(1), 1–66. doi: 10.1037/0033-295X.84.1.1

Schwarz, N., & Clore, G. L. (1983). Mood, misattribution, and judgments of well-being: Informative and directive functions of affective states. *Journal of Personality and Social Psychology*, *45*(3), 513–523. doi: 10.1037/0022-3514.45.3.513

Schwarz, N., & Clore, G. L. (1988). How do I feel about it? The informative function of affective states. In K. Fiedler & J. P. Forgas (Eds.), *Affect, cognition and social behavior* (pp. 44–62). Göttingen, Germany: Hogrefe.

Schwarz, N., & Clore, G. L. (1996). Feelings and phenomenal experiences. In E. T. Higgins & A. W. Kruglanski (Eds.), *Social psychology: Handbook of basic principles* (pp. 433–465). New York, NY, US: Guilford Press.

Seeley, W. W., Menon, V., Schatzberg, A. F., Keller, J., Glover, G. H., Kenna, H., … Greicius, M. D. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *The Journal of Neuroscience*, *27*(9), 2349–2356. doi: 10.1523/JNEUROSCI.5587-06.2007

Shackman, A. J., Salomons, T. V., Slagter, H. A., Fox, A. S., Winter, J. J., & Davidson, R. J. (2011). The integration of negative affect, pain and cognitive control in the cingulate cortex. *Nature Reviews Neuroscience*, *12*(3), 154–167. doi: 10.1038/nrn2994

Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: An integrative theory of anterior cingulate cortex function. *Neuron*, *79*(2), 217–240. doi: 10.1016/j.neuron.2013.07.007

Shenhav, A., Cohen, J. D., & Botvinick, M. M. (2016). Dorsal anterior cingulate cortex and the value of control. *Nature Neuroscience*, *19*(10), 1286–1291. doi: 10.1038/nn.4384

Shenhav, A., Musslick, S., Lieder, F., Kool, W., Griffiths, T. L., Cohen, J. D., & Botvinick, M. M. (2017). Toward a Rational and Mechanistic Account of Mental Effort. *Annual Review of Neuroscience*, *40*(1), null. doi: 10.1146/annurev-neuro-072116-031526

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review*, *84*(2), 127–190. doi: 10.1037/0033-295X.84.2.127

Silvestrini, N. (2015). The effort-related cost of implicit pain. *Motivation Science*, *1*(3), 151–164. doi: 10.1037/mot0000020

Silvestrini, N. (2017). Psychological and neural mechanisms associated with effort-related cardiovascular reactivity and cognitive control: An integrative approach. *International Journal of Psychophysiology*, *119*, 11–18. doi: 10.1016/j.ijpsycho.2016.12.009

Silvestrini, N. (2018). On the implicit influence of pain cues on cognitive effort: Evidence from cardiovascular reactivity. *Biological Psychology*, *132*, 45–54. doi: 10.1016/j.biopsycho.2017.11.002

Silvestrini, N., & Gendolla, G. H. E. (2009). Mood-regulative hedonic incentive interacts with mood and task difficulty to determine effort-related cardiovascular response and facial EMG. *Biological Psychology*, *82*(1), 54–63. doi: 10.1016/j.biopsycho.2009.05.005

Silvestrini, N., & Gendolla, G. H. E. (2011). Masked affective stimuli moderate task difficulty effects on effort-related cardiovascular response. *Psychophysiology*, *48*(8), 1157–1164. doi: 10.1111/j.1469-8986.2011.01181.x

Silvestrini, N., Vuignier, E., Matthey, A., & Piguet, V. (in press). The perception of available resources influences the after-effect of cognitive control on cognitive performance and pain. *Social Psychology*.

