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Prefrontal asymmetry and dealing with failure: Investigating affect regulation and performance

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Failures, repeated failures,
are finger posts on the road to
achievement.

- Charles Kettering -

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Table of contents

List of figures

List of abbreviations

ACC	Anterior cingulate cortex
AOF	Action orientation subsequent to failure
AIM	Asymmetric Inhibition Model
BAS	Behavioral activation system
BIS	Behavioral inhibition system
dlPFC	Dorsolateral prefrontal cortex
dmPFC	Dorsomedial prefrontal cortex
EEG	Electroencephalography
FFFS	Flight-flight-freeze system
fMRI	Functional magnetic resonance imagery
MRT	Mental rotation test
OFC	Orbitofrontal cortex
PFA	Prefrontal asymmetry
PFC	Prefrontal cortex
r-BIS	Revised behavioral inhibition system
RHH	Right hemisphere hypothesis
VAS	Visual analogue scale
VH	Valence hypothesis
vmPFC	Ventromedial prefrontal cortex

Abstract

Winning and losing are constituent elements of many performance areas, but they are especially salient in sports. However, failure is perceived as an adverse event that is accompanied by an increase in negative affect and decrease in positive affect. While some athletes manage to overcome this negative state quickly, others do not. An enduring negative state has the potential not only to affect well-being but also to impede subsequent performance. Here, effective affect regulation is key. Efficiency in the regulation of positive and negative affect has been shown to depend on the activity of certain brain areas and its hemispheres. More specifically, prefrontal asymmetry (PFA) as a phenomenon describing the relative activity of the left hemisphere compared to the right hemisphere of the prefrontal cortex, has shown to be involved in affective processing. This dissertation project investigates if PFA is associated with the recovery from negative affect after failure. The first study investigated the association of PFA with the downregulation of negative affect within a specific situation. Additionally, it assessed performance in a subsequent task. A higher relative left-hemispheric PFA indicated effective downregulation of negative affect following the failure experience. In contrast, a higher relative right-hemispheric PFA indicated sustained negative affect as well as detrimental effects on cognitive performance. Complementing this state perspective, the second study took on a trait perspective by investigating if PFA is also associated with affect regulation abilities in general. Results confirmed the findings from the first study: the ability to downregulate negative affect effectively was linked to a higher relative left-hemispheric PFA, and thereby highlighted PFA's role in personality variables. The third project aimed to apply the previous findings to sports by reviewing and mapping out the existing literature on PFA in the sports and exercise context. The scoping review revealed a positive relationship between a higher left-hemispheric PFA and adaptive regulatory skills as well as successful athletic performance. A general discussion integrates the findings into existing PFA theories and neurophysiological findings as well as highlights parallels with the constructs of volition and resilience. Finally, possible directions for future research are provided.

1 Introduction

Failure is an unavoidable part of life and is particularly prevalent in sports. In the Tokyo 2020 Olympic Games, 11,656 athletes participated and competed for 339 gold medals. This means that approximately 97% failed to win a gold medal. Obviously, not all of them would have viewed this as a failure, which is a two-step process consisting of a performance as well as the evaluation of this performance (Ball, 1976). Still, the likelihood of failure was high, as is the case in most competitive situations. Consequences reach from increased negative affect (Gustafsson et al., 2017), depressive symptoms (Hammond et al., 2013) to, in extreme cases, drop out from sports (Behr & Kuhn, 2019; Monteiro et al., 2017), and differ between individuals. While some recover quickly from such adverse events and setbacks, others experience an enduring negative state (Johnson, Gooding, et al., 2011), which might even impede subsequent competitive situations (Pensgaard & Duda, 2003; Vast et al., 2010).

So far, research on dealing with failure has tried to distinguish between individuals who recover quickly compared to those that remain in a negative state by identifying relevant personality variables, such as optimism and pessimism (Helton et al., 1999), perfectionism (Hill et al., 2011) or trait reappraisal (Johnson, Gooding, et al., 2011). However, they mainly focus on the initial reaction to the failure experience, instead of identifying variables that determine how fast someone recovers from this reaction and accompanying negative states. According to the affective neuroscientist Richard Davidson, recovery time is a component of "affective style", which comprises individual differences in affective chronometry including affect regulation and other affective phenomena (Davidson, 1998). An underlying constituent of affective style is prefrontal asymmetry (PFA), which has been suggested to represent the recovery time from negative affect (Davidson, 1998).

The current thesis aims to investigate if PFA is a suitable indicator of affective recovery from a negative state following failure. Based on research on affect and affective neuroscience, PFA and its potential association with affect regulation is introduced. In addition, the interaction between affect, cognition and behavior will be considered, particularly in regards to consequences for subsequent performance. Results will advance the research field of PFA and inform practitioners on the understanding of the issue (i.e., individual differences in dealing with failure) and determinants of performance.

1.1 Affective processes

Affect describes all emotion-related phenomena within a person. It embodies emotions and moods and encompasses the subjective experience of emotion (Scherer, 1984) as well as their appraisal. The definitions of all emotion-related phenomena (e.g., emotion, mood, feeling, etc.) are an ongoing debate in research. Particularly, when it comes to emotion there is still no consensually accepted definition of the construct (Gross & Thompson, 2007). Some of the attempts to define emotions describe it as "a genetic and acquired motivational predisposition to respond experientially, physiologically, and behaviorally to certain internal and external variables" (Carlson & Hatfield, 1992, p. 5). Similarly, Watson and Clark (1994) define emotion as "an organized, highly structured reaction to an event that is relevant to the needs, goals or survival of the organism" that "represents a response to specific types of events, and each gives rise to characteristic forms of adaptive behavior" (Watson & Clark, 1994, p. 89). Even though these definitions differ, they highlight some core features of emotion that are, first, emotions arise in response to a relevant event and, second, emotions lead to multifaceted, adaptive reactions. Gross and Thompson (2007) suggest a third feature which they describe as "imperative quality" (Gross & Thompson, 2007, p. 5) meaning that emotions can disrupt any ongoing processes and gain our attention. Based on these features, they developed the Modal Model of Emotion (Gross & Thompson, 2007).

1.1.1 Affect generation

The Modal Model of Emotion describes a person-situation interaction that explains the emergence of emotions (see Figure 1). First, a psychologically relevant situation is present. This situation can be either external, such as coming in fourth in the Olympic Games, or based on mental representations and therefore internal (e.g., thinking about having come in fourth in the previous Olympic Games). Second, individuals attend to this situation. For example, the athlete checks the picture of the photo-finish camera and the official ranking. Third, the attended situation is evaluated. This appraisal includes giving meaning and evaluating the capacity to manage the situation and determines the final step, the individual's affective response, which is accompanied by experiential, behavioral, and neurobiological changes. For example, based on whether the athlete thinks that coming in fourth is a good result or not, he or she will feel either upset or happy, drop their shoulders or carry their head upright, and dopamine levels might decrease or increase.

Several theories exist regarding the resulting affective response, which can be divided into theories supporting a discrete set of emotions and theories that view the affective response as dimensional. On the one hand, models of discrete emotions argue that individuals possess a discrete set of basic emotions that activate specific neural pathways and differ in the psychological, behavioral and physiological response they cause (Ekman, 1992; Panksepp, 1998). These basic emotions constitute the building blocks for other emotions. The number of basic emotions varies between different theories and ranges from two (Frijda, 1987; Mowrer, 1960) to 22 (Ortony et al., 1988). However, neurophysiological studies have not been able to validate the existence of any number of discrete emotions. Neither physiological correlates, nor specific facial expressions were found that clearly identify the emotions suggested (Kober et al., 2008; Posner et al., 2005). On the other hand, dimensional models describe the affective response as a point within a multi-dimensional system which can not only be described in terms of subjective experience but also neurophysiological substrates (Russell & Feldman Barrett, 1999). Similar to models of basic emotions, there is no unison regarding the labelling of the bipolar dimensions. While Watson et al. (1999) conceptualize them as positive and negative affect, Lang et al. (1998) talk about approach and withdrawal, Thayer (1996) suggests tension and energy and Russell (1980) reports valence and arousal. The latter suggested the idea of a Circumplex Model of Affect (Russell, 1980), which describes affective responses as a linear combination of two independent continua ranging from pleasant to unpleasant (i.e., valence) and activation to deactivation (i.e., arousal). This two-dimensional model is supported by neurophysiological research that, for example, showed that valence is associated with startle reflex magnitude (Lang, 1995), facial expressions (Lang et al., 1993), heart rate

(Lichtenstein et al., 2008), asymmetric activation of the prefrontal cortex (PFC) (Davidson, 1992) and the activity of brain networks including dorsal cortical areas and mesolimbic pathways (Colibazzi et al., 2010). In contrast, arousal is associated with skin conductance (Lang et al., 1993; Lichtenstein et al., 2008), right parietotemporal activation (Heller, 1993) and the activity of brain networks in midline and medial temporal lobe structures (Colibazzi et al., 2010).

1.1.2 Affect regulation

Once an affective response is elicited, it is subject to regulatory processes that can be initiated automatically or voluntarily and occur unconsciously or consciously (Gross, 1999). Again, affect regulation constitutes an overarching construct that describes all efforts to influence the affective response (Westen, 1994) and entails coping, emotion regulation, mood regulation and psychological defenses (Gross & Thompson, 2007). While coping predominantly focuses on the downregulation of negative affect over a longer period (Folkman & Moskowitz, 2004), defenses are usually unconscious, automatic tendencies to deal with negative experiences (Cramer, 2000; Westen & Blagov, 2007). Mood regulation and emotion regulation both target the regulation of any kind of affect, both automatically and unconsciously or voluntarily and consciously. However, they can be differentiated based on the result of the regulatory process. Mood regulation is concerned with the change of the affective experience instead of the affect-related behavioral response (Larsen, 2000). In contrast, emotion regulation includes all processes that influence the type, time and manner of the affective experience and expression (Gross, 1998b). This includes the latency, magnitude, duration, rise time and offset of the affective response (Gross & Thompson, 2007). Accordingly, emotion regulation strategies target any of these aspects. On a higher order level, these strategies can be differentiated between antecedent-focused and response-focused strategies (Gross, 1998a). When considering Gross and Thompson (2007) Modal Model of Emotions, this differentiation is based on whether emotion regulation is used before or after the affective response has been elicited. Accordingly, antecedent-focused strategies occur during the occurrence of a situation, during attention allocation or during the appraisal of the situation. In contrast, response-focused strategies occur after the affective response has been activated.

The Process Model of Emotion Regulation (Gross, 1998b) provides further elaboration on the differentiation between emotion regulation strategies (see Figure 1). It highlights five families of emotion regulation strategies, namely Situation Selection, Situation Modification, Attentional Deployment, Cognitive Change and Response Modulation. These strategies can be assigned to the four steps of the Modal Model of Emotion (Gross & Thompson, 2007) and are the product of cognitive control processes (Ochsner et al., 2012). First, Situation Selection describes strategies that change the likelihood of ending up in a potentially affect-eliciting situation. For example, when athletes choose the competitions they want to compete in, they have the choice between selecting important ones with strong opponents or rather insignificant ones with weaker opponents. Second, Situation Modification refers to the tailoring of a situation in a way that its affective impact is changed. Even though they might have selected the important competition, they can change its affective impact by, for example, choosing a very strong partner and thereby feeling more confident. Third, Attentional Deployment is used to direct attention to different aspects of a situation. The most commonly used strategies within this family are selective attention, which is used to shift attention toward or away from certain aspects of a situation and distraction, which shifts attention away from an external stimulus and toward internal information within the working memory (Ochsner & Gross, 2005; Ochsner et al., 2012). For example, they shift their attention away from the spectators and focus on the ball instead (selective attention). Fourth, Cognitive Change includes changing or selecting the meaning of the situation or changing how we evaluate our capacity to cope with the situation. Accordingly, they could change the meaning of the situation by reminding themselves that there are more important things in life than losing a competition. This is an example of cognitive reappraisal, which is a strategy that changes the interpretation of affective stimuli (Gross, 1998a; Ochsner et al., 2012). Fifth, Response Modulation occurs after response tendencies have been generated and aims at changing the behavioral, experiential and physiological response. For example, they might straighten up and take some deep breaths instead of dropping their head and allowing their heart rate to accelerate. This can be referred to as expressive suppression, which includes changing the behavioral or physiological response (Gross, 1998a).

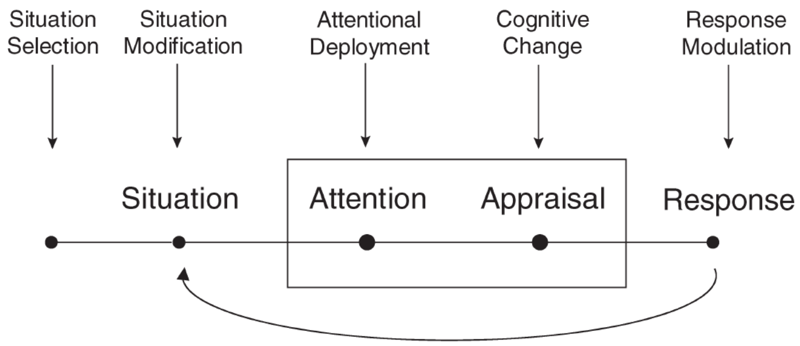

Figure 1. Process Model of Emotion Regulation by Gross (1998b). Illustration from Gross and Thompson (2007).

Research shows that these strategies vary in their effectiveness (Gross, 2002; Gross & John, 2003; McRae et al., 2010), duration of the effect (Gross & John, 2003; Kross & Ayduk, 2008; McRae et al., 2010) and cognitive (Gross, 1998a; McRae et al., 2010) and physiological costs (Gross, 1998a, 2002). According to current knowledge, reappraisal is the most effective and adaptive strategy, particularly for the downregulation of negative affect (Butler et al., 2014; Hofmann et al., 2009; Szasz et al., 2011; Urry, 2009). It is not only effective in regulating affect and physiological arousal but has proven to have longer-lasting effects (Kross & Ayduk, 2008; Ochsner & Gross, 2005) that do not come with the physiological or cognitive costs of other strategies (Gross, 1998a). For example, Kross and Ayduk (2008) compared reappraisal and distraction. Participants were asked to recall a sad or depressing experience and were allocated to either a self-immersed, a self-distanced or a distraction condition. Viewing a situation from a self-distanced perspective (i.e., observer of the self) is a form of cognitive reappraisal (McRae et al., 2012). After the manipulation, participants had to report their depressed affect. When returning to the lab after one and seven days, participants were asked to recall the same depressive situation and rerated their affective state. Results showed that, initially, participants in the self-immersed condition experienced more depressed affect compared to participants in the other two conditions. However, when returning to the lab, participants in the distraction condition even reported increases in depressed affect over time compared to both other conditions. In contrast, participants in the self-distanced condition continued showing lower levels of depressed affect, indicating that self-distancing (i.e., reappraisal) facilitates affect regulation of the same event in future situations. Accordingly, reappraisal has been shown to have long-term effects by influencing the tendency to have an affective response to a particular stimulus. Furthermore, reappraisal was found to be superior to suppression (Hofmann et al., 2009), which can have negative effects on physiological arousal (Campbell-Sills et al., 2006; Gross, 1998a; Ohira et al., 2006; Richards & Gross, 1999; Wegner & Zanakos, 1994) and cognition (Gross, 1998a, 2002; Richards & Gross, 1999, 2006).

1.1.3 Differentiating affect generation and regulation

Although affect regulation is a popular field of research, some researchers question whether a fundamental distinction between affect generation and affect regulation can be drawn (Kappas, 2011; Thompson, 2011) or is useful (Mesquita & Frijda, 2011). On the one hand, those opposed to the distinction hold the view that there is no such thing like unregulated affect, instead, regulatory processes are embedded throughout the affect generation process. For example, Mesquita and Frijda (2011) argue that a specific situation or stimuli always carries the potential to elicit several different affective responses. They conclude that one affective response can only be evoked, and hence guide action, when this response “gains power or intensity” (Mesquita & Frijda, 2011, p. 783). Consequently, the competing affective responses modulate and regulate each other. On the other hand, others counter that the distinction can be useful in some circumstances because the two processes activate different goals. While the goal that is activated during affect generation targets the environment, the goal that is activated during affect regulation targets the affect generation process (Gross & Feldman-Barrett, 2011; Gross et al., 2011a, 2011b). Additionally, they view the wide use of the distinction as proof for its’ utility and highlight subareas of psychology that have profited from the distinction. For example, neuroscience has shown that voluntary affect regulation activates areas like the dorsolateral prefrontal cortex (dlPFC) that are involved in cognitive control. More importantly, this activation is not visible when responding to affect-eliciting stimuli spontaneously (Ochsner & Gross, 2008). However, Ochsner and Gross (2008) conclude that one must make the distinction with care, considering "when and in what ways it is useful" (Gross et al., 2011a, p. 777) and suggest a continuum ranging from situations where it is justified to assume that affect regulation was employed and those where there is no clear reason.

To sum up, there is still a lot of debate going on in the area of affect, including affect generation and regulation. Therefore, it is particularly important to clarify the understanding of these phenomena within the current thesis. First, the present thesis works with the assumptions of the Circumplex Model of Affect and understands affective responses as a combination of valence and arousal dimensions. Second, it uses the terms affect and affect regulation to account for all emotion-related phenomena and their regulation in a more holistic fashion. Therefore, these terms are used exclusively in the following sections. Third, the usefulness of the distinction between affect generation (or affect reactivity) and affect regulation is part of the present research and will be further discussed within the studies.

1.1.4 Interaction between affect, cognition and behavior

The debate about affect generation and affect regulation shows that affective and cognitive processes are integrated and interactive: in order to be able to regulate affect, cognitive control processes need to become active (Ochsner & Gross, 2005). Similarly, affective processes can serve to regulate cognition (Gray, 2004). A growing number of research supports the assumption of an interactive nature of affect and cognition (e.g., Barrett et al., 2007; Damasio, 1994; Duncan & Barrett, 2007; Grimshaw & Carmel, 2014; Izard, 2007; Ochsner & Phelps, 2007). For example, Izard (2007) has integrated this dynamic interaction of affect and cognition in his Differential Emotion Theory, which uses the term "emotion schemas" to refer to the interaction of affect with "perceptual and cognitive processes to influence mind and behavior" (Izard, 2009, p. 8). He argues that affect and cognition interact to guide action, which serves a functional purpose. Therefore, particularly in personally or socially significant situations, affect has the potential to influence thought and action (Izard, 2009). Some even propose that “affect is a form of cognition” (Duncan & Barrett, 2007, p. 1185).

When talking about affect and cognition, behavior cannot be omitted. Both, the definitions of affect (see above) and cognition, which can be broadly defined as information processes that help to adapt and guide behavior (Izard et al., 1984), highlight their interrelatedness with behavior. However, they guide behavior in two different ways: while affect induces processes that respond quickly and affect behavior in a stereotypical way, cognition induces processes that are less automatic and have the potential to support a broader array of behaviors (McClure et al., 2007). In most cases, behavior is the result of the integration of cognitive and affective processes. However, there are situations when the affective response and the cognitive outcome support diverging behavioral responses, which is known as cognition–affect competition or conflict (McClure et al., 2007). This can be the case in delayed reward (McClure et al., 2004) or other decision making scenarios (Greene et al., 2001; Sanfey et al., 2003). When it comes to the affect-cognition-behavior interaction, decision-making is one of the most researched concepts. On the one side, affective processes can bias our judgement and choices in multiple ways which can be both, beneficial or harmful (Lerner et al., 2015). This is due to influences of affect on perception, attention, learning and memory (Dolan, 2002; Dolcos et al., 2014): information processing, encoding and retrieving vary depending on the affective state (Levine & Pizarro, 2004). On the other side, cognitive processes can overrule behavioral tendencies evoked by affective states. This can, for example, be the case in moral judgements where automatic affective responses favor one option but moral principles such as utility favor another option (Greene, 2014). Also, in the area of sport psychology affect and cognition have shown to interact to influence performance (i.e., behavior). This is for example the case in the phenomenon of choking under pressure which refers to a performance decrement during important competitions (Mesagno & Beckmann, 2017). When pressure rises, so does anxiety (Hardy et al., 1996). This change in affective state causes attention to shift in a way that inhibits optimal performance (Mesagno & Beckmann, 2017). Similarly, ruminative processes evoked by negative affect have shown to divert attention away from the task at hand (Beckmann, 1994) and therefore potentially impair task performance (Kröhler & Berti, 2019; Nicholls et al., 2012). This has not only been reported for sports-related tasks but also for cognitive tasks (Davis & Nolen-Hoeksema, 2000). Accordingly, experiencing failure does not only evoke negative affect but also influences accompanying cognitive processes and ultimately, behavior.

Given the extensive interaction of affect and cognition, researchers have raised the question whether it makes sense to distinguish between their individual contributions to behavior (Ochsner & Phelps, 2007). Although affect and cognition have long been viewed as two separate systems, the research reported above indicates that their relationship is rather interdependent. These observations within behavioral research are supported by neuroscientific research as will be outlined in the following section.

1.2 Affective neuroscience

Affective neuroscience is a fairly new discipline (Davidson & Sutton, 1995) that has emerged from behavioral neuroscience (Panksepp, 1998) and investigates the neural substrates of affective processes (Davidson, 1998). During the past decades, research has identified several brain areas that are involved in affective processing. The most relevant for the current thesis being the amygdala, the anterior cingulate cortex (ACC) and the PFC including the orbitofrontal cortex (OFC), dlPFC and ventromedial PFC (vmPFC) (Davidson, 2000). These regions are differentially involved in the generation and regulation of affect.