Silvetti, M., Vassena, E., Abrahamse, E., & Verguts, T. (2018). Dorsal anterior cingulate-brainstem ensemble as a reinforcement meta-learner. *PLOS Computational Biology*, *14*(8), e1006370. doi: 10.1371/journal.pcbi.1006370

Smith, B. T., & Hess, T. M. (2015). The impact of motivation and task difficulty on resource engagement: Differential influences on cardiovascular responses of young and older adults. *Motivation Science*, *1*(1), 22. doi: 10.1037/mot0000012

Tolman, E. C. (1932). *Purposive behavior in animals and men*. New York, NY, US: Appleton-Century-Crofts.

van der Linden, D., Frese, M., & Meijman, T. F. (2003). Mental fatigue and the control of cognitive processes: effects on perseveration and planning. *Acta Psychologica*, *113*(1), 45–65. doi: 10.1016/S0001-6918(02)00150-6

van der Wel, P., & van Steenbergen, H. (2018). Pupil dilation as an index of effort in cognitive control tasks: A review. *Psychonomic Bulletin & Review*, *25*(6), 2005–2015. doi: 10.3758/s13423-018-1432-y

van Steenbergen, H., Band, G. P. H., & Hommel, B. (2010). In the mood for adaptation: How affect regulates conflict-driven control. *Psychological Science*, *21*(11), 1629–1634. doi: 10.1177/0956797610385951

van Steenbergen, H. van, Band, G. P. H., & Hommel, B. (2009). Reward counteracts conflict adaptation: Evidence for a role of affect in executive control. *Psychological Science*, *20*(12), 1473–1477. doi: 10.1111/j.1467-9280.2009.02470.x

Vassena, E., Deraeve, J., & Alexander, W. H. (2019). Task-specific prioritization of reward and effort information: Novel insights from behavior and computational modeling. *Cognitive, Affective, & Behavioral Neuroscience*. doi: 10.3758/s13415-018-00685-w

Vassena, E., Holroyd, C. B., & Alexander, W. H. (2017). Computational Models of Anterior Cingulate Cortex: At the Crossroads between Prediction and Effort. *Frontiers in Neuroscience*, *11*. doi: 10.3389/fnins.2017.00316

Verguts, T., Vassena, E., & Silvetti, M. (2015). Adaptive effort investment in cognitive and physical tasks: a neurocomputational model. *Frontiers in Behavioral Neuroscience*, *9*. doi: 10.3389/fnbeh.2015.00057

Weiner, B. (2018). The legacy of an attribution approach to motivation and emotion: A no-crisis zone. *Motivation Science*, *4*(1), 4–14. doi: 10.1037/mot0000082

Wickens, C. D. (1984). Processing resources in attention. In R. Parasuraman & R. Davies (Eds.), *Varieties of Attention* (pp. 63–101). New York: Academic Press.

Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, *3*(2), 159–177. doi: 10.1080/14639220210123806

Wicklund, R. A., Cooper, J., & Linder, D. E. (1967). Effects of expected effort on attitude change prior to exposure. *Journal of Experimental Social Psychology*, *3*(4), 416–428. doi: 10.1016/0022-1031(67)90006-6

Winkielman, P., & Cacioppo, J. T. (2001). Mind at ease puts a smile on the face: Psychophysiological evidence that processing facilitation elicits positive affect. *Journal of Personality and Social Psychology*, *81*(6), 989–1000. doi: 10.1037/0022-3514.81.6.989

Wright, R. A. (1996). Brehm's theory of motivation as a model of effort and cardiovascular response. In P. M. Gollwitzer & J. A. Bargh (Eds.), *The psychology of action: Linking cognition and motivation to behavior* (pp. 424–453). New York, NY: Guilford Press.

Wright, R. A. (1998). Ability perception and cardiovascular response to behavioral challenge. In M. Kofta, G. Weary, & G. Sedek (Eds.), *Personal control in action: Cognitive and motivational mechanisms* (pp. 197–232). doi: 10.1007/978-1-4757-2901-6_8

Wright, R. A. (2008). Refining the prediction of effort: Brehm's distinction between potential motivation and motivation intensity. *Social and Personality Psychology Compass*, *2*(2), 682–701. doi: 10.1111/j.1751-9004.2008.00093.x

Wright, R. A., & Brehm, J. W. (1989). Energization and goal attractiveness. In L. A. Pervin (Ed.), *Goal concepts in personality and social psychology* (pp. 169–210). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Wright, R. A., Contrada, R. J., & Patane, M. J. (1986). Task difficulty, cardiovascular response, and the magnitude of goal valence. *Journal of Personality and Social Psychology*, *51*(4), 837–843. doi: 10.1037/0022-3514.51.4.837

Wright, R. A., Dill, J. C., Geen, R. G., & Anderson, C. A. (1998). Social evaluation influence on cardiovascular response to a fixed behavioral challenge: Effects across a range of difficulty levels. *Annals of Behavioral Medicine*, *20*(4), 277–285. doi: 10.1007/BF02886377

Wright, R. A., & Gregorich, S. (1989). Difficulty and instrumentality of imminent behavior as determinants of cardiovascular response and self-reported energy. *Psychophysiology*, *26*(5), 586–592. doi: 10.1111/j.1469-8986.1989.tb00715.x

Wright, R. A., & Kirby, L. D. (2001). Effort determination of cardiovascular response: An integrative analysis with applications in social psychology. In M. P. Zanna (Ed.), *Advances in Experimental Social Psychology* (Vol. 33, pp. 255–307). San Diego, CA: Academic Press.

Wright, R. A., & Mlynski, C. (2019). Fatigue determination of inhibitory strength and control: A babe in a bath. *Motivation Science*, *5*(1), 66–78. doi: 10.1037/mot0000114

Wright, R. A., & Stewart, C. C. (2012). Multifaceted effects of fatigue on effort and associated cardiovascular responses. In R. A. Wright & G. H. E. Gendolla (Eds.), *How motivation affects cardiovascular response: Mechanisms and applications* (pp. 199–218). doi: 10.1037/13090-010

Wyer, R. S., Clore, G. L., & Isbell, L. M. (1999). Affect and Information Processing. *Advances in Experimental Social Psychology*, *31*, 1–77. doi: 10.1016/S0065-2601(08)60271-3

Zafeiriou, A., & Gendolla, G. H. E. (2017). Implicit activation of the aging stereotype influences effort-related cardiovascular response: The role of incentive. *International Journal of Psychophysiology*, *119*, 79–86. doi: 10.1016/j.ijpsycho.2017.01.011

Zajonc, R. B. (1980). Feeling and thinking: Preferences need no inferences. *American Psychologist*, *35*(2), 151–175. doi: 10.1037/0003-066X.35.2.151

Zajonc, R. B. (1984). On the primacy of affect. *American Psychologist*, *39*(2), 117–123. doi: 10.1037/0003-066X.39.2.117

Zedelius, C. M., Veling, H., Custers, R., Bijleveld, E., Chiew, K. S., & Aarts, H. (2014). A new perspective on human reward research: How consciously and unconsciously perceived reward information influences performance. *Cognitive, Affective, & Behavioral Neuroscience*, *14*(2), 493–508. doi: 10.3758/s13415-013-0241-z

Zipf, G. K. (1949). *Human behavior and the principle of least effort*. Cambridge, MA: Addison-Wesley.

Footnotes

[1] It is of note that numerous other models investigated affect-cognition interactions (e.g., Abele & Petzold, 1994; Forgas, 1995; Schwarz & Clore, 1983). For instance, the motivational dimension model of affect proposes that affect may vary in terms of the intensity of approach vs. avoidance motivation, which determines in turn the breadth of attention and memory (e.g., Gable & Harmon-Jones, 2010; Harmon- Jones, Price, & Gable, 2012). However, providing an extensive review of this emotion-cognition literature would go beyond the scope of the present article, especially because cognition and not effort is the mere focus of these models. Therefore, given the initial purpose of this article, we find it more appropriate to exclusively focus on effort research.

Figure Captions

Figure 1

Theoretical predictions of the joint impact of task difficulty and potential motivation on effort intensity according to motivational intensity theory (Brehm & Self, 1989). *A* shows predictions for effort mobilization when low effort is justified (i.e., low potential motivation). *B* shows predictions for the condition that high effort is justified (i.e., high potential motivation). (Adapted from Gendolla & Wright, 2009, p. 134. Copyright: Oxford University Press, printed with permission.)

Figure 2

The combined impact of experienced and implicit affect and task difficulty on effort intensity.