1.2.1 Neurophysiology of affect generation

The limbic system has long been referred to as the “emotional brain” (Pessoa & Hof, 2015, p. 2498) with the amygdala being its core (LeDoux, 2000). Through its reciprocal connections to cortical regions that are involved in sensory processing, the amygdala detects relevant stimuli and initiates the affective response (MacDonald et al., 2000). This includes projections back to the sensory cortices (MacDonald et al., 2000) as well as to the PFC (Ghashghaei et al., 2007). Accordingly, the main task of the amygdala is to direct attention, modulate vigilance and initiate further processing of the stimuli in case the stimuli is relevant for the individual (Davis

& Whalen, 2001; LeDoux, 2000). This also includes the initiation of behavioral, autonomic and endocrine responses (LeDoux, 2000; Pourtois et al., 2013).

While the amygdala mainly serves to detect the affective significance of a stimulus, the PFC's main task is to guide goal-directed behavior (Damasio, 1994). Together, the amygdala and PFC interact to evaluate the potential outcomes of actions (Schoenbaum et al., 1998). Although the amygdala is connected with all regions of the PFC, connection is strongest between the amygdala and the OFC and the ACC (Ghashghaei et al., 2007), which lies directly between the PFC and limbic areas (Palomero-Gallagher et al., 2009). Similar to the amygdala, the PFC becomes active when a situation is ambiguous. It receives input from cortical and subcortical regions and sends signals back to those regions to make sure that the response is appropriate and in line with the goal by guiding sensory, memory and motor processes. This control function is particularly important when facing favorable alternatives (Miller & Cohen, 2001). Once a competition is detected, controlled processes are necessary. The dlPFC seems to be mainly responsible for that: when competition is detected it executes control by inhibiting or increasing different brain regions involved in the competition (Gray et al., 2002). This indicates its role in voluntary affect regulation (Phillips et al., 2008). In contrast to dlPFC, the other two important subdivisions of PFC, namely the OFC and vmPFC have been associated with the production of affective states and behavior. On the one side, the OFC is directly connected with the amygdala and serves to represent the reward value of a stimulus and how this guides goal-directed behavior (Schoenbaum et al., 1998). On the other side, the vmPFC represents negative and positive affective states when no immediate incentives are present (Davidson & Irwin, 1999) by representing the affective value of a stimulus in regards to context and goal-dependency (Roy et al., 2012; Winecoff et al., 2013). Both subdivisions are also responsible for autonomic changes, which typically accompany the affective states. This indicates their role in the automatic regulation of affective behavior (Phillips et al., 2003).

The ACC is a brain region that lies ajar to the corpus callosum and right between the PFC and the amygdala. It comprises different regions that are responsible for both cognitive (Carter et al., 1999; MacDonald et al., 2000) and affective conflict monitoring (Bush et al., 2000; Whalen et al., 1998) with some subdivisions reacting to affective stimuli and others reacting to cognitive stimuli. Subsequently to detecting conflict, the ACC recruits other brain areas to address the conflict via top-down control, which might be the first step in affect regulation (Carter et al., 1999). The affective region includes the ventral ACC (Devinsky et al., 1995), which has connections to the limbic area (Mayberg et al., 1997) and has been found to be implicated in resolving affective conflict (Etkin et al., 2006). The cognitive region, in contrast, contains the dorsal ACC, which is connected with the PFC, motor areas and the parietal cortex among others (Stevens et al., 2011) allowing it to integrate top-down and bottom-up stimuli (Bush et al., 2000). Support for the affective and cognitive subdivisions comes from several studies (Bush et al., 2000; Bush et al., 1998; MacDonald et al., 2000; Whalen et al., 1998). For example, Whalen et al. (1998) and Bush et al. (1998) applied two different versions of the Stroop test using one cognitive counting Stroop and one affective counting Stroop paradigm. During functional magnetic resonance imaging (fMRI) recording, participants had to indicate the number of words presented on a screen. In the cognitive version, the trials included number words whereas in the affective version the trials included emotionally valence words. Activation was observed in the cognitive (dorsal) and affective (ventral) subdivisions of the ACC respectively.

The roles of the ACC and PFC show how closely related affective and cognitive processes are within the brain (van Veen & Carter, 2006). Accordingly, neuroscience supports what has been observed in behavioral studies: brain areas involved in affect and cognition interact to control thought, affect and behavior (Gray et al., 2002; Russell, 2003).

1.2.2 Neurophysiology of affect regulation

These control functions are relevant in regulating cognitive and affective processes and therefore play a decisive role in affect regulation. That said, even though regulation can be implicit, the majority of neurophysiological research on affect regulation has focused on affect regulation guided by explicit regulatory goals (Ochsner et al., 2012). The neural bases of affect regulation relies on the same regions implicated in affect generation: affect regulation results out of the interaction between subcortical regions that are responsible for the processing of affective information and PFC regions implicated in cognitive and executive control (Phillips et al., 2008). As fMRI research showed, several regions of the PFC are directly or indirectly connected with subcortical regions (Öngür & Price, 2000). Particularly, the OFC seems to mediate the connections between limbic regions such as the amygdala and the lateral and dorsal regions of the PFC through its strong connectivity with the dlPFC and the amygdala. It thereby plays a decisive role in affect regulation (Stein et al., 2007). The connectivity between prefrontal regions and the amygdala is referred to as PFC-amygdala coupling (Urry et al., 2006). This infers that when it comes to negative affective states, the PFC is able to downregulate amygdala activity and thereby decrease negative affect through its inhibitory pathways to the amygdala. Accordingly, fMRI studies showed an increased activity in the PFC and decreased activity in the amygdala during attempts to downregulate negative affect (Johnstone et al., 2007; Lee et al., 2012). This observation can also explain individual differences in affect regulation: Johnstone et al. (2007) asked healthy participants to maintain, enhance or suppress their affective state while viewing negative pictures. fMRI data recorded during picture viewing, revealed that individuals with a greater ability to downregulate negative affect possessed a stronger connectivity of the PFC and amygdala indicated in a greater inverse functional coupling. Different affect regulation strategies engage different subregions of the PFC and limbic area, as well as additional cortical areas involved in cognitive and sensory processing. This includes cognitive reappraisal (Kim & Hamann, 2007; Ochsner et al., 2002; Ochsner et al., 2004; Ochsner et al., 2012; Urry et al., 2006), distraction (Kanske et al., 2011; McRae et al., 2010) and expressive suppression (Goldin et al., 2008; Hayes et al., 2010; Ohira et al., 2006; Vanderhasselt et al., 2013). Although these findings and suggested processes are based on a broad array of brain research (i.e., focal brain lesion studies, animal studies, functional neuroimaging studies and stimulation studies), there is still no unison regarding the neural mechanisms of affect regulation (Berkman & Lieberman, 2009). Also, many questions are left unanswered such as the differential recruitment of the brain systems over time (Harris et al., 2013).

In summary, these findings show that the PFC is important for affect regulation, particularly when it comes to the downregulation of negative affect (Davidson et al., 2000). While the subregions of the PFC serve different functions, the same seems to count for the two hemispheres. Further insights are provided by research regarding the differential involvement of the two brain hemispheres.

1.2.3 Hemispheric lateralization of affect

Brain asymmetries or hemispheric lateralization of brain functions have been the focus of neuroscience for decades. On the one hand, this concerns cognitive and motor functions such as the lateralization of attention (Bartolomeo & Malkinson, 2019), reasoning (Turner et al., 2015), language (Doucet et al., 2015), memory (Nagel et al., 2013), movement (Serrien et al., 2003) and motor learning (Hardwick et al., 2013). On the other hand, affective processes, such as affect production, perception and expression have been found to be lateralized (Silberman & Weingartner, 1986). Here, two main hypotheses, namely the Right Hemisphere Hypothesis (RHH) and the Valence Hypothesis (VH), have developed over time and are still subject to debate with several studies supporting both hypotheses (e.g., Fusar-Poli et al., 2009; Prete et al., 2015; Wyczesany et al., 2018). While the RHH suggests that the right hemisphere processes all affective stimuli (Gainotti, 1972, 2012), the VH proposes that the left hemisphere processes positive affect, whereas the right hemisphere processes negative affect (Baijal & Srinivasan, 2011; Davidson et al., 1987). For example, Jansari et al. (2011) presented emotional faces either to the right or left side of the visual field of their participants. They showed that emotional expression is identified more accurately as positive when presented on the right side and as negative when presented on the left side, which supports the VH. In contrast, other studies support the RHH. For example, Bourne (2010) found that participants showed a lateralization to the right hemisphere when completing a chimeric faces (i.e., vertically split face that comprises a neutral and an emotive half face) test. Also, studies on affective expression and the control of related behavior offer support for the RHH: facial expressions of different affective states are more pronounced in the left side of the face compared to the right side (Indersmitten & Gur, 2003). Due to the contralateral innervation of most of the face muscles, this might reflect right hemispheric control (Müri, 2016). However, it must be noted that the upper facial muscles are innervated bilaterally (Müri, 2016), which does not allow for an unequivocal interpretation of the results considering that negative facial expressions are more likely to be deducted from the eye region (Eisenbarth & Alpers, 2011).

These inconsistencies have led to the proposition of various alternative models. First, the modified VH states that posterior regions of the right hemisphere process all affective stimuli while frontal regions process stimuli according to the VH (Davidson, 1984; Killgore & Yurgelun-Todd, 2007). Second, the Motivational Hypothesis assumes that, instead of positive and negative valence, the left and right hemispheres are involved in the processing of approach- and withdrawal-related stimuli respectively (Harmon-Jones & Allen, 1998; Poole & Gable, 2014). Finally, Shobe (2014) suggests that both hemispheres are responsible for processing all affective states, however, at different levels. While the right hemisphere perceives and detects positive and negative affective stimuli, the left hemisphere interprets the stimuli on a higher level and directs the subsequent response. This assumption is related to Gainotti's (2005, 2007) suggestion of a more primitive functioning of the right hemisphere compared to the left hemisphere, which is based on the non-verbal and verbal functional organization of the right and left hemispheres respectively. Accordingly, the right hemisphere needs to rely on sensorimotor functions and processes affective stimuli automatically, whereas the left hemisphere processes the stimuli cognitively and hence, consciously and intentionally. This might be in line with a control function of the left hemisphere in affective expressions (Ross & Pulusu, 2013) and ultimately, in voluntary affect regulation (Ochsner et al., 2004).

Based on the findings regarding the asymmetrical processing of affect, a research approach has evolved that focuses on the role of the PFC hemispheres only. More specifically, it investigates the relative activity of the left PFC compared to the right PFC, also known as PFA.

1.3 Prefrontal asymmetry

PFA research is based on studies with patients with unilateral cortical damage (Gainotti, 1972; Robinson et al., 1984). These studies showed that the left and right cortex are differentially involved in affective processing with left cortical damage being related with an increase in the prevalence of depressive symptoms. Furthermore, Morris et al. (1996) studied stroke patients with small-sized lesions that were covering the left PFC only. Again, an association between left cortical damage and depressive symptoms was observed indicating that the PFC was responsible for the findings regarding left hemispheric lesion and depression. Research using the Wada test (i.e., amytal injection into one carotid artery) has shown that the two hemispheres seem to inhibit each other, with the left PFC processing positive affect and inhibiting the processing of negative affect in the right PFC and vice versa (Schutter & Harmon-Jones, 2013).

1.3.1 Prefrontal asymmetry and affective phenomena

Based on these findings and their own research, Davidson (1998) and Henriques and Davidson (1991) suggested a Diathesis-Stress Model of PFA. To determine PFA, they measured alpha power in the frequency band of 8-13 Hz via electroencephalography (EEG) and calculated difference scores comparing the two PFC hemispheres (Davidson & Tomarken, 1989). Higher values indicate a higher relative left-hemispheric activity. Their model states that functional or lesion-induced asymmetries in PFC activity represent a diathesis. They postulate that only in response to a challenge PFA will change the likelihood of the appearance of a particular affective reaction. Otherwise, affective states do not differ between individuals with a higher relative left-hemispheric activity compared to individuals with a higher relative right-hemispheric activity. Therefore, PFA was assumed to indicate an "affective style" described as the "quality and intensity of dispositional mood and emotional reactions to similar incentives and challenges" (Davidson, 1998, p. 307).

During the past decades, research in the field of PFA has been conducted extensively. Results confirmed the involvement of PFA in depression (Thibodeau et al., 2006) and extended this association to other affective contexts. Among others, a higher relative left-hemispheric PFA was associated with positive dispositional mood (Thibodeau et al., 2006; Tomarken, Davidson, Wheeler, & Doss, 1992), a repressive coping style (Tomarken & Davdison, 1994), approach-related dispositional tendencies (Coan & Allen, 2003; Harmon-Jones & Allen, 1997), higher sociability (Jetha et al., 2009; Schmidt, 1999), higher dispositional anger (Harmon-Jones & Allen, 1998) and an increased immune system activity (Davidson et al., 1999; Kang et al., 1991). While PFA was originally viewed as reflecting trait-like variations in affective processing (such as in depression; Davidson, Jackson, & Kalin, 2000), studies have shown that it has the potential to influence affective processes evoked by situational cues and also is influenced by situational factors (Allen, 2003; Hagemann et al., 2002). PFA is therefore also associated with state variations of affect, such as approach motivation (Pizzagalli et al., 2005; Rodrigues et al., 2018; Wacker et al., 2003), a decreased sensitivity to negative stimuli (Henderson et al., 2001; Nash et al., 2012; Tomarken et al., 1990; Wheeler et al., 1993) and adaptive dealing with challenges (Baeken et al., 2014; Jackson et al., 2003; Koslov et al., 2011; Larson et al., 1998). For example, Rodrigues et al. (2018) used a virtual reality maze to investigate situational approach and avoidance motivation. Participants were asked to navigate using a joystick while having their EEG recorded. Results showed a higher relative left PFC activation during approach behavior as well as a higher relative right PFC activation during avoidance behavior.

Integrating state- and trait-related findings, several theories regarding the associations of PFA with affect have been developed and tested. The initial model of PFA was formulated by Davidson and colleagues (Davidson et al., 1990; Davidson & Fox, 1982) and highlighted the association of PFA with affective valence (i.e., positive versus negative) and motivational direction (i.e., approach versus avoidance) of an affective stimulus. On the one hand, affective valence can be differentiated in positive or negative based on whether individuals like or dislike the experience of the affect (Harmon-Jones et al., 2011). On the other hand, motivational direction describes where the individual is motivated to go and can be differentiated in the impulse to go toward (approach) or away (withdraw or avoid) from something (Harmon-Jones et al., 2013). Even though affect and motivation are closely related, they are still distinguishable (Chiew & Braver, 2011). For example, Carver (2006) postulates that affect is the result of the discrepancy between actual and expected goal progress, whereas motivation drives the goal progress. More specifically, Davidson and colleagues (1990; 1982) state that a higher relative left-hemispheric activity is linked to an approach system, which is responsible for approach motivation and positive affect, and a higher relative right-hemispheric activity is associated with a withdrawal system responsible for withdrawal motivation and negative affect.

However, not all affective states are defined by either positive valence and approach motivation or negative affect and withdrawal motivation. As Harmon-Jones et al. (2013) argue, approach motivation can also be triggered by negative stimuli and experienced as a negative state. In regards to PFA, Harmon-Jones and Allen (1998) conducted research on anger which generally represents a negative affective state characterized by approach motivation. They showed that anger is linked to a higher relative left-hemispheric activity (approach motivation) rather than a higher relative right-hemispheric activity (negative affect) which indicates that PFA is conceptually associated with motivational direction instead of affective valence. This finding has been corroborated in several studies (Harmon-Jones & Gable, 2017).

1.3.2 Debate on the functional interpretation of prefrontal asymmetry

Despite a large variety of research that has been conducted, there is still no unison regarding the functional interpretation of PFA. Based on the acknowledgment of a role of PFA in motivational direction, researchers postulated that PFA is associated with the activity of basic approach and avoidance systems, also called behavioral activation and inhibition systems (BAS and BIS; Coan & Allen, 2003). According to Gray's Reinforcement Sensitivity Theory (Gray, 1972, 1987, 1994), BAS refers to the sensitivity to reward and is reflected in the tendency to approach rewarding stimuli (i.e., goal pursuit) and to elicit positive affect. In contrast, BIS refers to the sensitivity to negative stimuli reflected in the tendency to withdraw from punishment and nonreward and to elicit negative affect. However, while some researchers found positive associations between a higher relative left-hemispheric PFA and BAS, most failed to find an association between a higher relative right-hemispheric PFA and BIS (Amodio et al., 2008; Coan & Allen, 2003; Harmon-Jones & Allen, 1997). Still, findings regarding PFA and BAS are inconsistent (Wacker et al., 2010). Among others, these inconsistencies led to conceptual revisions of the traditional BAS/BIS perspective, and the BIS in particular, by introducing a fight-flight-freeze system (FFFS) and a revised BIS (r-BIS; Gray & McNaughton, 2000). The FFFS represents the traditional BIS withdrawal system and responds to nonreward and punishment as well as fear-related stimuli by raising arousal levels and shifting attention to aversive stimuli. Therefore, it facilitates avoidance and defensive behaviors (Gray & McNaughton, 2000). In contrast, r-BIS represents a regulatory system that monitors, detects and controls conflict between other systems, such as FFFS and BAS, BAS and BAS or FFFS and FFFS. More specifically, it controls conflict by enhancing negativity (Gray & McNaughton, 2000). While some argue that r-BIS, and not FFFS, is related to right-hemispheric PFC activity (for a recent review, see Gable et al., 2018), there is also evidence for the involvement of FFFS. A positive relationship between right-hemispheric PFC activity and FFFS (De Pascalis et al., 2018) as well as withdrawal motivation and affective arousal more generally (Papousek et al., 2009) is suggested.

These inconsistencies are complemented by another line of research that investigates the direct involvement of PFA in affect regulation and is based on neurophysiological evidence associating the ability to downregulate negative affect with the left PFC (Davidson, 2000; Ochsner & Gross, 2005). Several studies have shown both, a positive association between a higher relative left-hemispheric PFA and trait measures of affect regulation (Hannesdóttir et al., 2010; Mikolajczak et al., 2010) as well as state-dependent regulatory behavior (Jackson et al., 2003; Kline et al., 2007; Papousek et al., 2011; Papousek et al., 2012; Zhang et al., 2020). For example, Jackson et al. (2003) presented arousing and neutral visual stimuli to participants after recording their baseline EEG data. As an objective indicator of affective state and its' persistence, eye-blink startle data was measured during and after picture presentation. While all participants reacted equally to negative stimuli, participants with a higher relative left-hemispheric activity showed attenuated startle magnitude following the offset of arousing stimuli. This indicates an increased recovery from negative affect and suggests an involvement of PFA in affect regulation as opposed to affect generation or reactivity as indicated by BAS/BIS research. Similarly, Mikolajczak et al. (2010) found a positive association between trait emotional intelligence measured through the Trait Emotional Intelligence Questionnaire (TEIQue; Petrides & Furnham, 2003) and a higher left-hemispheric PFA. When controlling for the weight of all emotional intelligence factors, one of the main contributors to that result was the factor “self-control”, which refers to affect regulation. Interestingly, “emotionality” which touches the concept of BAS/BIS was no longer significant.

More recently, Papousek et al. (2017) have established a link between a higher relative left-hemispheric PFA and the ability to use cognitive reappraisal as an explicit affect regulation strategy. Participants were confronted with anger-eliciting situations and asked to produce as many distinct cognitive reappraisals as possible. PFA during reappraisal attempts predicted the number of cognitive reappraisals with a higher relative left-hemispheric activity indicating an enhanced capacity for generating reappraisals and hence, affect regulation. This finding suggests that successful cognitive reappraisal depends on the capacity to increase left-lateralized PFA and highlights the interrelatedness of cognitive and affective processes. One model that accounts for both, the interrelatedness of cognition and affect as well as PFA’s involvement in affect regulation is the Asymmetric Inhibition Model of hemispheric differences (AIM; Grimshaw & Carmel, 2014). AIM states that executive control processes in the PFC play an important role in affect regulation in general, and in the underlying mechanisms of PFA specifically. They suggest that a higher relative right-hemispheric activity is indicative of executive control that inhibits positive or approach-related distractors and a higher relative left-hemispheric activity inhibits negative or avoidance-related distractors. Accordingly, if individuals encounter an affective stimulus, executive control needs to become active to prevent interference with goal pursuit processes. This is an important function because even though reactions to affective stimuli are often adaptive, they can interfere with the task. For example, if a tennis player plays an important match and has lost the first set, he/she might feel upset. Generally, this is adaptive because if he/she does not experience negative affect after failing, why would he/ she continue to train and try to be successful? However, within the match, the athlete still needs all his/her cognitive resources to perform at his/her best. Therefore, distracting affective states need to be inhibited in order to continue pursuing the goal to win the match. Support for the AIM comes from studies using affective distractors and report difficulties in disengaging from negative stimuli in individuals with a lower relative left-hemispheric PFA (Grimshaw et al., 2014; Miskovic & Schmidt, 2010; Pérez-Edgar et al., 2013).

Returning to the situation described at the beginning of this thesis, these findings could help to provide some answers. After experiencing failure, an athlete who recovers quickly from accompanying negative affective states might be characterized by a higher relative left-hemispheric activity in the PFC as opposed to an athlete that has difficulties to overcome the negative state, which might be associated with a higher right-hemispheric PFA. In the sports and exercise context, only few studies on PFA have been conducted and attempts to provide overviews of the content and results (Lattari et al., 2014; Silveira et al., 2019) have been unable to capture the topic in its entirety. Instead, they have focused on affective outcomes only, mainly interpreting the observations as positive or negative affective reactions to exercise. A regulatory perspective has been neglected and therefore, no direct conclusion regarding affective recovery from negative affect can be drawn. Additionally, the topic of performance has been hardly touched. Considering the relevance of affective and motivational parameters in determining athletic success (Gillet et al., 2012; Gillet et al., 2013; Pensgaard & Duda, 2003; Vast et al., 2010) and the neurophysiological processes described above, an association is likely.

To sum up, affect is a multi-faceted construct that is unequivocally connected with cognitive processes in guiding behavior. This is also apparent in the neurophysiological basis of affective processes: while the limbic system is mainly responsible for the detection of affective stimuli and the generation of an affective state, the PFC exhibits cognitive control in line with the current goal. It is therefore also involved in affect regulation. Furthermore, asymmetries in PFC activity have been associated with a tendency to experience positive affect or approach motivation and negative affect or avoidance motivation in face of an affective stimulus. Debate on the underlying mechanisms of PFA is ongoing with an increasing number of empirical findings indicating that regulatory mechanisms are responsible for the observed phenomena.

1.4 Critique of the current studies

The literature described above provides a broad insight into PFA and its associations with affective processes, however, the current evidence is still inconclusive. This could be the result of the complexity of neurophysiological research and the brain itself, on the one hand, and methodological and conceptual limitations, on the other hand. In the following, I highlight the four main methodological and conceptual limitations.

1.4.1 Methodological concerns

When it comes to methodological issues, there are several technical aspects concerning EEG data collection protocols and analysis that need to be accounted for. However, at this point I want to highlight two methodological issues that are more specific to PFA research. First, there is no unison regarding the brain locations and electrode positions for EEG data collection and analysis. In many studies, EEG data is recorded from the whole scalp and asymmetry indices are analyzed from different regions that are not limited to PFC regions only (e.g., Kline et al., 2001; Keune et al., 2012; De Pascalis et al., 2018). Additionally, the regions included in the data analysis are either not mentioned explicitly (e.g., Harmon-Jones & Allen, 1998; Amodio et al., 2004) or rationales for the choice of regions are not provided (e.g., Jackson et al., 2003; Mikolajczak et al., 2010; Nash et al., 2012). Therefore, an unnecessarily large number of analyses are conducted and reported results only represent a subset of these analyses. This raises two concerns: outcome reporting bias, which describes the selective reporting of a subset of the original outcomes leading to overestimation of the effect reported (Dwan et al., 2008) and an enhanced risk of type I error inflation (i.e., false discovery rate) due to multiple testing (Benjamini, 2010). To prevent these concerns and to gain more theoretical insights into the underlying mechanisms of PFA, data collection and analysis need to be hypothesis-driven and therefore an a-priori selection of electrode positions is required. Accordingly, choices should be informed by theoretical considerations, previous evidence and the research question and hypothesis.

Second, in the majority of experimental and quasi-experimental studies on PFA measures to induce affective (i.e., also motivational) states do not involve participants in the situation itself.

EEG measurement is a very sensitive technique that requires the control of many parameters, such as movement (Kline et al., 2015; Thompson et al., 2008). Therefore, it is typically conducted in the lab as opposed to the field. Here, the most widely used paradigms include presenting affective pictures (Deng et al., 2021) or films (Zhao et al., 2018), listening to music/sounds (Papousek et al., 2012), manipulating facial expressions (Coan et al., 2001; Coan & Allen, 2003) or imagining scenarios (Wacker et al., 2003). However, these raise several concerns including ambiguity of constructs, limited intensity of affective response and ultimately, a lack of ecological validity. For example, when watching pictures or videos portraying people in pain, the generation of an affective reaction also depends on the participant's ability to be empathetic (Moriguchi et al., 2007). As PFC also plays a role in empathy, potential changes in PFA could be either related to the affective reaction or to the ability to show empathy (Singer & Lamm, 2009). Also, in case of low levels of empathy, the resulting affective reaction might be too mild to reliably show detectable changes in brain activity (Philippot, 1993). Another reason for weak affective reactions could be a lack of ecological validity. Ecological validity addresses the concern whether behavior observed in the lab can generalize to behavior in the real world and poses a challenge on psychological research in general (Scheidt, 1981). There are three dimensions that need to be considered when aiming to achieve ecological validity, namely the nature of the environmental setting, the stimuli under investigation and the response (Schmuckler, 2001). Accordingly, one way of enhancing ecological validity is to adapt the stimuli. Instead of using the traditional paradigms, more realistic situations or modern techniques could be used. A promising candidate is the manipulation of success and failure, which can be applied in the lab and has been shown to reliably induce positive and negative affective states respectively (Nummenmaa & Niemi, 2004). In PFA research, failure induction has been used successfully using error-related negativity as an indicator of affective change (Amodio et al., 2008; Nash et al., 2012). An alternative option to enhance ecological validity is the use of virtual reality. Although posing a greater challenge on EEG measurement, virtual reality scenarios bare an immense potential to elicit authentic affective states (Felnhofer et al., 2015; Riva et al., 2007). Up to date, few studies in the area of PFA have already used virtual reality scenarios to induce affective and motivational states (see Brouwer et al., 2001 and Rodrigues et al., 2018 for examples).

1.4.2 Conceptual concerns

Furthermore, conceptual issues must be mentioned. Third, a large degree of research continues to focus on the association between PFA and BAS/BIS although numerous contradictory results exist (Gable et al., 2015; Neal & Gable, 2016; Wacker et al., 2010). The persistent continuation of research in this area partly ignores an alternative research strand highlighting an association between PFA and affect regulation. Therefore, the two strands continue to exist alongside each other with few scholars trying to challenge their co-existence (e.g., Papousek et al., 2012; Jackson et al., 2003). Since the affect generation and affect regulation processes are tightly interconnected, it is hard to distinguish between their differential influences. Accordingly, many findings could be interpreted as both, supporting a positive association between a higher relative left-hemispheric PFA and BAS as well as the successful downregulation of negative affect: for example, Nash et al. (2012) measured EEG baseline activity before assessing error-related negativity during the Stroop task, which reflects distress and aversive motivation in response to an error. Their results showed a negative association between a higher relative left-hemispheric PFA at baseline and error-related negativity amplitude. This result can be interpreted as a reduced reactivity towards negative stimuli or as an enhanced ability to regulate negative affect. Both options can result in approach motivation (or positive affect). Additionally, definitional issues regarding traditional and more recent conceptualizations of BAS/BIS further enhance uncertainty (Gable et al., 2018). Therefore, we suggest looking beyond BAS/BIS and focusing on disentangling the differential influences of reactive and regulatory mechanisms by considering both at the same time or observing the affective reaction over time.

Finally, most theories and models of PFA fail to account for the interplay of affective and cognitive processes. For example, the motivational direction theory states that a higher relative left-hemispheric activity is associated with appetitive motivation and approach-related affect (Harmon-Jones, 2003). However, it fails to provide specific fundamental brain mechanisms responsible for the findings. Considering the diverse roles of the PFC (e.g., in goal pursuit), it is highly unlikely that the asymmetrical activity by itself explains the reported findings. Instead, the association of PFA and affective or motivational phenomena might depend on other cognitive processes that compete for the resources. This is similar to the idea of affect regulation, which reflects the cognitive regulation of an affective state and has been shown to depend on the current cognitive capacity (Gross, 2002; Schmeichel & Demaree, 2010). The AIM is the only PFA model that explicitly accounts for this interplay and considers the underlying mechanisms. It states that affective processing can take up PFC's capacity to deal with other cognitive tasks or inversely, high cognitive demands can lead to difficulties in inhibiting affective distractions (Grimshaw & Carmel, 2014). Investigating interactive effects of cognitive and affective processes could therefore help to better understand PFA and potentially explain inconsistent findings.

2 Aims of the research

This dissertation project followed four main aims. First, to investigate the mechanisms responsible for the differences between individuals that can cope well with failure experiences compared to individuals that remain in a negative state for an extensive time. Based on the findings described above, PFA seemed to be a promising candidate to explain some of the variance, particularly considering the work of Jackson et al. (2003) on affective recovery and the AIM of PFA, which also implies an involvement in performance. Second, to investigate whether those who can handle failure well not only benefit from a more positive affective state but also a better performance in subsequent tasks. Third, to contribute to the current debate on the functional interpretation of PFA regarding its involvement in affect reactivity versus affect regulation. Finally, to look at PFA in the specific context of sport and exercise.

The first article addressed the first three general aims while also overcoming the four concerns mentioned above. In terms of PFA, it focused on the involvement of PFA in state affect regulation within a university setting. It aimed to differentiate between affect reactivity and regulation using a pre-post design with several measurement points to depict the time course of affective responding. This was done by inducing failure in an ego-relevant cognitive task suitable to elicit negative affect. Affective, cognitive and behavioral consequences were of interest to understand their interactive nature.

The second article focused on investigating the differences between individuals that can cope well with failure by being able to discard the experience and focus on the next steps and individuals that continue feeling upset and ruminate about their mistakes. Since PFA research has not only focused on states but also on traits, the second study complemented the first by focusing on trait affect regulation (i.e., affect regulation across various situations) instead of state affect regulation in a specific situation. This was tested by differentiating affect reactivity and regulation, this time, however, using trait questionnaires. The particular aim was to provide a potential explanation for the inconsistencies in the BAS/BIS literature by assessing

BAS/BIS and a measure of affect regulation, namely action orientation, within the same study and analyzing their individual contributions to PFA.

The third article was concerned with the role of PFA in the sport and exercise context. Since the second article highlighted an involvement of PFA in affect regulation abilities in general, the assumption was made that findings can be extended to a sports setting. To provide a comprehensive overview of the literature, a scoping review was conducted that structured the existing studies and mapped out further characteristics. Affective, motivational and performance parameters were of interest and complemented the previous articles by adding a sport psychological perspective to the topic.

3 Methodology

Both studies (article 1 and article 2) followed a confirmatory quantitative approach. All research questions and hypotheses were developed based on literature and served to inform the choice of methodology. A particular focus was put on affect regulation, which was the key construct in both studies – first measuring state affect regulation and then trait affect regulation. In addition, the context for affect regulation was the same: both studies looked at how individuals deal with failure. The review article (article 3) applied a scoping review approach to structure and map out all evidence on PFA in the sport and exercise context. In the following, the methodology is described in a two-step process. First, the general methodological approach is described followed by a detailed description with rationales for all methodological choices.

3.1 Article 1

This study used a one-group pretest-posttest quasi-experimental design investigating how PFA is related to an individual's affective, cognitive and behavioral reactions to a failure experience. It is important to note, that the focus was solely on the consequences of failure and not of success, because PFA research has yielded more reliable results for negative affect (Reznik & Allen, 2018) and to ensure a reason for affect regulation. Therefore, a success condition that could have served as a control group was not included (quasi-experimental). Instead, all participants followed the same procedure (one-group) and affect, cognition and behavior were assessed before (pretest) and after (posttest) the manipulation. Also, because PFA scores were kept as a continuous variable and no counterbalancing was applied, it was neither a within- nor a between-subjects design (Cozby & Bates, 2018).

Despite affect being the main variable of interest, cognition and behavior were measured as well to see how affective and cognitive processes interact to determine behavior, that is, performance in a task. This interaction is particularly interesting in the perspective of the AIM of PFA, which states that cognitive processes need to be considered, in order to fully understand PFA's involvement in affective processes (Grimshaw & Carmel, 2014).

Additionally, while affect and cognition were assessed via self-report questionnaires and are therefore subjective, behavior served as a more objective measure. A focused description of the methodology is provided within the first study. For further information, details and rationales for the study design are presented in the following paragraphs.

The quasi-experimental set up consisted of one EEG measurement, three time points assessing affective and cognitive states and two cognitive tests (see Figure 1 in article 1 for an overview of the procedure). According to Hagemann et al. (2005), 40% of the variance in PFA activity is caused by situational factors (state), while 60% are determined by stable individual differences (trait). Therefore, to avoid additional situational confounders resting baseline EEG was measured at the beginning of the study in the ventrolateral and dlPFC right after signing informed consent. These locations were chosen based on their involvement in cognitive and affective processes and their relevance in previous studies and PFA models (see above for further details). The measurement procedure followed the protocol recommended by Hagemann (2004) which included eight recordings of one minute each with a short break in between. While four recordings were conducted with eye open (O), the remaining four were with eyes closed (C). The sequence of O and C was randomized and was either COOC-OCCO or OCCO-COOC. These sequences account for carry-over effects from one measuring condition (O or C) to the other, because all potential combinations are included. This EEG protocol was chosen because it has shown an adequate internal consistency (Tomarken, Davidson, Wheeler, & Kinney, 1992).

The EEG measurement was followed by the pre-test state assessment, which was handed out to the participants right before the first and the second test. This assessment served to measure the current affective and cognitive state and consisted of three sections. First, the affective questionnaire asked to indicate the current affective state by drawing a line on a 10cm visual analogue scale (VAS). It comprised the four affective states: upset, angry, anxious and happy. The design of the questionnaire was based on three considerations: a) failure experiences elicit specific affective states (Nummenmaa & Niemi, 2004), b) limiting the questionnaire to four affective states reduced the duration of the experiment in favor of cost-benefit considerations and thereby followed ethical standards (Hobbs, 1948) and c) compared to a Likert scale, the VAS is more precise and able to detect even minor changes (Pfennings et al., 1995; Voutilainen et al., 2016). Second, the cognitive questionnaire asked for challenge and threat states by posing two questions (i.e., "To what extent do you regard performing this task as challenging and fun?" and "To what extent do you regard performing this task as threatening and unenjoyable?") in accordance with Besser et al. (2004). This procedure was chosen due to the lack of validated questionnaires suitable to assess challenge and threat states right before a cognitive test. To keep the answering format consistent and therefore to enhance usability, again a VAS was chosen. Third, control variables were assessed: motivation was checked by asking how important it is to achieve a good result and how well they believe they will do in the test. Additionally, to ensure understanding and to raise awareness of the specific goal of the test, participants had to indicate information provided by the task instructions including what the test measures, the maximum score and the average score of university students.

Cognitive performance was measured using the 24 items MRT-A version of Peters et al. (1995) mental rotation tests. This specific test was chosen because most students are unfamiliar with mental rotation tasks and even if known, mental rotation tasks are quite ambiguous (especially under time pressure) and therefore it is hard to estimate performance before receiving feedback. This was important to increase credibility of the failure feedback. Also, the MRT-A standard version has a medium difficulty level and therefore is less prone to evoke task disengagement that might have been caused by the more difficult MRT-C version (Lench & Levine, 2008; Wrosch et al., 2003). Avoiding task disengagement was particularly important, because participants needed to stay motivated for the second test. According to the original instructions, the MRT-A was split into two tests with twelve tasks each and a time limit of three minutes. The instructions of the test included an explanation of the task, scoring and information about mental rotation skills as reliable indicators of intellectual abilities and hence, professional success. Additionally, to align expectations and set a reference for the feedback score, (bogus) norm values for a general (15/24 points) and a student population (17/24 points) were presented. Before starting with the first test, understanding of the instructions was insured by three practice trials that were observed by the experimenter allowing for discussion of any open questions. Following the first test, all participants received failure feedback. The feedback process was adapted from Stoeber et al. (2014) and consisted of two steps: a) the final score was presented on the computer screen (e.g., “You scored 10/24 points”) and b) participants were asked to call the experimenter who verbally repeated the score also adding “that did not go well” and noted the score on a clipboard. The feedback score was chosen to be clearly below the norm values and varied randomly between 9 and 12 if all tasks were attempted. Due to the time limit not everyone is able to work on all tasks (Peters, 2005). Therefore, another algorithm returned lower scores depending on the number of tasks attempted.

The post-test state assessment was filled out after receiving feedback in the first test and also used VAS only. It consisted of the same affective questionnaire as the pre-test state assessment. The cognitive questionnaire differed and assessed state rumination by posing one question (i.e., “How difficult is it for you to stop thinking about the mistakes you made in the test?”) also in accordance with Besser et al. (2004). Again, this procedure was chosen due to the lack of validated questionnaires suitable to assess state rumination right after a cognitive test. Additionally, a control item was included that asked, “How well did you score in the test?” and served as another manipulation check. After filling out the questionnaire, the experimenter announced a short break of ten minutes. The break was justified by having to keep the time span between the two tests the same for all participants and was chosen to allow for a change in affective state. Within the break time, participants were free to choose between the following activities: to practice the task, to simply sit and wait (without using their mobile phones) or to read magazines provided by the experimenter. This variety of activities allowed for different affect regulation strategies (i.e., attentional, cognitive and behavioral; Phillips et al., 2008) to be employed and thereby maintained ecological validity. Free choice was provided to avoid influencing their affective state further by forcing them to do something they do not want to do. The break was followed by another pre-test assessment and the second test.

The initial sample comprised 50 participants. This number was targeted based on an a priori G*Power analysis (Faul et al., 2009) for testing the effect of single regression coefficients, an expected power of 0.80, a medium effect size (resulting in n = 43) and a buffer of 15% to account for measurement errors and missing data. Three data sets had to be dismissed due to EEG measurement errors and another one due to poor EEG data. Therefore, the final sample consisted of 46 university students. The sample was further reduced to various degrees for the individual analyses due to occasional missing data in the questionnaires. University students were chosen to ensure ego-involvement because the mental rotation task was introduced as a reliable measure of intellectual abilities and professional success. Since the success of the manipulation depends on the motivation and skill estimation, namely the individual appraisal of the task, the tasks should be related to meaningful situations and was therefore tailored to the particular sample (Nummenmaa & Niemi, 2004).

For the statistical analyses, regression based analyses were chosen instead of analyses of variance, because all variables of interest were continuous and forming post-hoc categories would have led to information loss and hence, a reduction of statistical power (Cohen, 1983). A moderation analysis was chosen to investigate the first hypotheses with PFA as the independent variable (X), change in affect (before and after the break) as dependent variable (Y) and affective state after failure as moderator variable (W). A moderation analysis tests if the association between X and Y changes depending on the value of W (Baron & Kenny, 1986). In the present study, W accounted for various levels of negative affect induced by failure and was important because affect regulation is only adaptive in individuals with elevated levels of negative affect. Accordingly, effects were only expected in a subpopulation, which is a common reason for conducting moderation analyses (Baron & Kenny, 1986). As indicated by Hayes and Rockwood (2017), centering or standardizing of X and W, as well as a hierarchical entry of variables is not necessary, therefore the unstandardized interaction term X*W was entered directly into the regression equation. Additionally, break activity was included as a control variable to account for the different affect regulation strategies that might have been used. The combinations of brain regions and affective states led to a series of eight moderation analyses.

Since we did not formulate a-priori hypotheses regarding their differential roles, these were done testing a common hypothesis. This procedure increased the probability to detect a significant result to 34% using the conventional significance criterion. Therefore, Bonferroni correction was applied to correct for multiple comparisons and, hence, to reduce the probability of type-I error (Bland & Altman, 1995): the alpha level was adjusted to $\alpha = .006$. There are critical voices regarding the application of Bonferroni corrections, particularly because reducing the probability of type-I error automatically increases the probability of type-II error (Rothman, 1990). However, since the universal hypotheses including all affective states and both brain locations was of greater interest (i.e., does any affective state change depending on PFA in any brain region?) than individual hypotheses (i.e., which particular affective state changes based on the PFA in a certain brain region?), the application was still justified (Perneger, 1998).

The second hypothesis was investigated using hierarchical multiple regression (blockwise entry). In contrast to forced entry (i.e., all variables are entered at once), this procedure includes entering predictors in steps. However, the entry of predictors is based on theory and past research instead of mathematical criteria as is the case in stepwise regression (Cohen et al., 2002). Particularly, when predictor variables tend to be correlated with each other, hierarchical regression is suitable (Pedhazur, 1997). In addition, blockwise entering was chosen to examine the incremental validity of the cognitive and affective variables by controlling for other variables. Again, eight regression analyses were conducted to account for the different combinations of brain regions and affective states ($\alpha = .006$). The outcome variable was cognitive performance in the second mental rotation test. Performance in test 1 and break activity were used as control variables to control for different levels of mental rotation ability and learning effects by practicing the task respectively. For the predictors, the order of entry was informed by past work. Accordingly, new predictors were entered last: control variables (i.e., cognitive performance in the first test, break activity) were entered first, followed by cognitive variables (i.e., challenge and threat states, state rumination) and in a third step, the interaction term of affective state and PFA was introduced. Significant interaction terms were followed up by means of simple slope analyses. As recommended by Aiken et al. (1991), the significance of the slope was tested at three levels of affective state defined as one *SD* below the mean (i.e., low levels of upset), the mean (i.e., medium levels of upset) and one *SD* above the mean (i.e., high levels of upset). Accordingly, the same test was repeated in three subsamples, which justified the use of Bonferroni correction (Perneger, 1998): the alpha level was adjusted to $\alpha = .017$.

3.2 Article 2

This study used a correlational design to investigate if PFA is related to trait affect regulation. Correlational research aims to investigate relationships either between two or more variables within one population, or between one variable in two populations (Leedy & Ormrod, 2005). In contrast to experimental studies, a correlational design does not require manipulation of variables (Campbell & Stanley, 1963). Since traits are defined as "dimensions of individual differences in tendencies to show consistent patterns of thoughts, feelings, and actions" (McCrae & Costa, 2003, p. 18) and are therefore enduring or stable, correlational designs are suitable for studies that assess trait variables exclusively. Additional to individual differences in affect regulation, trait affect reactivity was assessed to allow for the differentiation between affect generating and regulatory processes. According to Gross et al. (2011a), the distinction between affect regulation and generation is relevant, if affect regulation explains unique variance that goes beyond the variance explained by affect generation. For further information, details and rationales for the study design are presented in the following paragraphs.