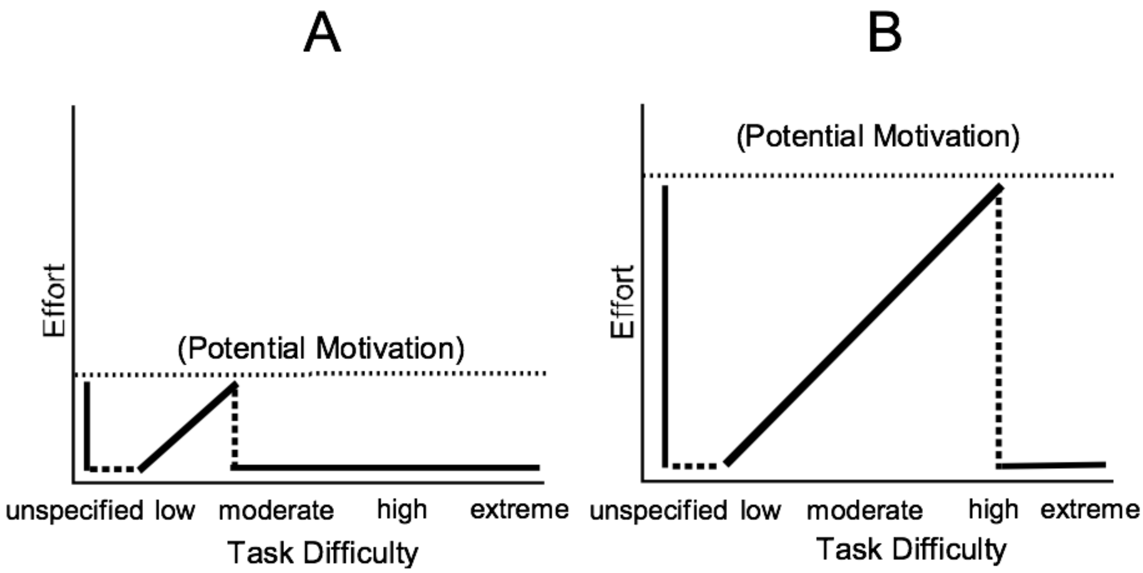

Figure 1

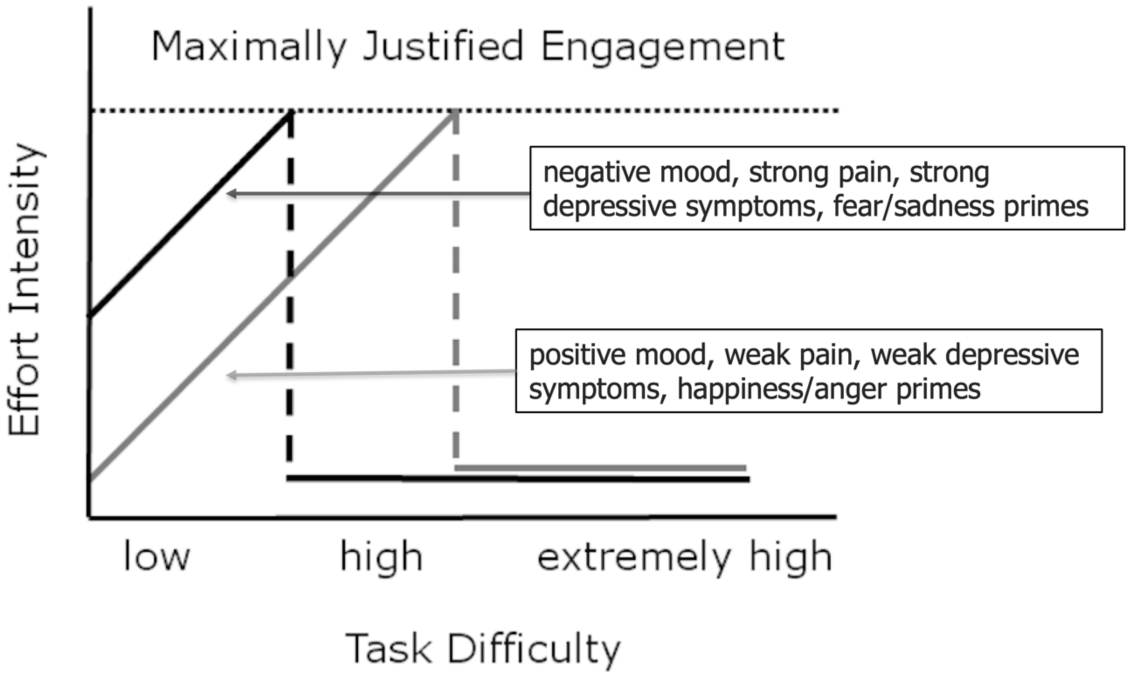

Figure 2