Following the same resting baseline EEG measurement procedure described for study 1, both trait variables were measured using self-report questionnaires. Regarding affect regulation, questionnaires typically assess the preference for different affect regulation strategies. For example, Gross and John's (2003) widely used Emotion Regulation Questionnaire (ERQ) measures the preference for the two most commonly used affect regulation strategies – suppression and reappraisal. However, the present study was interested in the extent to which individuals succeed in regulating negative affect instead of identifying the particular affect regulation strategy. Therefore, the "Action orientation subsequent to failure" (AOF) subscale of the German Action Control Scale (HAKEMP-90; Kuhl, 1994a, 1994b) was chosen. It does not only indicate the extent of regulatory success (i.e., position on the continuum between state and action orientation) but also puts affect regulation in the context of failure experiences. Further information regarding the content of the HAKEMP-90, its interpretation and psychometric criteria are described within the published article. Again, it is important to note, that for the reason mentioned above and to keep the two studies consistent, this study was solely interested in the regulation of negative affect (i.e., failure). To asses affect reactivity the German version (Strobel et al., 2001) of Carver and White's (1994) BAS/BIS Scale was used. It is the most widely applied measure of affect reactivity in PFA research. Therefore, comparability between studies is facilitated and issues highlighted in previous studies (i.e., inconsistent findings) can be addressed. Further information on the questionnaire is provided within the published article.

The initial sample comprised 49 university students. This number was targeted based on an a priori G*Power analysis (Faul et al., 2009) for testing R^2 increase in linear multiple regression, an expected power of 0.80, a medium effect size (resulting in $n = 42$) and a buffer of 15% to account for measurement errors and missing data. Two data sets had to be dismissed due to EEG measurement errors. The final sample consisted of 47 participants, which was further reduced to different degrees based on EEG outlier analyses.

For the statistical analysis, hierarchical multiple regression was chosen. It is a suitable means to analyze individual contributions of several variables (i.e., predictors) to the outcome variable (Cohen et al., 2002). Additionally, a blockwise entry process helps to differentiate between individual contributions and contributions when controlling for the other variables and is advisable when predictors tend to correlate with each other (Pedhazur, 1997). As recommended by Cohen et al. (2002), the order of entry was informed by past research: BAS and BIS values were entered in the first step, followed by the AOF value in the second step. Resting baseline PFA served as outcome variable.

As the result of the hierarchical multiple regression indicated a suppression effect, further analyses were conducted to test for suppression. A suppressor is “a variable which increases the predictive validity of another variable (or set of variables) by its inclusion in a regression equation. This variable is a suppressor only for those variables whose regression weights are increased.” (Conger, 1975, p. 36-37). Therefore, it can be clearly differentiated from a mediator, which decreases the predictive validity of another variable (MacKinnon et al., 2000). The third variable model consists of an independent variable (X; AOF), a dependent variable (Y; PFA) and a third variable (Z; BIS/BAS). In the present example, the suppression effect was visible in an increase of the regression weights and semi-partial correlation coefficient ($r_{Y.(X.Z)}$) of X in the overall model, when compared to the zero-order correlation (r_{yx}) of X and Y. This means that Z suppressed the irrelevant variance of X in predicting Y. As suggested by MacKinnon et al. (2000), this observation should be further examined by assessing the third variable effect, which is the product ($\alpha\beta$) of the coefficient associated with Z (β) and the coefficient relating X to Z (α). This coefficient is computed using another regression model where Z is the dependent variable and X the independent variable. If $\alpha\beta$ has an opposite sign to the regression weight of X (overall model), it provides an estimation of the suppressor effect.

3.3 Article 3

This review followed a scoping review approach to provide an overview of all existing evidence on PFA in the sport and exercise context and to structure and map out the evidence based on the differentiation between PFA activity and PFA activation. The two constructs measure trait and state PFA respectively and should be distinguished in order to gain a more precise understanding of the functional interpretation of PFA (cf. Reznik & Allen, 2018).

Scoping reviews are reviews that aim to provide an overview of a body of literature and are suitable to answer broad questions instead of answering a discrete research question. In contrast, systematic reviews are used to address a particular question and to appraise the quality of the results (Munn et al., 2018). Research on PFA in the sport and exercise context is scarce, therefore, a systematic review was not feasible. Meta-analyses are also suitable means to consolidate data from a variety of studies (Garg et al., 2008). However, studies included in a meta-analysis should be rather consistent meaning that they look at the same variables of interest. Given the diversity in the literature, this would have let to a remainder of only a very small number of studies. Therefore, a scoping review was the best fit considering the aim to provide a broad overview of the evidence and the diversity in designs and methods (Davis et al., 2009). Further details on the conduct of the scoping review can be found in the manuscript or within the following paragraphs.

Initially, a scoping review protocol was developed that included the criteria for the literature search and selection. Most importantly, only empirical articles were included. In order to ensure comparability with PFA research from other areas (including article 1 and article 2 of the current thesis) and adherence to good scientific practice, eligible articles were further screened for exclusion criteria, which covered specific aspects concerning the measurement of PFA as well as reporting and interpreting of the results. Further details on eligibility and exclusion criteria are provided within the manuscript. Writing and reporting followed the PRISMA extension for scoping reviews (PRISMA-ScR; Tricco et al., 2018). According to the PRISMA-ScR registration of a review protocol is not obligatory, however, information within the manuscript should be provided. Additionally, the flow chart of the screening process is presented within the article and includes all information suggested in PRISMA-ScR (see Figure 1 in article 3).

The search string was developed based on the most fundamental criteria, which were PFA and the context of sport and exercise. For PFA, the most prevalent synonyms were chosen (i.e., “frontal asymmetry”, “brain asymmetry”, “prefrontal asymmetry” and “alpha asymmetry”) and for sport and exercise “performance” was added (i.e., “physical activity”, “sport”, “exercise”, “athlete” and “performance”) to ensure that all performance-relevant articles are detected, which was the main variable of interest. The search terms were connected using the logical parameters OR and AND (see manuscript for complete search string). After initial testing of the search string, the literature search was conducted on the databases PubMed, SPORTDiscuss, PsychInfo and Web of Science, which represent the research field of interest and cover a wide range of publications.

The initial sample comprised 659 records with 484 remaining after removing duplicates. Screening of title and abstract resulted in 38 records that were further examined using full-text review. Finally, 27 studies were identified that matched the eligibility and exclusion criteria. Data of the studies was extracted and inserted into a table including the most relevant variables, namely authors, year, population & sample size, exercise type & more, PFA location, PFA interpretation, psychological variables, results and performance association. The variables were chosen based on the relevance for providing a comprehensive overview of the literature on PFA in a sport and exercise context.

4 Publications and submissions

4.1 Article 1

Authors: Wiebke Haehl, Arash Mirifar, Mengkai Luan, & Jürgen Beckmann

Title: Dealing with failure: Prefrontal asymmetry predicts affective recovery and cognitive performance

Journal: Biological Psychology

Doi: 10.1016/j.biopsycho.2020.107927

Summary:

Experiencing failure is linked to increases in negative affect. In order to successfully recover from this negative state, downregulation of negative affect is required. Past research showed evidence of the involvement of PFA in affect regulation. Therefore, PFA might also play a role in dealing with failure. The aim of the study was to test if PFA is related to affect regulation following a failure experience (affective recovery). Since enduring negative affect can interfere with cognitive processes, changes in cognitive performance were also investigated. The study thereby focused on situational influences of PFA.

The experimental set up consisted of an EEG baseline measurement followed by a cognitive task with negative performance feedback. After a short break, a second cognitive task had to be completed. Before and after each task, the current affective state was measured using VAS. As a cognitive variable, rumination was also measured right after the first task. The neurophysiological, self-report and behavioral data of 46 participants was analyzed by means of moderation and regression analyses. The failure manipulation reliably increased negative affect and decreased positive affect. Regarding affect regulation, results showed that the change of negative affect during the short break depended on the initial strength of negative affect induced by the failure experience as well as PFA. On the one side, those participants that were upset after failing and had a higher relative right-hemispheric PFA still showed high levels of upset after the break. On the other side, a higher relative left-hemispheric PFA was associated with a reduction of negative affect. Regarding cognitive performance in the second task, similar results were observed: participants that were still upset before the second task showed poorer performance in the task, particularly when they had a higher relative right-hemispheric PFA. In the overall model, rumination further impaired performance. It appears that ruminative thoughts and processing of negative affect occupied executive processes of the PFC that were necessary to solve the tasks successfully. In line with the assumptions of the AIM of PFA, these detrimental effects can be observed in individuals with a higher relative right-hemispheric PFA because they cannot inhibit negative affect efficiently. Therefore, for them, the affect regulation process takes up more resources. These findings give a first insight, into PFA's involvement in affect regulation in a challenging situation. Additionally, they show that PFA's involvement goes beyond affective processes and has the potential to influence behavior. Further research is needed to investigate behavioral effects in different contexts, such as sports.

The manuscript was submitted in January 2020, accepted in June 2020, and published in September 2020 in the Journal *Biological Psychology*. *Biological Psychology* is an international peer-reviewed journal publishing research on the biological aspects of psychological states and processes.

Contribution:

Wiebke Hähl was the author of the published article. As principal investigator, she developed the research questions, deducted hypotheses and designed the study. Mengkai Luan programmed the experimental procedure in Mathlab and thereby supported her with the implementation of the study. Arash Mirifar offered his advice and feedback on the EEG recording and analysis. Data collection and data analysis were conducted by Wiebke Hähl. She wrote the published article, while receiving feedback from all of her co-authors. The publication process was guided by Jürgen Beckmann.

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Dealing with failure: Prefrontal asymmetry predicts affective recovery and cognitive performance

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ABSTRACT

Individuals differ in how they deal with their emotions after failure. While some stay in a negative mood for hours, others recover quickly. The present study investigates whether prefrontal alpha asymmetry (PFA) influences affective recovery and cognitive performance following failure. Forty-seven participants completed two mental rotation tasks separated by a short break and received negative feedback on their performance. Electroencephalographic (EEG) data was collected before the first task and affective and cognitive changes were tracked using visual analogue scales throughout the experiment. In participants that felt upset, higher right-hemispheric PFA was associated with a persistence of negative affect. These participants showed poor performance on the second task. The findings suggest that PFA is a vulnerability factor that prevents individuals from regaining their initial affective state and impairs their cognitive performance.

1. Introduction

Failing is not pleasant. It is accompanied by a decrease in positive and an increase in negative emotions such as sadness, defeat and frustration (Besser, Flett, & Hewitt, 2004; Johnson, Gooding, Wood, Taylor, & Tarrier, 2011; Nummenmaa & Niemi, 2004). In some individuals this negative affect is dominant and enduring, while in others it seems to fade quickly (Johnson et al., 2011). Sustained negative affect can have detrimental effects on subsequent performance (Beedie, Terry, & Lane, 2000; Gillet, Vallerand, Lafreniere, & Bureau, 2013) and therefore may increase the likelihood of further failure experiences. While much research was done on the effects of negative affect on performance, additional research is needed to identify factors that influence the duration of negative affect and hence their potential for long term consequences such as physical (Cohen, Tyrrell, & Smith, 1993) and mental health (Davidson, 2000).

The present research investigates the role of PFA in affective and behavioral consequences of failure experiences. We first present evidence for the interplay of affect, cognition and performance and then go further into detail with the neural basis of affective processing in the light of PFA research.

1.1. Affect, cognition and performance

Emotion and affect are often used interchangeably. The present study uses the term affect to address all emotion-related phenomena within a person because affect is a broader term that embodies emotions and moods and encompasses the subjective experience of emotion (Scherer, 1984). Affect has been found to influence thought and action especially when a situation is personally or socially significant for someone (Fossati, 2012; Izard, 2009). It was shown that affect can interfere with the execution of a perceptual and cognitive task at hand (Viviani, 2013). A large degree of research has focused on the neural integration of affect and cognition (Cacioppo & Berntson, 1999; Gray, Braver, & Raichle, 2002; Miller & Cohen, 2001; Ochsner & Gross, 2005; Phelps, 2006; Tops, Quirin, Boksem, & Koole, 2017). On a neurophysiological level, the presence of emotionally-relevant stimuli is detected by subcortical structures, such as the amygdala. These structures initiate the affective response by activating a sequence of physiological responses (Pourtois, Schettino, & Vuilleumier, 2013). Once elicited, processing of affect is taken over by lateral regions of the prefrontal cortex (PFC) and the anterior cingulate cortex (ACC; Miller & Cohen, 2001). Both have been linked to cognitive functions (van Veen & Carter, 2006). The affective and cognitive neural circuits interact to control thought, affect and behavior conjointly (Dolan, 2002; Gray et al., 2002; Russell, 2003). On the one hand, studies on affect regulation showed

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that the cognitive reappraisal of negative affect activates the ACC and PFC and deactivates the amygdala (Ochsner et al., 2004). The precise interaction between the different brain areas depends on various factors. While the region of the PFC involved in cognitive reappraisal differ depending on the valence of the stimulus (Golkar et al., 2012; Parvaz, MacNamara, & Goldstein, 2012), attentional and behavioral strategies such as distraction also show differential activation of the PFC regions and the amygdala (Kanske, Heissler, Schönfelder, Bongers, & Wessa, 2011; Phillips, Ladouceur, & Drevets, 2008). On the other hand, the amygdala is known to facilitate attention in the presence of emotional stimuli through projections to sensory cortical regions and thereby is able to influence attention and perception (Anderson, 2005). Through the amygdala's impact on attention and perception, higher order cognitive functions such as memory can also be affected by affective states (Easterbrook, 1959). For example, Adolphs, Tranel, and Buchanan (2005) tested the effect of emotional stimuli on the encoding of information in patients with amygdala damage. The results showed that amygdala damage impairs memory for central details but not for peripheral details of pictures embedded in a strongly emotional context.

Negative stimuli have been found to cause more behavioral interference than positive stimuli (Horstmann, Scharlau, & Ansorge, 2006). For example, Gillet et al. (2013) tested cognitive performance of university students in the classroom. Students were asked to solve as many anagram tasks as possible within 5 min. Afterwards the students had to fill out a short form of the Positive and Negative Affect Schedule (PANAS; Watson, Clark, and Tellegen (1988)) to assess their affective state. Performance feedback was not provided. Interestingly, negative affect negatively predicted cognitive performance. Studies in the sport domain report similar results. One well-researched example is the phenomenon of choking under pressure that describes the decrease of performance when best performance is required (for a recent overview, see Mesagno & Beckmann, 2017). Hereby pressure is defined as an elevation of anxiety due to the desire to perform at a high level (Hardy, Mullen, & Jones, 1996). As a reason for choking, scholars report shifts in attention due to anxiety (Baumeister, 1984; Wine, 1971). Oudejans, Kuijpers, Kooijman, and Bakker (2011) investigated the focus of attention expert athletes exhibited when performing poorly under pressure. Using a qualitative approach the authors collected verbal reports from 70 athletes about their focus of attention during pressure. Results revealed that attention was most often focused on worries or external factors supporting the notion that affective states influence performance by their immediate effect on attentional processes.

Further cognitive processes associated with affect are state rumination and the motivational states of challenge and threat. Failure experiences can influence the evaluation of future tasks as threatening or challenging and thereby guide subsequent behavior (Blascovich & Mendes, 2000). Threat states occur when individuals perceive that their well-being or self-esteem are in danger and they possess low coping confidence. Conversely, if they are confident that they can meet the demands of the situation and obtain positive benefits, challenge states occur (Smith, 1991). While challenge states are associated with positive affect and beneficial perception of affective states, threat states are often accompanied by negative affect that is perceived as detrimental for performance (Skinner & Brewer, 2004). For example, if failure is attributed to a lack of ability it is likely to induce a threat state, increases negative affect and may result in state rumination (Beckmann, 1994) which diverts attention away from the task (Martin & Tesser, 1996). State rumination, which focuses on the failure experience per se, can impair executive processing and task performance (Ciarocco, Vohs, & Baumeister, 2010).

The detrimental effects of threat states and rumination on performance have been reported across a wide range of tasks and contexts, such as in cognitive tasks (Brinker, Campisi, Gibbs, & Izzard, 2013; Davis & Nolen-Hoeksema, 2000; Gildea, Schneider, & Shebilske, 2007; Mendes, Blascovich, Hunter, Lickel, & Jost, 2007), academia (Lyubomirsky, Kasri, & Zehm, 2003; Seery, Weisbuch, Hetenyi, & Blascovich, 2010) and sports (Jones, Meijen, McCarthy, & Sheffield, 2009; Kröhler & Berti, 2019; Nicholls, Polman, & Levy, 2012). For example, Mendes et al. (2007) conducted a series of studies with undergraduates who interacted with either stereotypical or counter-stereotypical partners and afterwards completed a word-finding task. Violation of expectation was supposed to take up cognitive resources. The authors assumed that participants would experience threat states and perform worse on the cognitive task when facing counter-stereotypical partners opposed to stereotypical partners. Physiological, questionnaire and performance data confirmed the expected effects. Participants experiencing threat states showed reduced cognitive performance.

To summarize, it is important to note that increased negative affect leads to attention selectivity with a reduced utilization of peripheral cues that can impair cognitive performance especially when they manifest in ruminations that are irrelevant to the task or when they result in a threat state. In order to avoid subsequent performance decrements that increase the likelihood of another failure experience, a fast recovery from negative affect is essential.

1.2. *Affective recovery and prefrontal asymmetry*

Affective recovery, described as the recovery following perturbation in the affective system, is a central parameter of affective style. Affective style relates to different aspects of affective processing, such as magnitude of response, latency to peak of response, threshold to respond and duration of affective response (Davidson, 1998a). It can be measured in both central and peripheral systems (Davidson, 2004). One of the earliest central phenomena that has been studied systematically in that context is the PFA (Gainotti, 1972; Robinson, Kubos, Starr, Rao, & Price, 1984; Sackeim et al., 1982). PFA describes the relative activity of the left PFC compared to the right PFC (Davidson & Tomarken, 1989). To determine PFA, alpha power in the frequency band of 8 − 13 Hz is measured via EEG in homologous sites of the PFC and difference scores are calculated (Smith, Reznik, Stewart, & Allen, 2017). PFA is indicative of state- and trait-like variations in affective processing and therefore predicts trait-like affective tendencies but is also influenced by situational factors (Allen, 2003; Hagemann, Naumann, Thayer, & Bartussek, 2002; Reznik & Allen, 2018)

PFA has been linked to both, affective valence and motivational direction (for a recent review, see Harmon-Jones & Gable, 2018). Several studies have associated a higher relative left-hemispheric activity with approach motivation (Coan & Allen, 2003; Harmon-Jones & Allen, 1997), the experience and expression of positive affect (Thibodeau, Jorgensen, & Kim, 2006; Tomarken, Davidson, Wheeler, & Doss, 1992) as well as a decreased sensitivity to negative stimuli (Henderson, Fox, & Rubin, 2001; Nash, Inzlicht, & McGregor, 2012; Tomarken, Davidson, & Henriques, 1990; Wheeler, Davidson, & Tomarken, 1993). Similarly, research found higher relative left-hemispheric PFA to be associated with adaptive dealing with challenges (Baeken et al., 2014; Koslov, Mendes, Pajtas, & Pizzagalli, 2011; Swingler, Perry, Calkins, & Bell, 2014). These findings are in line with the diathesis-stress model of PFA proposed by Davidson (1998b) suggesting that PFA determines the vulnerability to develop depression. Hence, PFA does not generally correlate with affective state but rather indicates a propensity to modulate a certain state. The capability model of PFA and personality (Coan, Allen, & McKnight, 2006) makes similar assumptions implying that individual differences in affective recovery are only related to PFA during affective challenge. The authors suggest the best way to account for the interaction is to measure PFA during the demanding situation instead of using baseline measures.

However, studies using baseline measures of PFA also support the idea that PFA is involved in affect regulation. For example, Jackson et al. (2003) suggest that PFA is involved in affective recovery. They recorded baseline EEG data from forty-seven participants before presenting emotionally arousing and neutral visual stimuli. Eye-blink startle data was collected during and after the presentation to measure affective state and its' persistence. Results showed that participants with a higher relative left-hemispheric activity displayed attenuated startle magnitude after the offset of negative stimuli. Those participants seemed to have recovered more from the negative affect induced by the stimuli. Interestingly, no differences in affective reaction were found during stimulus presentation. Apparently, an acute negative event called for a normative response across all participants. This study was a replication of the findings by Larson, Sutton, and Davidson (1998), who also reported that participants with a higher right-hemispheric activity showed larger blink magnitudes after the negative stimuli have been presented when accounting for blink magnitude during stimulus presentation. To sum up, PFA seems to be associated with affective recovery following affective challenge. This implies that PFA might also play a role following the experience of failure.

1.3. Present research and hypotheses

If PFA does influence affective recovery from negative affect, and sustained negative affect leads to performance decrements, then, PFA should influence performance following a failure experience. To investigate these assumptions, we recorded baseline EEG and assessed changes in affect, cognition, and cognitive performance after experiencing failure. Based on previous findings (e.g. Jackson et al., 2003; Larson, Sutton, & Davidson, 1998), we hypothesized that participants with a higher relative left-hemispheric activity recover more from negative affect elicited by a failure experience. Particularly, we expected them to show increased reductions in negative affect after a short recovery period compared to participants with a higher relative right-hemispheric activity.

Because of the behavioral interference that negative stimuli can cause due to the involvement of the amygdala and the PFC, we predicted that PFA and affective state would explain additional variance in cognitive task performance when controlling for cognitive factors (rumination and challenge/threat states). Namely, we expected participants with a higher relative right-hemispheric activity to perform poorly on a subsequent task if a negative state persisted.

2. Methods

2.1. Participants

Forty-seven participants were recruited via flyers and postings at the Technical University of Munich. Self-reported psychological (e.g. attention deficit hyperactivity disorder, anxiety disorders and depression) or neurological (e.g. epilepsy) disorders served as exclusion criteria. Since Smit, Posthuma, Boomsma, and De Geus (2007) suggest that the effect of handedness on PFA is negligible, left-handed participants ($n = 7$) were included in the study. Participants were offered to take part in a raffle for 30€ vouchers (US$33). The study was approved by the university's ethics committee. After dismissing the data of one participant due to poor EEG data, the final sample included forty-six participants (17 male, 29 female) with a mean age of 22.59 years (SD = 3.08).

2.2. Procedure

The present study is a one-group pretest-posttest quasi-experimental design (see Fig. 1). Participants were invited and tested individually. After they were informed about the experimental procedure, their rights and anonymity of the data, and had given written consent, EEG data was collected from the prefrontal regions. Subsequently, a mental rotation task was introduced. To ensure maximum effort the relevance of mental rotation skills and spatial abilities for academic and career success was highlighted. Additionally, norm values for the general and the student population were provided. Before the task started, participants had to fill out the pre-task appraisal questionnaire. After the first task negative feedback (score clearly below norm values) was presented on the screen and the participants were asked to call the experimenter who noted the result and further provided verbal feedback ("You achieved x out of 24, this did not go well at all"), followed by the post-task appraisal questionnaire. This procedure was adopted from Stoeber, Schneider, Hussain, and Matthews (2014). Subsequently, the experimenter announced "in order to ensure standardization, we will have a 10 min break before the second task. In the meantime, you can read any of the magazines provided, practice the task or simply sit and wait. However, you are not allowed to use your mobile phone. If you want to practice, simply press Enter and practice tasks will appear on the screen. I will be back in 10 min to give you further instructions."[1]
. The break activity was recorded by the experimenter and coded as 1 (participant practiced mental rotation task, $n = 35$) or 0 (participant did not practice, $n = 11$). Then, after filling out another pre-task appraisal questionnaire, the participants completed the second mental rotation task. This task was the same as the first one but contained different figures. Finally, participants were asked to indicate on a 10 cm visual analogue scale (VAS) ranging from not at all (0) to very much (10) to what extent they believed in the feedback they had received ($M = 5.14$, $SD = 2.77$). Eventually, they were debriefed with a full explanation of the study including the aim of the study and the necessity for the false feedback.

2.3. Measures

2.3.1. Affect

To measure participants' affective state a questionnaire consisting of four affective adjectives (upset, anxious, angry and happy) was designed based on current literature (Besser et al., 2004; Nummenmaa & Niemi, 2004). Negative affect was represented by the adjectives upset, anxious and angry. Positive affect was represented by the adjective happy. These discrete affective states had been assigned to either negative or positive affect based on their valence of being pleasant or unpleasant as suggested by the circumplex model of affect (Russell & Feldman Barrett, 1999). In order to be able to detect even small affective changes a continuous measure was used. Participants rated their current affective state on a VAS ranging from not at all (0) to very much (10). Affective state questionnaires had to be filled out right before each test (T1 & T3) and after having received performance feedback (T2).

2.3.2. Cognition

To measure participants' cognitive state, questions were used in line with Besser et al. (2004). State cognitive rumination was measured by asking the participants to rate the question "How difficult is it for you to stop thinking about the mistakes you made?" after having received negative feedback (T2). Challenge and threat states were measured before each test (T1 & T3) by asking "To what extent do you regard performing this task as challenging and fun/threatening and unenjoyable?" accordingly. All questions had to be rated on a VAS ranging from not at all (0) to very much (10).

2.3.3. Cognitive performance

To measure participants' cognitive performance, the MRT-A version of the Peters et al. (1995) mental rotation task was used. This task includes 24 questions that show a 3-dimensional figure that needs to be compared to four similar figures that are either 3-dimensional rotations of the first figure or a mirror image. Participants had to identify the two

[1] Break activities were chosen to maintain ecological validity and were based on common affect regulation strategies suggested in the literature that can be categorized in attentional (e.g. read magazines), behavioral (e.g. practice task) and cognitive (e.g. reappraise or ruminate while sitting and waiting) techniques (Phillips et al., 2008).

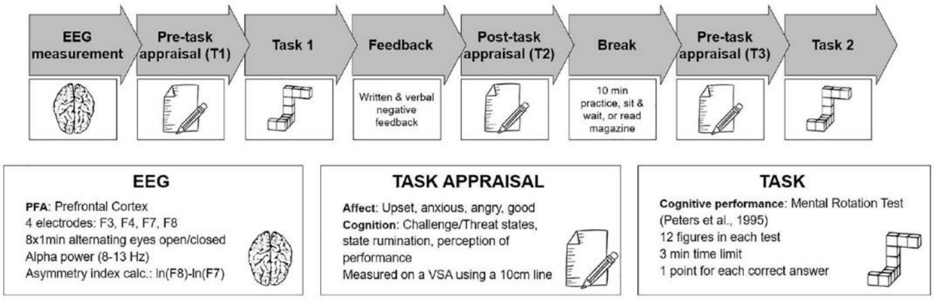

Fig. 1. Illustration of experimental procedure and methods.

figures that were exact rotations of the sample figure. Each correct choice was rewarded with one point. There was no deduction of points for wrong answers. As suggested by Peters et al. (1995) the task was divided into two parts – task 1 and task 2. The time limit for each part was 3 min. To test subjective performance, participants were asked to indicate "How well did you perform in the test?" on a VAS ranging from not at all (0) to very much (10) after receiving feedback for task 1 (T2).

2.3.4. EEG recording and processing

EEG was recorded with the NeXus-10 MKII (Mind Media B.V.; Herten, Netherlands) from four electrode sites (F3, F4, F7, F8) according to the international 10–10 system. The electrode sites were chosen based on their frequent use in former studies (Coan & Allen, 2004; Thibodeau et al., 2006). An abrasive gel (Nuprep) was applied to reduce impedance. EEG was recorded and digitized with the BioTrace + V2017A software (Mind Media B.V.) at a sampling rate of 256 Hz. Average ear reference and bone protuberance in the neck as a ground were used. Following the protocol recommended by Hagemann (2004), eight 1-min intervals (4 eyes open (O), 4 eyes closed (C)) were recorded with 45 s breaks in between. The order of condition was randomized and was either COOC-OCCO or OCCO-COOC. During the EEG recording, participants were instructed to sit still, look straight ahead and try to avoid excessive blinking.

EEG data was processed and analyzed with the BioTrace + V2017A (Mind Media B.V.) software. The data was band-pass filtered at 1–45 Hz to reduce noise. We also applied a notch filter at 50 Hz to ensure that all unwanted noise produced by ambient alternating current was removed. Movement artefacts were automatically detected and rejected with a ± 75 μV threshold. As blinks have negligible effects on PFA and their removal carries the risk of rejecting relevant neural activity (Hagemann, 2004; Hagemann & Naumann, 2001), no additional correction for blinks was conducted. Artefact-free epochs were segmented in 2 s-periods and were extracted through a Hanning Window. A 75 % overlap reduced data loss due to windowing. Fast Fourier Transformation yielded spectral power values (μV^2) within the alpha band (8–13 Hz) that were averaged over the epochs from each 1-min period. Power values were logarithmically transformed to ensure normalized values (Allen, Coan, & Nazarian, 2004).

To obtain asymmetry indices for each 1-min period, ln alpha power of left electrode sites was subtracted from ln alpha power of homologous sites of the right hemisphere (e.g. log [F8] – log[F7]). Higher values indicate relatively stronger left-hemispheric activity. Cronbach's alpha coefficients of the asymmetry indices for each minute showed satisfactory reliability ranging from .89 to .96.

2.3.5. Statistical analysis

To test the stated hypotheses several analyses were conducted. As a prerequisite, a manipulation check was done. We computed paired samples t-tests comparing the affective state before (T1) and after task 1 (T2). An increase in negative affect and decrease in positive affect were assumed to be indicative of a successful manipulation. Additionally, correlation analyses between negative affect and subjective performance would further support the conclusion that changes in affect were due to the perception of failure.

To examine participants' affective recovery after the failure event, we conducted moderation analyses with the change in affective state between T2 and T3 (T3 – T2) as dependent variable (affective recovery), PFA as independent variable and affective state after task 1 (T2) as moderator (affective reactivity). Since the break activities can be viewed as different affect regulation strategies (e.g. distraction or cognitive reappraisal), break activity was included as a control variable. The main effects and interaction of PFA, affective state at T2 and break activity were entered into a regression model. In order to correct for multiple comparisons and thus to limit the potential inflation of Type-I error, the alpha level was adjusted using Bonferroni correction. This yields a significance criterion of $\alpha = .006$ for all moderation analyses performed.

To investigate whether affective state and PFA predict cognitive performance in task 2, hierarchical multiple regression analyses were conducted. As a first step, cognitive performance in task 1 and break activity were entered to control for differences in mental rotation skills and learning effects (if participants decided to practice the task during the break) accordingly. In step 2, the cognitive variables, state rumination, challenge state, threat state and in step 3, the interaction and main effects of affective state at T3 and PFA were entered.

All significant interaction terms were further examined using simple slope analyses, in which the significance of the slopes at three levels of the target variable was calculated, that is, at low (i.e. < 1 *SD* below the mean), medium (i.e. the mean) and high (i.e. > 1 *SD* above the mean) levels (Aiken, West, & Reno, 1991). The alpha level for the three planned comparisons within the simple slope analysis was adjusted to $\alpha = .017$ using Bonferroni correction.

3. Results

3.1. Manipulation check

As expected, participants were more upset, $t(45) = -4.92$, $p < .001$, more anxious, $t(45) = -3.89$, $p < .001$, and more angry, $t(45) = -3.99$, $p < .001$, at T2 than T1. Positive affect was significantly reduced, $t(45) = 4.42$, $p < .001$. Effect sizes, mean values and standard deviations are provided in Table 1. Additionally, participants' subjective rating of their performance in task 1 showed a significant negative correlation with upset at T2, $r(44) = -.33$, $p = .024$, and a significant positive correlation with happiness, $r(44) = .32$, $p = .028$. The correlations between subjective performance and anxiety, $r(44) = -.16$, $p = .285$, and anger, $r(44) = -.24$, $p = .105$ did not reach significance.

Table 1
Paired samples *t*-tests comparing affective state before and after the manipulation.

Affect	T1		T2				
	M [95% CI]	*SD*	*M* [95% CI]	*SD*	*t*-value	*p*-value	Cohen's *d*
Upset	1.57 [0.9; 2.1]	2.07	3.38 [2.6; 4.1]	2.54	−4.92	< .001	0.78
Angry	1.30 [0.7; 1.8]	1.82	2.69 [2.0; 3.3]	2.21	−3.99	< .001	0.55
Anxious	0.87 [0.5; 1.2]	1.23	1.89 [1.2; 2.5]	2.09	−3.89	< .001	0.68
Happy	6.17 [5.5; 6.7]	2.12	4.68 [4.0; 5.3]	2.17	4.42	< .001	0.69

Notes. n = 46. T1 = before task 1, T2 = after task 1. All *p*-values are two-tailed.

As intended, negative affect increased and positive affect decreased after task 1. This increase or decrease was related to the perception of failure for upset and happy but not for anxiety and anger.

3.2. Affective recovery

Two Welch's t-tests confirmed that there were no differences in PFA between left- and right-handed participants for both, F8/F7, $t(10.34) = -1.24$, $p = .243$, and F4/F3, $t(13.34) = 0.83$, $p = .421$. Accordingly, all participants were included for further analyses.

A series of 8 moderation analyses (four affective states, two prefrontal regions), showed a significant interaction for F8/F7 and the affective state upset (T2), $b = -2.13$, $SE = 0.69$, $t(36) = -3.10$, $p = .004$. No further interactions or main effects were observed in this model, $ps > .120$. The model accounted for 29 % of the variance, $F(7,37) = 3.62$, $p = .005$. The significant interaction was further examined by means of simple slope analyses. Results showed that PFA predicted the change in affective state in participants that experienced high levels of upset, $b = -11.62$, $SE = 2.72$, $t(36) = -4.28$, $p < .000$, and in participants that experienced medium levels of upset at T2, $b = -6.15$, $SE = 1.50$, $t(36) = -4.11$, $p < .000$. Participants with low levels of upset, experienced similar levels of affective change across the whole range of asymmetry scores, $b = -0.68$, $SE = 1.83$, $t(36) = -0.37$, $p = .713$. Fig. 2 illustrates the interaction term. As can be seen, participants with a higher relative right-hemispheric PFA tend to show no reduction or even an increase in upset when they reported medium or high levels of upset after experiencing failure. In contrast, in participants that experienced low levels of upset, affect changed independently of the asymmetry score. None of the other models, including different affective states (anxiety, anger and happiness) or prefrontal region (F4/F3) reached a significant interaction, $ps > .215$, or main effect, $ps > .149$.

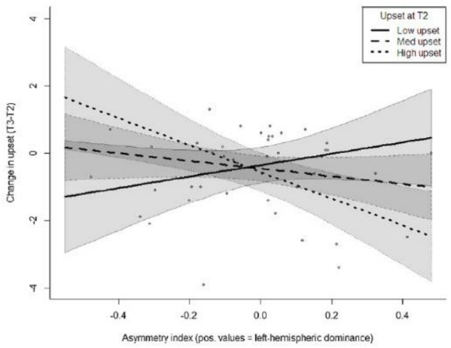

Fig. 2. Simple slopes analysis illustrating the influence of the two-way interaction PFA (F8/F7) X Upset (T2) on the change in upset (includes 95 % CI).

3.3. Predictors of performance

Based on the findings of the previous analyses, only the results for the affective state upset (T3) will be reported here. The regression analyses for the remaining three affective states can be found in the appendix (see Table A1, A2 and A3).

The results of the hierarchical regression analysis predicting performance in task 2 are shown in Table 2. As can be seen, all three cognitive factors were significant predictors of performance with the influence of previous performance and break activity controlled. While, in step 2, increased rumination lead to significantly lower performance, challenge and threat states both seemed to enhance performance levels. In the last step, differences between the prefrontal regions became apparent. Even though the model further improved when entering F8/F7 and upset, $F(3,36) = 4.20$, $p = .012$, the interaction term fell short of the conventional significance criterion, $t(35) = 1.93$, $p = .061$. In contrast, entering F4/F3 and upset revealed a significant interaction, $t(32) = 3.15$, $p = .003$, and main effect of upset, $t(32) = -3.51$, $p = .001$. The more upset the participants were the lower their performance. The overall model accounted for 60 % of the variance in cognitive performance, $F(3,33) = 5.00$, $p = .006$.

To illustrate the interaction, we plotted the regression of F4/F3 on performance at high, medium and low levels of upset (see Fig. 3). As can be seen in Fig. 3, there was a strong positive relationship between PFA and performance at high levels of upset, $t(32) = -2.72$, $p = .010$. Participants with medium and low levels of upset, showed similar levels of performance across the whole range of asymmetry scores, $ps > .137$. That is, participants with a higher right-hemispheric PFA achieved lower scores in the mental rotation task only if they were highly upset. In contrast, participants that experienced low or medium levels of upset performed at similar levels regardless of their PFA.

Table 2
Hierarchical multiple regression analysis predicting performance in task 2 from upset and PFA at F8/F7 and F4/3.

Predictor	Prefrontal region			
	F8/F7		F4/F3	
	ΔR^2_{adj}	*b*	ΔR^2_{adj}	*b*
Step 1	.28**		.25*	
Control variables[a]				
Step 2	.17*		.22**	
Rumination		−1.02**		−0.86*
Threat		1.34**		1.63***
Challenge		0.74*		0.97**
Step 3	.12		.13*	
Upset		−0.43		−1.09*
PFA		−0.89		−12.28
Upset x PFA		1.42		5.28*
Total R^2_{adj}	.56***		.60***	
n	44		41	

Note. [a]Control variables included performance in task 1 and break activity. *$p < .050$. **$p < .010$. ***$p < .001$.

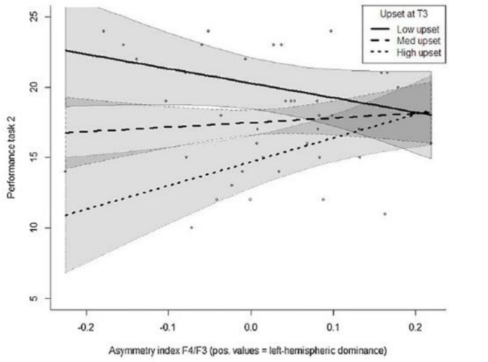

Fig. 3. Simple slopes analysis illustrating the influence of the two-way interaction PFA (F4/F3) X Upset (T3) on performance in task 2 (includes 95 % CI).

4. Discussion

The present study investigated the relationship between PFA and affective recovery as well as cognitive performance. Firstly, we addressed the question whether PFA influences affective recovery from negative affect that has been elicited by failure in a cognitive task. Secondly, we focused on whether PFA and affective state influence cognitive performance following the failure experience in addition to the cognitive factors (rumination, challenge/threat states).

The failure experience successfully induced an increase in negative affect and decrease in positive affect. However, upset was the only negative affective state that seemed to be reliably associated with the failure experience itself. Following failure, we found that participants with a higher right-hemispheric PFA who felt moderately or strongly upset after failing on the cognitive task, showed no recovery from their negative affective state during the break between tasks. Instead, they remained in a negative state independent of the activity they engaged in while waiting for the second task. The opposite pattern was observed for participants with a higher left-hemispheric PFA. Furthermore, our results showed that participants with a higher right-hemispheric PFA who still felt highly upset right before the second task, performed poorly on this task. Further performance decrements were observed in participants that ruminated about their mistakes, and those that did not view the task as a challenge or a threat. The present findings support previous findings indicating that a higher left-hemispheric PFA reduces the duration of negative affect following a negative event (Jackson et al., 2003; Larson et al., 1998) and give indications of how PFA and negative affect interact to influence cognitive performance.

4.1. Affective recovery

On a neurophysiological level, the role of PFA in affective recovery can be explained by PFC-amygdala coupling (Lee, Heller, Van Reekum, Nelson, & Davidson, 2012). As suggested by Davidson, Jackson, and Kalin (2000)), PFA has the potential to influence affective recovery through PFC inverse functional connectivity with the amygdala. The different regions of the PFC engage in various cognitive functions such as response selection and inhibition (Kane & Engle, 2002; Viviani, 2013), orienting attention to behaviorally- and goal-relevant stimuli (Corbetta & Shulman, 2002) and working memory (Kane & Engle, 2002). Through its inhibitory pathway to the amygdala, several regions of the PFC have been found to be involved in voluntary affect regulation, especially in reducing negative affect (Johnstone, van Reekum, Urry, Kalin, & Davidson, 2007; Lee et al., 2012; Ochsner et al., 2004). For example, Johnstone et al. (2007) collected fMRI data from depressed and non-depressed participants while regulating negative affective states evoked by affective pictures. They found that the lack of engagement of the left ventromedial PFC (vmPFC) in depressed participants lead to difficulties in downregulating negative affect whereas non-depressed participants showed an inverse relationship between activation in the left ventrolateral PFC (vlPFC) and the amygdala (Johnstone et al., 2007). Hence, the reduction of negative affect seems to require the downregulation of the amygdala response to negative stimuli by the PFC and presumably the left lateral PFC in particular (Davidson, 1998a; Ochsner et al., 2004; Phan et al., 2005).

To sum up, fMRI data does not only support our findings regarding the role of PFA in affective recovery but also highlights that the vlPFC rather than the dorsolateral PFC (dlPFC) is involved in affect regulation. As reliability studies comparing EEG electrode placement and fMRI data suggest, F4 and F3 regions of the 10-10 international system seem to approximate the dlPFC while F8 and F7 approximate the vlPFC (Ives-Deliperi & Butler, 2018; Koessler et al., 2009). This is in accordance with our findings that only PFA in F8/F7 and not in F4/F3 was involved in affective recovery. Additional support comes from an EEG study by Papousek et al. (2017) that reported that individuals with a high capacity for affect regulation showed more left-hemispheric activation, especially in the vlPFC (F8/F7), during affective challenge. Similar results were reported in an earlier study (Papousek, Freudenthaler, & Schulter, 2011), which showed less left-hemispheric activation when facing anxiety evoking stimuli and no return to baseline in individuals with low affect regulation abilities. Moreover, this effect was only present in individuals with high affect sensitivity, which is in line with the control function of affect regulation (Carver & Scheier, 1998) and with our findings indicating that PFA only predicts affective recovery in participants who experienced strong negative affect after failing in the task. Since the levels of anxiety and anger were well below the levels of upset, this might explain the absence of any significant results in regards to other discrete states. However, previous research has established an association between PFA and anxiety (Thibodeau et al., 2006) as well as anger (Harmon-Jones, Gable, & Peterson, 2010).

4.2. Predictors of performance

The various functions of the PFC in affect regulation and cognitive processes may also explain our second finding. It is widely recognized that specific mechanisms prioritize the processing of information that is relevant for goal attainment and survival (Phelps, 2006; Vuilleumier, 2005). In particular, emotionally arousing stimuli are successful in capturing working memory resources (Vuilleumier, 2005). Spatial tasks, such as the mental rotation task, engage the working memory quite extensively (D'Esposito et al., 1995). Therefore, when the processing of negative stimuli takes up executive resources of the PFC, subsequent performance on a cognitive task can be impaired (Viviani, 2013).

A new model of PFA, the Asymmetric Inhibition Model (Grimshaw & Carmel, 2014), integrates these findings and explains PFA in the light of affect inhibition. The inhibition model states that "EEG asymmetries reflect the integrity of executive control mechanisms that inhibit interference from irrelevant emotional distractors" (p. 3). Even though focusing on emotional stimuli is adaptive, their inhibition can be crucial when dealing with cognitively demanding tasks. It is further proposed that the right PFC inhibits processing of positive (or perhaps approach-related stimuli) whereas the left PFC inhibits processing of negative (or perhaps withdrawal-related) stimuli. At present, the model does not specify whether it is valence or motivational direction that best accounts for PFA; this issue needs to be clarified in future research. However, first support for the model comes from studies using irrelevant emotional distractors in an emotionally neutral task (Grimshaw, Foster, & Corballis, 2014; Miskovic & Schmidt, 2010; Pérez-Edgar, Kujawa, Nelson, Cole, & Zapp, 2013). For example, Miskovic and Schmidt (2010) found that participants with right PFA and low cardiac vagal tone had difficulties shifting attention away from angry but not from happy faces. Further research suggests that task interference by negative affect seems to be limited to strong negative stimuli (Mogg et al., 2000; Schimmack, 2005; Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008). They argue, in accordance with our findings, that the level of negative affect influences allocation of cognitive resources.

The level of remaining cognitive resources does not only depend on affective states but also on other cognitive processes, such as rumination. Rumination may further consume resources that would otherwise be directed towards the cognitive task (Brinker et al., 2013; Watkins & Brown, 2002). Particularly, regions including the medial PFC have been associated with mentalization (Frith & Frith, 1999) and self-reflective thought (Johnson et al., 2002). Therefore, our results on the detrimental effects of ruminative state on performance do not seem surprising. Regarding challenge and threat states, our findings conflict with our predictions and current literature. Contrary to expectation, challenge and threat states both influenced performance positively. According to the literature, challenge states facilitate performance and threat states hinder performance (Gildea et al., 2007; Mendes et al., 2007; Moore, Vine, Wilson, & Freeman, 2012; Seery, 2011), which was not confirmed in the current study. Nevertheless, if we view challenge and threat states as motivational states independent of their interpretation, they could be viewed as a general indicator of motivational involvement in the task (Blascovich, 2013). As PARCS theory (Tops et al., 2017) suggests, negative affective states associated with the perception of threat, motivate the individual to eliminate the problem which in turn leads to more effortful information processing. However, in order to better understand the influence of challenge and threat states on performance, objective measures should be preferred over subjective measures (Blascovich, 2013). Since the evaluation of demands and resources often occurs unconsciously, cardiovascular responses seem to be a more suitable indicator of challenge and threat states (Blascovich & Mendes, 2000; Seery, 2011).

4.3. Distinctive roles of prefrontal regions

Also, our findings require further elaboration of the different locations of the PFC. Whereas affective recovery was associated with F8/F7, cognitive performance was predicted by activity in F4/F3 only. Therefore, we would like to briefly provide a preliminary framework for interpreting findings in the two prefrontal regions selected for the present study. The most commonly known neural models of affect regulation differentiate between a dorsal and a ventral neural system (Ochsner, 2007; Phillips, Drevets, Rauch, & Lane, 2003). As suggested by Phillips et al. (2008), the dorsal system comprises the hippocampus, dorsal ACC and dorsal PFC. Its functions are mainly executive and include selective attention, planning, performance monitoring and voluntary affect regulation. Thereby it maintains the focus of attention in face of distraction based on prior information or goals (Viviani, 2013) and integrates cognitive processes with affective input (Phillips et al., 2003). Accordingly, the dlPFC has been recognized to be critically involved in the integration of motivational and cognitive processes (Hikosaka & Watanabe, 2000). Within the dorsal system the dlPFC is of particular interest for PFA research. Theoretical implications might be that F4 and F3 are more closely related to the motivational direction implied in PFA and executive functions.

In contrast, the ventral system comprises the amygdala, insula, ventral striatum, ventral ACC and ventral PFC. Its functions are mainly emotive and include the identification of affective stimuli, generation of an affective state and automatic affect regulation (Phillips et al., 2003, 2008). This allows for the conclusion that F8 and F7 as part of the ventral system might be more closely related to the valence component of PFA. The suggested framework is in accordance with our findings, indicating that F8/F7 plays a role in (automatic) affective recovery from negative affect through the ventral system and F4/F3 influences cognitive performance that relies on executive processes in the dorsal system. However, we must note that it only accounts for our findings regarding PFA and upset, which has been the focus of our analyses due to its' evident association with the failure experience. The additional analyses (e.g. see Table A1, A2 and A3 in the Appendix) show different patterns which can not be accounted for by the suggested framework.

Nevertheless, previous research provides further support. For example, Zhang et al. (2018) tested whether stress induction using an automatized bilateral feet cold pressor test modulates PFA and thereby influences the cardiovascular and cortisol response. What they found were significant changes in F8/F7 during the intervention. In contrast, cardiovascular and cortisol responses only correlated with F4/F3. Looking at the experimental setup, one may assume that the experience of the cold water elicited negative affect (valence) that lead to a shift towards relative right-hemispheric activity in F8/F7. However, from a physiological perspective cardiovascular and cortisol responses generally serve to withdraw (motivational direction) from an unpleasant stimuli (Jansen et al., 1999) and may therefore be related to F4/F3. Further studies focusing on the differentiation between specific prefrontal regions are needed and may contribute to a deeper understanding of the underlying mechanisms.

4.4. Limitations and future directions

Limitations of the current study and future directions should be considered. First, our findings do not allow for conclusions regarding the specific contributions of the different hemispheres of the PFC. While there are good reasons for using asymmetry scores instead of absolute values, a deeper understanding of the mechanisms requires analyses of the two hemispheres independently (Allen et al., 2004). Therefore, it would be desirable to include additional analyses of both hemispheres in future studies. Second, whereas other studies have included analyses of various regions of the cortex, our analyses focused on the four electrode sites exclusively. For example, Jackson et al. (2003) found effects of frontal pole and fronto-central regions on affective recovery. A replication of their results as well as comparisons to other prefrontal regions or even parietal and temporal cortices could not have been conducted. Third, a broader range of cognitive or non-cognitive tasks may help to understand the functional role of PFA in the interaction of affective state and performance. This line of research would generate the basis for more applied research testing interventions such as neurofeedback training (Allen, Harmon-Jones, & Cavender, 2001), mindfulness meditation (Davidson et al., 2003), hand contractions (Harmon-Jones, 2006; Schiff & Lamon, 1994) or aerobic exercise (Hicks, Hall, Staines, & McIlroy, 2018; Woo, Kim, Kim, Petruzzello, & Hatfield, 2009; Woo, Kim, Kim, Petruzzello, & Hatfield, 2010) to help people to deal with failure more efficiently.

Fourth, we controlled for break activity in our analyses but only differentiated between whether participants decided to practice or not. If participants decided not to practice, we did not further track the break activity. As mentioned before, the different activities were chosen based on common affect regulation strategies suggested in the literature. As previous research shows, affect regulation strategies influence the affective recovery process differentially (Webb, Miles, & Sheeran, 2012). They do not only vary in their effectiveness but also in where they intervene in the affect generation process (Sheppes & Gross, 2012). However, our data does not allow any further analysis regarding the specific strategy chosen, which leaves the clarification of the interconnectedness between PFA, affect regulation strategy and affective recovery open for future research.

Finally, in the present study failure was induced in a laboratory setting and therefore lacks generalizability. Personal relevance of the task could not have been ensured and varied between participants. Nevertheless, the present findings confirm that the experience of failure is a reliable elicitor of negative affect. Particularly, an increase in upset was observed. Concerns raised regarding more traditional induction procedures such as watching films or pictures mainly criticize their ecological validity, because people are not involved in the situation per se (Nummenmaa & Niemi, 2004). Therefore, future research could profit from using failure induction scenarios to induce negative affect. Since experiencing failure is more closely related to real situations this would allow for more authentic affective experiences.

5. Conclusion

PFA was found to influence affective recovery and performance following a failure experience. These findings might be due to PFA's involvement in automatic affect regulation and resource allocation of executive processes. Moreover, our results support the assumptions proposed by the Asymmetric Inhibition Model suggesting that instead of the support of approach or positive affect, left-hemispheric PFA might be associated with the inhibition of withdrawal or negative affect.

Declaration of interests

The authors declare the following financial interests/personal relationships which may be consideredas potential competing interests.

Appendix A

See Table A1, A2 and A3.

Table A1
Hierarchical multiple regression analysis predicting performance in task 2 from anxious and PFA at F8/F7 and F4/F3.

Predictor	Prefrontal region			
	F8/F7		F4/F3	
	ΔR^2_{adj}	*b*	ΔR^2_{adj}	*b*
Step 1	.28***		.25**	
Control variables[a]				
Step 2	.17**		.22***	
Rumination		−1.12***		−1.21***
Threat		1.41***		1.44***
Challenge		0.68**		0.86**
Step 3	.12*		.06	
Anxious		−0.56		−0.50
PFA		−2.36		−12.46
Anxious x PFA		2.79*		7.08*
Total R^2_{adj}	.56***		.53***	
n	44		41	

Note. [a]Control variables included performance in task 1 and break activity. *p < .050. **p < .010.

Table A2
Hierarchical multiple regression analysis predicting performance in task 2 from angry and PFA at F8/F7 and F4/F3.

Predictor	Prefrontal region			
	F8/F7		F4/F3	
	ΔR^2_{adj}	*b*	ΔR^2_{adj}	*b*
Step 1	.28***		.25**	
Control variables[a]				
Step 2	.17**		.22***	
Rumination		−1.09***		−1.06***
Threat		1.51***		1.56***
Challenge		0.77**		0.86**
Step 3	.12**		.05	
Angry		−0.74*		−0.74*
PFA		−1.50		−3.88
Angry x PFA		2.48*		1.94
Total R^2_{adj}	.57***		.52***	
n	44		41	

Note. [a]Control variables included performance in task 1 and break activity. *$p < .050$. **$p < .010$. ***$p < .001$.

Table A3
Hierarchical multiple regression analysis predicting performance in task 2 from happy and PFA at F8/F7 and F4/F3.

Predictor	Prefrontal region			
	F8/F7		F4/F3	
	ΔR^2_{adj}	b	ΔR^2_{adj}	b
Step 1	.28***		.25**	
Control variables[a]				
Step 2	.17**		.22**	
Rumination		−1.11***		−0.98**
Threat		0.94*		0.92*
Challenge		0.82**		0.90**
Step 3	.07*		−.02	
Happy		−0.23		−0.21
PFA		13.28*		8.69
Happy x PFA		−2.16*		−1.73
Total R^2_{adj}	.52***		.45***	
n	44		41	

Note. [a]Control variables included performance in task 1 and break activity. *$p < .050$. **$p < .010$. ***$p < .001$.

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4.2 Article 2

Authors: Wiebke Haehl, Arash Mirifar, Markus Quirin, & Jürgen Beckmann

Title: Differentiating reactivity and regulation: Evidence for a role of prefrontal asymmetry in affect regulation

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Summary:

PFA has not only been shown to be associated with affective states but also with a number of affective traits, such as emotional intelligence or depression. Accordingly, PFA could potentially also be associated with how individuals generally deal with failure. The aim of the study was to test if PFA is associated with a trait measure of affect regulation in failure situations. Additionally, the inconsistencies in the BAS/BIS literature should be examined by assessing both, trait affect regulation and BAS/BIS.

The study followed a correlational design including a baseline EEG measurement and two trait questionnaires. The first questionnaire was the German version of the Action Control Scale and examined trait affect regulation by assessing AOF. The second questionnaire was the German version of the BAS/BIS scale and served to assess BAS/BIS (i.e., trait affect reactivity). The neurophysiological and self-report data of 43 (F4/F3) and 46 (F8/F7) participants was analyzed by means of correlation and hierarchical regression analyses. The correlation analyses revealed significant associations between BIS, BAS and AOF, which highlighted the close relationship between the constructs and hence, the interconnectedness of affect reactivity and regulation. Regarding the association of PFA and trait affect regulation, the results showed that PFA was unrelated to all three variables. However, when controlling for BIS and BAS, a higher relative left-hemispheric activity was associated with higher levels of AOF. This can be interpreted as a suppression effect and indicates an involvement of PFA in individual

differences in affect regulation instead of affect reactivity. These findings provide an explanation for the inconsistencies in the BAS/BIS literature and contribute to the understanding of the mechanisms underlying PFA and individual differences in affective processes. Further research is needed to investigate if these findings can be translated to the regulation of positive affect.

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Contribution:

Wiebke Hähl was the author of the published article. As principal investigator, she developed the research questions, deducted hypotheses and designed the study. Again, Arash Mirifar offered his advice and feedback on the EEG recording and analysis. Data collection and data analysis were conducted by Wiebke Hähl. Markus Quirin offered his feedback on the data analysis and his ideas for structuring some parts of the manuscript. Wiebke Hähl wrote the published article, while receiving feedback from Jürgen Beckmann and Markus Quirin.

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Differentiating reactivity and regulation: Evidence for a role of prefrontal asymmetry in affect regulation

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ABSTRACT

Prefrontal asymmetry (PFA) has originally been referred to as "affective style" and is said to be associated with an individual's personality. Therefore, previous research has focused on finding a link between PFA and trait variables associated with affective processing, such as the behavioral activation and inhibition systems (BAS/BIS). However, recent evidence suggests that PFA might be involved in regulatory processes rather than initial affective reactions. Here, we investigated if failure-related action orientation (AOF), as a personality variable reflecting the ability to disengage from negative experiences, is related to PFA. Forty-seven participants completed two trait questionnaires to assess BAS/BIS and AOF, followed by 8 min of resting EEG measurement. Results showed that higher AOF scores predicted a higher relative left-hemispheric PFA when BAS/BIS was controlled for. The findings suggest that a suppression effect might account for the inconsistencies in the literature regarding the association between PFA and BAS/BIS.

1. Introduction

Non-responder or regulatory expert? Prefrontal asymmetry (PFA), indicating the relative activity of the prefrontal cortex (PFC) of one hemisphere compared to the other hemisphere, is associated with individual differences in affective style (Davidson, 1998a). It reflects tendencies toward approach versus avoidance motivation (Harmon-Jones & Allen, 1998) or positive versus negative affect (Harmon-Jones & Allen, 1998). While most research in PFA has focused on the reactive component of affective style, describing how likely an individual enters an affective state (e.g. Harmon-Jones & Gable, 2017), a growing number of evidence supports an involvement of the regulative component, i.e. affect regulation (e.g. Papousek, Freudenthaler, & Schulter, 2011).

The usefulness of the distinction between affect reactivity and affect regulation has been highlighted by research on personality (Fajkowska, 2015; Robinson, 2007) and emotions (Gross & Feldman-Barrett, 2011; Gross, Sheppes, & Urry, 2011). However, as both components are positively correlated (e.g. individuals that show a high reactivity toward affective stimuli often also have difficulties regulating their affective response), it is hard to distinguish between their differential influences (Fajkowska, 2015; Quirin et al., 2020). To account for the interrelatedness of affect reactivity and affect regulation and identify their unique contributions, both processes need to be considered within the same study. Therefore, the present study aims to enhance the understanding of the functional interpretation of the trait-like portion of PFA by investigating the differential roles of affect reactivity and regulation.

Depending on the specific recording methods (e.g. resting condition), PFA measured via electroencephalography (EEG) is related to both, state and trait-like affective processes (Allen, 2003; Hagemann, Naumann, Thayer, & Bartussek, 2002; Reznik & Allen, 2018). On the state site, a higher relative left-hemispheric activity has been associated with adaptive dealing with challenges (Baeken et al., 2014; Koslov, Mendes, Pajtas, & Pizzagalli, 2011), approach motivation (Rodrigues, Müller, Mühlberger, & Hewig, 2018; Wacker, Heldmann, & Stemmler, 2003), affective recovery (Haehl, Mirifar, Luan, & Beckmann, 2020; Jackson et al., 2003) and a decreased sensitivity to negative stimuli (Nash, Inzlicht, & McGregor, 2012). On the trait site, it has been linked to positive dispositional mood (Tomarken, Davidson, Wheeler, & Doss, 1992), approach-related dispositional tendencies (Coan & Allen, 2003; Harmon-Jones & Allen, 1997), higher sociability (Jetha, Schmidt, &

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Goldberg, 2009; Schmidt, 1999), higher dispositional anger (Harmon-Jones, 2007; Harmon-Jones & Allen, 1998) as well as lower depression and anxiety scores (Thibodeau, Jorgensen, & Kim, 2006). Trait associations typically measure PFA in a resting baseline condition and can be explained by the Diathesis Stress model of PFA (Davidson, 1998b) stating that PFA does not generally correlate with affective state but rather indicates a propensity to react to certain events. For example, an individual with a higher relative left-hemispheric activity may be more vulnerable to anger evoking stimuli and therefore, as indicated in a higher dispositional anger, generally experiences more anger.

The observed associations can be interpreted as both, an involvement of PFA in affect reactivity as well as affect regulation. However, while research findings increasingly report distinct associations with regulatory behavior (Hannesdóttir, Doxie, Bell, Ollendick, & Wolfe, 2010; Jackson et al., 2003; Kim & Bell, 2006; Kline, Blackhart, & Williams, 2007; Larson, Sutton, & Davidson, 1998; Mikolajczak, Bodarwé, Laloyaux, Hansenne, & Nelis, 2010; Papousek et al., 2011; Zhang, Hua, Xiu, Oei, & Hu, 2020), PFA recorded in a resting condition is still mainly interpreted as an indicator for reactive processes, namely the behavioral activation and behavioral inhibition systems (BAS/BIS; Coan & Allen, 2003). BAS/BIS are trait-like motivational systems that are interconnected with the affective experience (Elliot, Eder, & Harmon-Jones, 2013). On the one hand, the BIS is considered to react to conflict or aversive stimuli with the elicitation of negative affect such as fear or sadness. On the other hand, the BAS is considered to react to and prompt the individual to approach rewards, and thus to elicit reward-related positive affect (Carver & White, 1994; Gray, 1994). Accordingly, BIS and BAS reflect a tendency to react to appetitive or aversive stimuli with positive (approach motivation) or negative affect (avoidance motivation) respectively (Carver & White, 1994). As research has shown, high BAS is also associated with a reduced sensitivity (i.e. reactivity) to negative events (Nash et al., 2012). Moreover, recent approaches discuss an involvement of BAS/BIS that goes beyond the reactive view (e.g. Gable, Neal, & Threadgill, 2018).

However, research in the area of PFA has mainly focused on the original conceptualization provided by Gray (1994) and does not fully support a reliable association between BAS/BIS and PFA. Several studies report a positive relation between a higher relative left-hemispheric PFA and the BAS scale by Carver and White (1994), but most studies fail to find associations with a higher relative right-hemispheric PFA and their BIS scale (e.g. Coan & Allen, 2003; Harmon-Jones & Allen, 1997; Hewig, Hagemann, Seifert, Naumann, & Bartussek, 2006). Furthermore, results from research on PFA and BAS are far from being consistent. A meta-analysis by Wacker, Chavanon, and Stemmler (2010) systematically investigated the association between resting PFA and BAS as well as other measures used to assess affect reactivity. Their findings showed no relationship between resting PFA and affect reactivity in general and BAS or BIS in particular. We propose that differences in affect regulation abilities may be accountable for the inconsistencies that persist in the PFA and BIS/BAS literature and are not the first ones to suggest this idea (Düsing, Tops, Radtke, Kuhl, & Quirin, 2016; Kim & Bell, 2006).

Support for an involvement of PFA in affect regulation abilities comes from several domains, such as personality and functional magnetic resonance imaging (fMRI) research. For example, a higher relative left-hemispheric activity has been associated with high levels of action orientation (AO; Harmon-Jones, Harmon-Jones, Fearn, Sigelman, & Johnson, 2008; Harmon-Jones, Harmon-Jones, Serra, & Gable, 2011). In general, AO is a personality trait that reflects an individual's dispositional readiness to pursue (approach) their goals even when facing positive (rewarding) or negative (aversive) distractions (Kuhl, 1994a). Therefore, AO refers to a volitional regulatory process of disengaging from affective experiences and accompanying thoughts. Depending on the manifestation of AO, this volitional process is facilitated or inhibited. Affect regulation is a core aspect of AO (Kuhl, 2001; Quirin, Kuhl, & Düsing, 2011; Radtke, Düsing, Kuhl, Tops, & Quirin, 2020) and can be differentiated from the reactivity with which individuals initially react to affective experiences (Koole & Kuhl, 2008; Koole, 2009; Kuhl, 2001). While action-oriented individuals (high AO) are able to down-regulate negative affect, on the other end of the continuum state-oriented individuals (low AO) are unable to control their affective states effectively (Koole & Jostmann, 2004). In one experiment, Harmon-Jones et al. (2008) asked the participants to make a difficult decision (choosing between two equally attractive alternatives). Afterwards, their mindsets were manipulated by asking them to describe how they could address a goal they want to pursue (action-oriented mindset) or to describe a normal or happy day. Following EEG data collection, the decision alternatives had to be rerated. The results showed an increased left-hemispheric PFA in individuals with an action-oriented mindset. These individuals also regulated their affect more effectively: they evaluated their chosen alternative more positively and the rejected alternative more negatively than prior to the mindset manipulation.

Evidence from fMRI studies, namely PFC-Amygdala coupling, further supports these findings. While the amygdala detects and reacts to potentially affect-eliciting stimuli (Phelps, 2006), the PFC exhibits cognitive control in accordance with internal goals (Corbetta & Shulman, 2002; Miller & Cohen, 2001). Therefore, inhibitory pathways from the PFC to the amygdala are responsible for the achievement of regulatory goals that include the regulation of affect (Lee, Heller, Van Reekum, Nelson, & Davidson, 2012; Miller & Cohen, 2001). In particular, the left dorsal and lateral PFC have been found to be involved in reducing negative affect (Davidson, 1998a; Johnstone, van Reekum, Urry, Kalin, & Davidson, 2007; Ochsner et al., 2004; Phan et al., 2005). Moreover, Lee et al. (2012) showed that individuals with a greater functional connectivity between PFC and the amygdala indexed greater affect regulation abilities measured via corrugator electromyography.

From a theoretical perspective, the regulatory involvement of PFA is compatible with the Asymmetric Inhibition Model (AIM; Grimshaw & Carmel, 2014) of PFA. The AIM states that the inhibition of interference from affective stimuli can be crucial when dealing with cognitively demanding tasks. Therefore, the PFC is suggested to have inhibitory control over the interference from affective states. They further propose that this inhibitory control is lateralized and located in the dorsolateral PFC due to its involvement in executive control. While the right dorsolateral PFC is responsible for the inhibition of positive or approach-related distractors, the left dorsolateral PFC inhibits processing of negative or withdrawal-related distractors. This model has been supported by several studies (Grimshaw, Foster, & Corballis, 2014; Miskovic & Schmidt, 2010; Pérez-Edgar, Kujawa, Nelson, Cole, & Zapp, 2013).

To sum up, the existing research on PFA and traits is inconsistent regarding the association of BAS/BIS and PFA and thereby raises doubts regarding PFA's immediate involvement in affect reactivity. Furthermore, the literature suggests that PFA plays a role in affect regulation and self-regulatory processes regarding the continuation of goal pursuit. Particularly, an association between PFA and AO has been reported. Therefore, PFA may primarily reflect individual differences in regulatory processes.

The goal of the present study is to clarify the role of individual differences in resting PFA in affective processes by investigating whether it is related to regulatory or reactive components of affective style, i.e. AO or BAS/BIS. To test the differential influences, we recorded baseline EEG and assessed AO subsequent to failure (AOF) as the ability to down-regulate negative affect, and BAS/BIS using trait questionnaires. We hypothesize that affect regulation is a better predictor of PFA than affect reactivity: when considered independently from BAS/BIS (reflecting individual differences in affect reactivity), individuals with a higher relative left-hemispheric PFA in a resting condition show higher levels of AOF (reflecting better affect regulation) compared to individuals with a higher relative right-hemispheric PFA.

2. Methods

2.1. Participants and procedure

Forty-seven participants (29 female) with a mean age of 22.59 years ($SD = 3.08$) were recruited via flyers and postings and were offered to take part in a raffle for 30€ vouchers (US$33). None of the participants reported a psychological (e.g. attention deficit hyperactivity disorder, anxiety disorders and depression) or neurological disorder (e.g. epilepsy). Seven participants were left-handed as indicated by self-report. Ethics approval was granted by the university's ethics committee.

The present study is a correlational study. Participants were informed about the EEG procedure, their rights and anonymity of the data and gave their consent. Following the recommendations by Hagemann (2004), EEG was recorded in eight 1-min intervals alternating eyes open (O) and eyes-closed (C) (COOC-OCCO or OCCO-COOC) with 45 s breaks in between. During the EEG recording, participants were instructed to sit still, look straight ahead and try to avoid excessive blinking. Afterwards they filled out the two personality assessments.

2.2. Personality assessment

2.2.1. Affect regulation

Self-reported affect regulation abilities were measured using the AO subsequent to failure subscale (AOF) of the German version of the Action Control Scale (ACS-90; Kuhl, 1994a, 1994b). The ACS-90 consists of three subscales that can not be integrated into a single value. Instead, they describe AO in different phases of goal pursuit. The ACS-90 consists of three subscales measuring AOF, decision-related AO and AO during (successful) performance. Due to test diagnostic reasons, the participants filled out the complete ACS-90. In relevance to our research question, we included only the AOF subscale for further analysis because it measures affect regulation subsequent to an affective stimulus. The other two subscales are not part of the present research and therefore have not been processed further. Single subscales of the ACS-90 have been used in prior studies (e.g. Düsing et al., 2016; Palfai, 2002; Radtke et al., 2020). The AOF subscale refers to the degree to which individuals are able to disengage from negative experiences and concentrate on new activities (high AOF), instead of ruminating about the negative experience and its consequences and being detained by it (low AOF). Therefore, the scale is an indicator of the regulation of negative affect. The scale consists of 12 items which describe demanding situations from everyday life, such as "When I'm in a competition and lose every time". Each item consists of two response options that describe either an action orientated ("I can soon put losing out of my mind.") or preoccupation related ("The thought that I lost keeps running through my mind.") reaction. Participants are asked to choose their typical reaction in the situation. Each action-oriented response yields 1 point whereas each preoccupation related response yields 0 points. The failure-related AO subscale has sufficient reliability (Cronbach's $\alpha = .70$) and adequate construct validity (Kuhl, 1994b). The internal consistency of the AO subscale in the present sample was satisfactory, Cronbach's $\alpha = .74$.

2.2.2. Affect reactivity

Affect reactivity was measured using the German version of Carver and White's (1994) BAS/BIS Scales (Strobel, Beauducel, Debener, & Brocke, 2001) as was done by previous studies (Baumann, Kaschel, & Kuhl, 2007; Claes, Vertommen, Smits, & Bijttebier, 2009; Düsing et al., 2016; Wacker et al., 2010). The questionnaire is based on the conceptualization of BAS/BIS provided by Gray (1972, 1987, 1990, Gray, 1994): while BIS refers to the sensitivity to negative cues and is therefore related to a greater proneness to experience negative affect, BAS is responsible for the experience of positive affect (Carver & White, 1994; Gray, 1990). Both have been also linked to the tendency to inhibit or initiate movement toward goals respectively (Carver, 2006; Corr, 2013; Shackman, McMenamin, Maxwell, Greischar, & Davidson, 2009). The scale consists of 24 items that measure general BIS and BAS sensitivity. The BAS can further be divided into a BAS drive, fun seeking and reward responsiveness subscale, which describe persistence in goal pursuit, desire for and approach of new rewards and positive responses towards rewards respectively (Carver & White, 1994). On a 4-point Likert scale, participants are asked to indicate the extent to which the statement applies to them (e.g. "I feel worried when I think I have done poorly at something important."). The validation of the German version of the BAS/BIS Scale showed sufficient reliability (Cronbach's $\alpha > .78$). For the present sample, Cronbach's alpha was comparable to the reported ranges and satisfactory for BAS ($\alpha = .74$) and BIS ($\alpha = .81$).

2.2.3. EEG data collection and processing

EEG data was recorded with the NeXus-10 MKII (Mind Media B.V.; Herten, Netherlands) and band-pass filtered (1–45 Hz), notch filtered (50 Hz) and digitized with a sampling rate of 256 Hz. After cleaning the scalp and applying an abrasive gel (Nuprep) to reduce impedance, four electrodes were placed according to the international 10–20 system, two on the left PFC (F3, F7) and two on homologous sites of the right PFC (F4, F8). These locations target the dorsolateral PFC (F3, F4) and ventrolateral PFC (F7, F8) specifically (Ives-Deliperi & Butler, 2018; Koessler et al., 2009). The two electrode sites were chosen based on their relevance in previous PFA studies (Coan & Allen, 2004; Papousek, Reiser, Weber, Freudenthaler, & Schulter, 2012; Thibodeau, Jorgensen, & Kim, 2006) and our research question. As indicated above, both, evidence from fMRI studies and AIM suggest their involvement in affective processes and executive control. Average ear reference and bone protuberance in the neck as a ground were used.

All off-line procedures were conducted using BioTrace + V2017A software (Mind Media B.V.). Movement artefacts were automatically detected and rejected with a ± 75 µ threshold. For further analysis, artefact-free epochs were segmented in 2 s-periods and were extracted through a Hanning window (75 % overlap). A fast Fourier transformation extracted spectral power values (μV^2) within the alpha frequency range (8–13 Hz) averaged over the epochs from each 1-min period. To obtain normalized values, power values were logarithmically transformed (Allen, Coan, & Nazarian, 2004). These values served to calculate the asymmetry scores by subtracting ln alpha power of the left electrode sites from ln alpha power of homologous sites of the right hemisphere (e.g. ln[F4] – ln[F3]). Because alpha power is inversely related to cortical activity (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998), higher values indicate relatively stronger left-hemispheric activity. Asymmetry scores for each minute showed satisfactory reliability with Cronbach's alpha coefficients ranging from .89 to .96.

3. Results

First, EEG data was screened for outliers (1.5 * interquartile range). Boxplot analyses indicated four outliers for the F4/F3 region and one outlier for the F8/F7 region which resulted in $n = 43$ and $n = 46$ respectively. Second, differences in PFA between right- and left-handed participants were analyzed using Welch Two Sample t-tests, which revealed no differences for F4/F3, $t(13.34) = 0.83$, $p = .421$, and F8/F7, $t(10.34) = -1.24$, $p = .243$. Accordingly, the data of left-handed participants was not excluded.

Correlation analyses of BIS, BAS, AOF and PFA are reported in Table 1. Interestingly, the correlation between F4/F3 and AOF was close to reaching the conventional significance criterion, $r = .29$, $p = .059$. Moreover, BIS and BAS were significantly correlated with AOF. While BIS revealed a negative relationship ($r = -.55$, $p < .000$), BAS was positively related to AOF ($r = .32$, $p = .028$). Both were uncorrelated to PFA, $ps > .413$.

To further investigate the relationship between PFA and AOF, we conducted hierarchical regression analyses with PFA as criterion variable. As a first step, BIS and BAS were entered to control for trait

Table 1
Means, standard deviations, and correlations for BIS, BAS, AOF, and PFA at F4/F3 and F8/F7.

	II	III	IV	V	*M*	*SD*
BIS (I)	−.21	−.55***	.00	.12	19.91	4.27
BAS (II)		.32*	−.15	−.04	42.20	4.65
AOF (III)			.16	.29	5.74	3.36
F4/F3 (IV)				.51***	0.02	0.10
F8/F7 (V)					−0.03	0.22

Note. *$p < .050$, *** $p < .001$.

variance in affect reactivity. In a second step, AOF was added to the model. The intercorrelations of the predictors (see Table 1) might be of concern as we are interested in isolated effects of each predictor on the dependent variable. Therefore, we screened for multicollinearity to check the severity. Variance inflation factors indicated that there was low multicollinearity, *VIF* = 1.12–1.52, which does not warrant corrective measures.

As implicated by the correlation analyses, the regression models (see Table 2) revealed that BIS and BAS were unrelated to PFA at F4/F3 and at F8/F7, *ps* > .315. For F4/F3, adding AOF increased predictions by 16 %, $F(1,41) = 40.97$, $p = .007$. In this model, AOF ($\beta = .49$, $p = .007$) is a significant predictor of PFA when BIS and BAS are hold constant. As can be seen in Table 2, the semi-partial correlation coefficient ($sr = .40$) of AOF in the second step increased compared to the zero-order correlation ($r = .29$). These observations can be interpreted as a suppression effect because the statistical adjustment for BIS and BAS increased the magnitude of the relationship between AOF and PFA. To further support this finding, two regression models with BIS and BAS as dependent variables and AOF as independent variable were calculated. Subsequently, the resulting coefficients ($\alpha_{BIS} = -.54$, $\alpha_{BAS} = .32$) relating the independent to the third variable were multiplied with the coefficient for the third variable from step 2 ($\beta_{BIS} = .22$, $\beta_{BAS} = -.28$). The product of the two coefficients serves as an indicator of the third variable effect ($\alpha\beta_{BIS} = -.12$, $\alpha\beta_{BAS} = -.09$). According to MacKinnon, Krull, and Lockwood (2000), those cases where the direct effect and the third variable effect have opposite signs indicate suppression.

For F8/F7, adding AOF did not increase predictions significantly, $\Delta R^2 = .08$, $F(1,42) = 1.97$, $p = .061$, and no further analyses were conducted. Fig. 1 illustrates the regression models.

4. Discussion

The present study investigated the differential influences of individual differences in affect reactivity and affect regulation on PFA. We found that BIS and BAS (as indicators of affect reactivity) and AOF (as an indicator of affect regulation) were uncorrelated with PFA. The results regarding BIS and BAS are in line with many previous studies that could not find a relationship between PFA and indicators of individual differences in affect reactivity (e.g. Wacker et al., 2010). Subsequent multiple regression analyses that mutually controlled for potential effects from either variable revealed that AOF strongly predicted relatively higher left-hemispheric PFA. This suppression effect suggests that PFA is related to individual differences in affect regulation rather than affect reactivity, and thereby highlights the necessity for future research to differentiate more clearly between reactive versus regulatory components.

Overall, the results of the present study are in line with previous findings that indicated a relationship between PFA and different measures of affect regulation, such as AO (Harmon-Jones, Lueck, Fearn, & Harmon-Jones, 2006, 2008), affect regulation following affective challenge (Jackson et al., 2003; Larson et al., 1998; Papousek et al., 2012) and affect regulation abilities more generally (Hannesdóttir et al., 2010; Mikolajczak et al., 2010). It contributes to our understanding that there is a regulatory component to PFA. The present findings are also compatible with the AIM of PFA and neural models of affect regulation (Ochsner & Gross, 2007; Phillips, Drevets, Rauch, & Lane, 2003). As suggested by Phillips, Ladouceur, and Drevets (2008) neural systems comprising the dorsolateral and ventrolateral PFC are involved in voluntary and automatic affect regulation respectively.

Furthermore, AOF can also be considered an individual difference variable in reactive approach motivation. Reactive approach motivation inhibits the impact of goal-irrelevant and dissonant information (Gable & Harmon-Jones, 2008; Harmon-Jones & Gable, 2009; Harmon-Jones & Harmon-Jones, 2002) by countering negative affect with approach motivation (McGregor, Nash, Mann, & Phills, 2010). Accordingly, associations between PFA and reactive approach motivation have been established with a higher left-hemispheric activity reflecting more reactive approach (McGregor et al., 2010). These findings are in line with our findings on PFA and AOF and highlight AOF's involvement in affect regulation.

However, we did not observe a direct relation between PFA and affect regulation. Instead, we found a suppression effect: accounting for affect reactivity increased the magnitude of the relationship between PFA and affect regulation. Previous studies have found a similar interrelation between affect reactivity and affect regulation (Smith, Diaz, Day, & Bell, 2016; Zhang et al., 2020). For example, Zhang et al. (2020) showed that participants with a higher relative left-hemispheric activity have less affect regulation difficulties only when controlling for depression scores which have been related to an increased sensitivity towards negative affective stimuli (Ho et al., 2014). This does not seem surprising considering the control function of affect regulation. In order for control processes to become active, a change in the relevant system must be detected (Carver & Scheier, 1998). This implies that an affective response must be present before affect regulation abilities become relevant, i.e. individuals that are not very reactive to affective stimuli do not necessarily apply affect regulation in response to a certain stimulus.

The indicated interrelation between the two constructs might be responsible for the diverse findings on the relation between PFA and affect reactivity reported above. Specifically, while a weak affective

Table 2
Hierarchical regression analyses summary for predicting PFA.

Predictor	Prefrontal region							
	F8/F7				F4/F3			
	R^2	β	*sr*	95 % CI	R^2	β	*sr*	95 % CI
Model 1	.02				.02			
BIS		.12	.12	[−0.19, 0.43]		−.02	.00	[−0.35, 0.29]
BAS		−.01	−.04	[−0.32, 0.29]		−.16	−.15	[−0.48, 0.16]
Model 2	.09				.19*			
BIS		.30	.25	[−0.05, 0.64]		.22	.18	[−0.13, 0.56]
BAS		−.09	−.09	[−0.40, 0.22]		−.28	−.26	[−0.58, 0.03]
AOF		.35	.28	[−0.01, 0.71]		.50**	.40**	[0.14, 0.85]
n	46				43			

Note. CI = confidence interval. *$p < .050$. **$p < .010$.

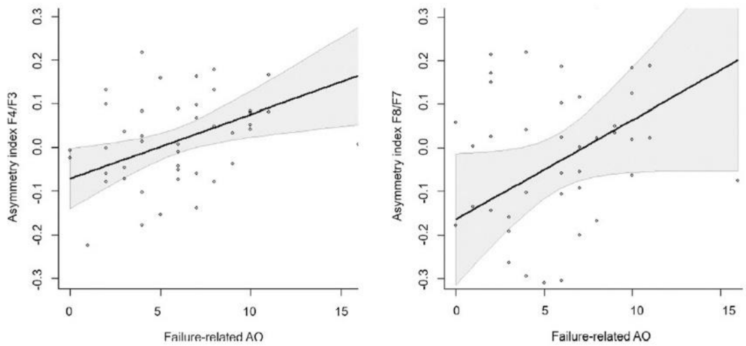

Fig. 1. Regression slopes of the relationship between PFA and AOF when BIS and BAS are hold constant.

reaction to a stimulus may be due to a weak affect reactivity, it could be also due to a strong affect reactivity but good affect regulation abilities and vice versa. This highlights the necessity for future research to either have a more specific approach to measure affect-related phenomena or account for both, affect reactivity and affect regulation (Papousek, Freudenthaler, & Schulter, 2008, 2011).

A potential alternative explanation for our results could be given based on the capability model of PFA and personality (Coan, Allen, & McKnight, 2006). The model states that individual differences are more pronounced during affective challenge than under resting conditions. This implies that individual differences are only related to PFA when PFA is measured during affective challenge. The same pattern should be observed during similar situations in everyday life, but not during other affective challenges (Coan et al., 2006). Support for the model comes from research that has shown that individual differences in PFA show stronger associations with individual trait measures if PFA is measured during affective challenge. For example, Stewart, Coan, Towers, and Allen (2014) collected EEG data at rest and during a facial emotion task in individuals with and without major depressive disorder. Their results showed that PFA during the affective task was a better indicator of major depressive disorder than resting PFA for all references but current-source-density. Therefore, the capacity for affect regulation might be captured better by measuring PFA during affective challenges. Measuring PFA during affective challenge also ensures that differences in initial affect reactivity are controlled for across participants. In the present study, controlling for affect reactivity might resemble a similar mechanism and emphasizes the association between PFA and affect regulation abilities.

Limitations of the current study and future directions should be considered. First, the relationship between affect regulation and PFA was only observed in the dorsolateral PFC (F3, F4). While other studies also find associations with one prefrontal region but not the other (e.g. Kline, Knapp-Kline, Schwartz, & Russek, 2001; Papousek et al., 2017), their differential roles are not completely clarified. Therefore, we did not postulate any apriori hypotheses regarding the roles of the different locations in the PFC and are not able to fully explain the non-significant findings in the F8/F7 region. However, as also mentioned by the AIM, neurophysiological findings show that the dorsolateral PFC is of particular interest in relation to affect regulation and AO in particular. It is involved in controlling attention based on goals especially in face of distraction (Viviani, 2013) and in integrating motivational and cognitive processes (Hikosaka & Watanabe, 2000; Phillips et al., 2003).Therefore, it is significantly involved in volitional affect regulation (Ochsner & Gross, 2008; Phillips et al., 2008). This is in accordance with our findings and could provide a first indication for future studies.

Second, the AOF subscale is well-suited to measure individual differences in affect regulation but only captures the ability to reduce negative affect and therefore, does not allow to draw any conclusions regarding the ability to overcome a lack of positive affect (Kuhl, 1994a). Additionally, this AOF scale does not capture all negative affective states but rather mainly includes situations in which we usually experience frustration (e.g. "When I've bought a lot of stuff at a store and realize when I get home that I paid too much – but can't get my money back") or upset (e.g. "When I am told that my work has been completely unsatisfactory"). From a motivational perspective, both these states are associated with withdrawal motivation. Since previous research showed an association between anger, classified as a negative affect that triggers approach-motivation, and a higher relative left-hemispheric PFA (Harmon-Jones, 2007; Harmon-Jones, Gable, & Peterson, 2010; Wacker et al., 2003), one might expect different results for regulating anger. Therefore, future studies should investigate other measures of affect regulation abilities, including different negative affective states as well as the up-regulation of positive affect.

Third, while Carver and White's BIS/BAS theory is still prominent in PFA research, there has been a conceptual revision by Gray and McNaughton (2000) that is increasingly receiving attention in the literature on BIS/BAS and PFA (for a recent review see Gable et al., 2018). This revision differentiates between three motivational systems, the approach-related system (BAS), the avoidance-related system called the fight-flight-freeze system (FFFS) and a regulatory system called the revised-BIS (r-BIS). The major conceptual changes are that, on the one hand, the FFFS replaces the traditional BIS and, on the other hand, the r-BIS is introduced to resolve conflict between the other systems, i.e. goal conflict. Accordingly, Heym, Ferguson, and Lawrence (2008) suggested that the BIS scale of Carver and White's BAS/BIS scale contains some items that are related to conflict monitoring and others that are related to avoidance motivation. This differentiation could become relevant in the context of PFA research. For example, a recent study conducted by Neal and Gable (2017) suggests that r-BIS is associated with a higher relative right-hemispheric activity while FFFS is unrelated to PFA. Adding to these findings, De Pascalis, Sommer, and Scacchia (2018) conducted a study measuring resting EEG and using the newly developed Reinforcement Sensitivity Theory Personality Questionnaire (RST-PQ; Corr & Cooper, 2016) to assess trait BAS/BIS. The RST-PQ allows for the distinction between r-BIS and FFFS and includes four subscales of BAS with impulsivity being the most relevant for PFA research. Parallel to Neal and Gable (2017), their results showed an association of a higher relative left-hemispheric frontal activity and trait impulsivity. In contrast, a higher relative right-hemispheric frontocentral activity was linked to the FFFS scale, which measures active avoidance. These findings suggest that the RST-PQ subscales distinguish between differential aspects of BIS and BAS and its' subscales might therefore be more suitable to measure affect reactivity more explicitly (e.g. "FFFS" to measure reactivity to negative stimuli and "Reward reactivity" to measure reactivity to positive stimuli). However, since we considered the traditional conception of BAS/BIS, our results do not differentiate between the r-BIS and FFFS and therefore do not allow any further conclusions regarding their differential associations with PFA. The subscales of the RST-PQ could be used in future research to extent the findings by De Pascalis et al. (2018) and to further advance the understanding of regulatory mechanisms in PFA.

Finally, the sample size and effect sizes observed in the present study yielded a power of 0.79 for R^2 increase ($n = 43$). The power of a statistical test reflects the probability of a false-negative finding. Cohen (1988) suggested that a power of 0.80 is satisfactory to detect a true effect, which was achieved by the present study. However, some researchers argue that higher powers such as 0.85 or 0.90 should be targeted (Lenth, 2001) in order to make replicable results more likely (Asendorpf et al., 2016). The achieved power of the present study did not quite reach this target. Since power increases as effect size and sample size increase, a higher sample size would have been advisable.

The suggested considerations will not only help to better understand the neural mechanism but will also give implications for practice. If PFA can be reliably linked to affect regulation, this might not only be relevant for clinical purposes but also for other fields as well, such as forensic psychology. For example, studies have shown that affect regulation skills influence treatment success in sexual offenders (Gillespie, Mitchell, Fisher, & Beech, 2012; Gunst, Watson, Willemsen, & Desmet, 2019) and PFA may thus serve as an indicator of treatment success and risk of recidivism.

5. Conclusion

Previous research has linked PFA to affective style but the differential effects of affect regulation and affect reactivity have been neglected. The present study suggests an association between PFA and affect regulation abilities when indicators of individual differences in affect reactivity were controlled for. More precisely, a higher relative left-hemispheric PFA was indicative of more efficient down-regulation of negative affect. These findings might be due to the involvement of the PFC in neural systems responsible for affect regulation and support prior research indicating that it is important to differentiate between reactive and regulative components. Future studies need to consider both components conjointly in order to investigate their specific effects.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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4.3 Article 3

Authors: Wiebke Haehl, Arash Mirifar, & Jürgen Beckmann

Title: Regulate to facilitate: A scoping review of prefrontal asymmetry in sport and exercise

Journal: Manuscript submitted to Psychology of Sport and Exercise (currently under review)

Summary:

Research on PFA has also been applied to the sport and exercise context. Here, most studies are concerned with affective changes following an exercise intervention. These have been synthesized in two previous systematic reviews. However, research questions and methods are much more diverse and cover a wide range of affective and motivational variables with some of them also suggesting an involvement of PFA in athletic performance. Therefore, the aim was to compile all research on PFA in the sport and exercise context and structure it according to the conceptual differentiation between PFA activity (i.e., activity at a given time) and PFA activation (i.e., change of activity in response to a stimulus). Additionally, a particular focus was put on the role of performance-related variables, which have been categorized into cognitive and motor performance.

The review followed a scoping review approach and was conducted in line with PRISMA-ScR recommendations. Initially, the search string was defined based on the main variables of interest, namely PFA and sport and exercise. The literature search on four scientific databases yielded 659 records that were reduced to a final selection of 27 records following title, abstract and full-text screening. Eligible records included quantitative, empirical research in English language published in peer-reviewed journals, which measured PFA via EEG in the brain regions F8-F7 and/or F4-F3 in a sport or exercise setting. The majority of the selected studies was conducted with a non-athlete sample (78%), interpreted PFA in terms of affective valence (70%) and assessed PFA at several time points (i.e., PFA activation, 56%).

Findings are inconsistent but suggest an association between PFA and post-exercise affective state as well as motivational state before and during exercise with a higher relative left-hemispheric PFA indicating higher levels of positive affect and increased motivation. More specifically, results suggest an involvement of PFA in regulatory processes, which might also explain the reported associations between PFA and successful performance. Accordingly, PFA might reflect the adaptive regulation of internal state. For studies investigating a long-term change in PFA induced by regular exercise, a dose-response relationship might be responsible for the inconsistent findings. Further research is needed to investigate the direct associations between PFA and motivational outcomes and to assess the role of self-regulatory mechanisms more explicitly.

The manuscript was submitted in August 2021 and is currently under review in the Journal *Psychology of Sport and Exercise*. *Psychology of Sport and Exercise* is an international peer-reviewed journal publishing research in the area of sport and exercise psychology.

Contribution:

Wiebke Hähl was the author of the published article. As principal investigator, she developed the research question, conducted the literature search and screening. Arash Mirifar offered his advice and feedback on the research question and literature search and screening process. Data synthesis and mapping were conducted by Wiebke Hähl. Wiebke Hähl wrote the published article, while receiving feedback from Jürgen Beckmann.

Regulate to facilitate: A scoping review of prefrontal asymmetry in sport and exercise

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Abstract

Background: Prefrontal asymmetry (PFA) describes the relative activity of the right PFC compared to the left PFC. It has been shown that PFA is associated with affective and motivational variables in several contexts, including sport and exercise. Considering the significant roles of affect and motivation in different performance settings, PFA might also be an important indicator of athletic performance. However, the relevance of PFA in the sport and exercise setting has not yet been addressed in its entirety. Instead, previous systematic reviews have solely focused on affective variables. Mapping out the complex interactions between PFA and affective, motivational as well as performance variables could help to understand what determines successful athletic performance as well as the positive psychological effects associated with exercise.

Approach: Scientific databases were searched for quantitative studies in English language published in international peer-reviewed journals. All 27 selected studies assessed physical activity and measured PFA in the brain locations F4-F3 and/or F8-F7 using electroencephalography.

Findings: The majority of the studies used a non-athlete sample (78%) and exercise types were diverse. While all studies focused on affective or motivational processes, 19% also reported associations with performance. Even though findings are inconsistent, they support the assumption that PFA plays a role in self-regulation.

Conclusion: There is evidence for an involvement of PFA in affective, motivational and performance processes in the sport and exercise setting that can be interpreted as regulatory mechanisms. Future research on the underlying mechanisms is warranted, in particular, associations with motivational processes and performance need to be investigated more explicitly.

Keywords: Frontal asymmetry, EEG, self-regulation, athletic performance, affect, motivation

Introduction

Research on mechanisms underlying human performance is addressed in various disciplines including neuroscience, cognitive psychology and sport psychology (Cheron et al., 2016; Herrmann et al., 2010; Moran, 2012). In sport and exercise psychology, athletic performance is viewed as a complex task that relies on cognitive and motor processes such as decision-making, attention, coordination of complex actions and incorporating feedback (Araujo et al., 2009; Carpentier & Mageau, 2016; Cona et al., 2015; Porter et al., 2010; Seifert et al., 2013). Additionally, athletic success is highly dependent on affective and motivational processes (Gillet et al., 2013; Lazarus, 2000), which interact with cognitive and motor control functions and thereby either enhance or impair performance (Pessoa, 2009).

In investigating all these processes and their associations with athletic performance, a particular focus has been on neurophysiology; more specifically the role of hemispheric activity (i.e., activity at a given time) and activation (i.e., change in activity in response to a stimulus). For example, Beckmann et al. (2013) have investigated the effects of hemisphere-specific priming in motor skill failure. In a series of experiments, they have increased right-hemispheric activation by asking the participants to squeeze a ball in their left-hand, which successfully inhibited performance decrements after pressure induction. Among others, these findings highlight the importance of understanding neurophysiological processes in order to foster optimal performance. Therefore, the present review focuses on a neurophysiological perspective of athletic performance and its affective and motivational determinants by reviewing studies on prefrontal asymmetry (PFA) in the sport and exercise context.

When it comes to the coordination of several functions in line with a specific goal (e.g. show optimal performance), executive control processes in the prefrontal cortex (PFC) play a major role (Pessoa, 2009). Particularly, research on functional asymmetries of the PFC highlight a relationship between PFA, describing the relative activity of the right PFC compared to the left PFC, and motivational (motivational direction, i.e., approach or withdrawal) and affective (affective valence, i.e., positive or negative) processes. It has therefore also been associated with the performance on several cognitive tasks, such as spatial or verbal tasks (Gray et al., 2002; Haehl et al., 2020). PFA is measured by collecting electroencephalographic (EEG) activity in the alpha band (8-13 Hz) in the dorsolateral and ventrolateral PFC (Papousek et al., 2017). A higher relative left-hemispheric activity is related to positive affect or approach motivation and a higher relative right-hemispheric activity is related to negative affect or avoidance motivation (Davidson, 2004; Harmon-Jones & Gable, 2017). These associations have been investigated in both, studies measuring PFA activity at rest (e.g. Jackson et al., 2003) and PFA activation in response to stimuli (e.g. Papousek et al., 2009). Accordingly, research has focused on PFA as a moderator and mediator of affect (Coan & Allen, 2004). To ensure a common understanding, it is important to note, that the present review uses the term affect as an umbrella term that includes all emotion-related phenomena within a person (Scherer, 1984), which result from the discrepancy between the actual and preferred progress in goal pursuit (Carver, 2006). In regards to motivation, we use the definition by Heckhausen and Heckhausen (2006), which states that motivation is what drives goal pursuit and is characterized by its direction, intensity and persistence.

PFA has not only been associated with the presence of motivational and affective states but also with the automatic and voluntary regulation of these states (Haehl et al., 2020; Jackson et al., 2003; Papousek et al., 2017). These findings can be explained in light of the Asymmetric Inhibition Model of PFA (AIM; Grimshaw & Carmel, 2014) which states that the left dorsolateral PFC is responsible for inhibiting negative (or avoidance-related) distractors whereas the right dorsolateral PFC inhibits positive (or approach-related) distractors. Regarding performance, this is relevant because attending to affective stimuli is adaptive and takes up resources of the PFC, which in turn, are no longer available for accomplishing the task. Therefore, efficient inhibition of affective distractors is beneficial when dealing with cognitive challenges (Pessoa, 2013).

Potential distractors play an important role in athletic performance and have been found to be involved in motor skill failure. For example, distraction, reflected in attention shifts away from the task, has been found to be one of the major contributors to performance decrements. Shifts of attention to task-irrelevant stimuli are frequently due to anxiety as in choking under pressure, which describes suboptimal performance below the individual’s potential in competitive situations (Mesagno & Beckmann, 2017). Furthermore, several theories have addressed the interrelation of affective and motivational processes and performance, such as the Cognitive-Motivational-Relational Theory (Lazarus, 2000), the Individual Zone of Optimal Functioning (Hanin, 2000) and the Theory of Challenge and Threat State in Athletes (Jones et al., 2009). Accordingly, PFA might not only play a role in affective and motivational processes accompanying sport and exercise but also affect athletic performance.

Past research has investigated a diverse set of research questions regarding PFA in the sports and exercise context. Studies seem to provide mixed results. However, a comprehensive overview is still missing. To our knowledge, there are two systematic reviews on PFA in the sport and exercise context to date (05.08.2021). The first article by Lattari et al. (2014) systematically reviewed the influence of cortical activity on post-exercise mood states. They identified eleven studies that showed contradictory evidence. However, they did not only focus on PFA but included studies on absolute and relative power as well as one that used sLORETA. Silveira et al. (2019) also focused on the association of PFA and psychological responses to exercises. They reviewed eight studies and concluded that a higher relative left-hemispheric activity is linked to positive psychological responses. Accordingly, previous reviews were limited to affective responses to exercise and missed to account for the variety of existing research settings. Particularly, a differentiation between PFA activity and activation is not provided although conceptual differences are important to consider (Reznik & Allen, 2018).

Therefore, the present review aims at providing an overview of all existing studies about PFA measured via

EEG in the sports and exercise context with both, athlete and non-athlete samples and most interestingly, to see if there is evidence for a role of PFA in athletic performance. A scoping review was chosen due to the rather broad area and the limited number of studies (Levac et al., 2010). The specific objectives of this scoping review were (1) review the literature on PFA in the sports and exercise context, (2) structure the studies based on their focus on PFA activity or activation and (3) map out further characteristics (i.e., affect, motivation, performance) of the studies and their use of PFA.

By following these steps, we make several contributions. First, we will provide the first attempt to map all research on PFA in the sport and exercise context. Second, we advance research on affective and motivational processes and their role in athletic performance by structuring existing literature and its results. This will not only provide insights into the positive psychological effects associated with exercise but also help to understand what determines successful athletic performance. Finally, by investigating PFA in the sport and exercise context we contribute to the general understanding of the underlying mechanisms of PFA and therefore, contribute to PFA research more generally.

Approach

Our scoping review protocol was developed based on the PRISMA-ScR (PRISMA extension for Scoping Reviews) recommendations. It was drafted by the research team consisting of three independent researchers with expertise in PFA research, neuropsychological research and sport psychological research. The aim of this scoping review was to investigate the role of PFA in the sports and exercise context including both, athletes and non-athletes, with a particular focus on performance.

Eligibility criteria

We included quantitative studies that met all of the following criteria: 1) used original empirical data; 2) were published in a peer-reviewed scientific journal in English language; 3) assessed physical activity regardless of exercise type and mode; 4) measured PFA. PFA was defined as the natural logarithm of the alpha power at the electrode site of the left PFC minus the natural logarithm of the alpha power at the homologous electrode site of the right PFC. Requiring the use of this formula follows methodological recommendations (Allen et al., 2004) and ensures comparability of results. All studies that met the eligibility criteria were further screened for the following exclusion criteria: 1) PFA was measured with a method other than EEG; 2) PFA brain regions did not include F4-F3 and/or F8-F7 according to the international 10-20 system; 3) results were only reported for absolute alpha values of individual hemispheres (instead of asymmetry indices); 4) no provision of a rational for PFA analysis. These criteria were chosen based on the definition of PFA provided above (criteria 1 and 3), the relevance of F4-F3 and F8-F7 in numerous studies (criteria 2; e.g. Coan & Allen, 2004; Papousek et al., 2012) and good scientific practice that requires hypothesis-driven analyses in confirmatory research (criteria 4; e.g. Świątkowski & Dompnier, 2017).

Sources, search and selection

First, a literature search was conducted by one of the researchers in April 2021. The following four databases were searched: PubMed, SPORTDiscus, PsychArticles, Web of Science. They were chosen based on their relevance for the topic and extensiveness. This initial search was peer-reviewed by another researcher and modified to fit the eligibility criteria more closely. The final search was conducted on PubMed, Web of Science, SPORTDiscus and PsychInfo using the search string "("frontal asymmetry" OR "brain asymmetry" OR "prefrontal asymmetry" OR "alpha asymmetry") AND (physical activity OR exercise OR sport OR performance OR athlete)". We decided to substitute PsychArticles by PsychInfo due to its larger scope. Additionally, we searched Google scholar and the reference lists of retrieved articles for further studies. The results of the search were imported into the citation management software EndNote X8 Desktop (ClarivateTM). Two independent researchers sifted through and selected studies in two stages: results were first reviewed by title and abstract and then by the full-text version of the paper. At each step, studies that did not meet the eligibility criteria were excluded, and in case of conflicting opinions, disagreement was resolved through discussion. The remaining studies were further screened for the exclusion criteria.

Data items and data charting process

The included studies were organized into PFA activity and PFA activation according to the PFA measurement points.

If a study analyzed both, PFA activity and PFA activation, the study and respective results were reported in both categories. Further organization included the differentiation between athlete and non-athlete samples. One researcher extracted the study characteristics, variables and results. This categorization and extraction process was initially tested with eight studies. After assuring suitability by discussion with another researcher, the categorization and extraction was completed for all included papers. Subsequently, a second researcher checked the final data chart for accuracy. The study characteristics included authors, year, population and sample size, exercise type and mode (i.e., duration, intensity, frequency) as well as PFA location (i.e., F4-F3 and/or F8-F7) and interpretation (i.e., affective valence and/or motivational direction). For the psychological variables, all affect and motivation related variables are reported. The same counts for the results: PFA results were extracted exclusively. These results were further evaluated in regards to their direct or indirect association with athletic performance (i.e., motor, cognitive, none). Due to a lack of information within the original papers, some data could not have been charted in its entirety.

Findings

Literature search

The database search yielded 659 records. Seven additional records were identified through other sources. After removing duplicates, 474 records remained. Screening of title and abstract for eligibility resulted in 38 potentially relevant records, which were further reduced to 27 following full-text review (see Figure 1). Four records were excluded for neither including the prefrontal regions F4/F3 nor F8/F7, two were excluded due to lacking an active sport or exercise context, two were excluded for not calculating an asymmetry index, one was excluded for not providing a rational for PFA use and another one was excluded due to the lack of EEG measurement. All studies included in this review were quantitative studies.

Study characteristics

The relevant characteristics of the studies are presented in Table 1. These include population, exercise type, PFA location and interpretation as well as PFA measurement and associated performance. All studies were published between 1994 and 2021. The study population was classified as athlete (22%) and non-athlete (78%). Sample sizes were mostly small, with 63% of studies having a sample smaller than 30 and only three studies reporting a sample larger than 50. Exercise types included physical activity in general, walking, cycling, badminton, golf, freediving, rifle shooting or a mix of different activities with walking (37%) and cycling (33%) being the most widely used. When it comes to EEG measurement, most studies assessed F4-F3 (96%) alone (70%), in combination with F8-F7 (15%) or as part of an average prefrontal asymmetry index together with F8-F7 and Fp2-Fp1 (11%). While 37% focused on EEG baseline activity only, 56% measured PFA at several time points and were interested in PFA activation. The studies provided different interpretations of their results in regards to PFA. They were classified based on PFA theories in affective valence (70%) and motivational direction (19%) with 11% of studies providing interpretations based on both categories. Additional to affective and motivational associations, five studies suggested an association of PFA with performance related variables. These have been categorized in motor (15%) and cognitive performance (4%).

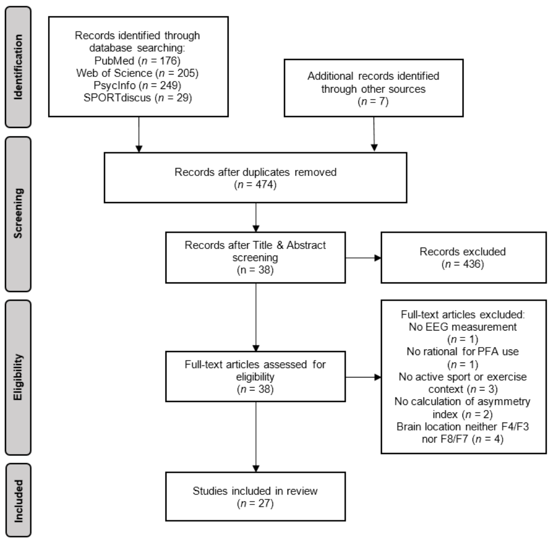

Figure 1. PRISMA flowchart of study screening process

PFA activity

Characteristics and results of studies that measured PFA activity at a given time (including long-term changes in PFA activity) are summarized in Table 2. They primarily focused on predicting affective outcomes after exercise.

Affect. In 12 out of 13 studies, the variable of interest was affect induced by exercise. Following the Circumplex Model of Affect (Russell & Feldman Barrett, 1999), affect can further be differentiated in a valence (pleasant or unpleasant) and a arousal (activation or deactivation) dimension. For the valence dimension associations between PFA and positive or negative affect post-exercise were found in three studies (Landers et al., 1994; Petruzzello & Tate, 1997; Schneider et al., 2009), one study reported associations of PFA with negative affect dependent on physical activity levels (Hall & Petruzzello, 1999) and another study failed to predict affect post-exercise (Hall et al., 2010). For the arousal dimension, results are more consistent. All three studies investigating the association of PFA activity and post-exercise arousal levels assessed with the Activation Deactivation Adjective Checklist (ADACL; Thayer, 1986) report significant results: PFA predicted post-exercise arousal including energetic arousal (Hall et al., 2010; Petruzzello, 2001) as well as tiredness and calmness (Hall et al., 2007). None of the studies reported a significant association between PFA and affective states during exercise.

Motivation. An involvement of PFA in motivational processes was implied in two studies with a higher relative left-hemispheric activity indicating higher levels of motivation to engage in exercise. Cantisani et al. (2015) investigated the physical activity level using wrist actigraphy in depressive patients and healthy adults and found a positive correlation with PFA activity in patients. These results have been interpreted in light of the increased tendency of depressive patients to experience negative affect and a lack of motivational drive (i.e., reduced approach-related motivation). Particularly in depressive patients, motivation plays an important role in physical activity participation (Scarapicchia et al., 2014; Vancampfort et al., 2015). Therefore, motivational mechanisms might be accountable for the reported findings. The second study showed that PFA can predict perceived effort during walking (Hall et al., 2000). Effort can be seen as an motivation factor indicating motivation intensity and its regulation (Gendolla et al., 2012; Wright & Brehm, 1989) and has been associated with motivation in promoting physical activity (Ajzen, 1985; Wallhead et al., 2014).

Performance. A first indication regarding the predictive ability of PFA regarding motor performance was provided by the study of Hall et al. (2000). Additional to affective and motivational factors, they predicted walking speed based on PFA activity at F4-F3: higher relative left-hemispheric activity predicted faster walking speed in students.

Table 1
Study characteristics (n = 27)

Characteristic		Count	Percentage
Population	Non-athlete	21	78%
	Athlete	6	22%
Sample size	$n < 30$	17	63%
	$30 \leq n \leq 50$	7	26%
	$n > 50$	3	11%
Exercise	Walking	10	37%
	Cycling	9	33%
	Physical activity	2	7%
	Badminton	1	4%
	Golf putting	1	4%
	Rifle shooting	1	4%
	Freediving	1	4%
	Bench press	1	4%
	Multiple exercises	1	4%
PFA location	F4-F3 only	19	70%
	F8-F7 & F4/F3	4	15%
	Average of F8-F7, F4-F3, Fp2-Fp1	3	11%
	F8-F7 only	1	4%
PFA interpretation	Affective valence	19	70%
	Motivational direction	5	19%
	Affective valence & Motivational direction	3	11%
PFA measurement	Activation	14	52%
	Activity	11	41%
	Activity & Activation	2	7%
PFA & Performance	None Motor	22	81%
	Motor Cognitive	4	15%
	Cognitive None	1	4%

Long-term adaptations. Brain plasticity allows for long-term adaptations in neural activity and accompanying changes in behavior (Kolb et al., 2003). Four studies investigated the potential of long-term physical activity in producing adaptations in PFA. Results are ambiguous: while two studies report an increase in PFA in response to ten sessions (Chen et al., 2021) and six sessions (Hong et al., 2020) of physical activity, the other two report no change after 12 weeks (Lattari et al., 2018) and 12 months (Deslandes et al., 2010) of regular exercise. Differences between the studies can be found for exercise duration with shorter durations of exercise sessions (i.e., 35 min and 25 min) for the two studies with non-significant findings and longer durations (i.e., 50 min and 90 min) for the two studies with significant changes in PFA.

PFA activation

Characteristics and results of studies that measured PFA activation as a change in activity in response to a stimulus are summarized in Table 3. These studies primarily focused on changes in PFA during and after physical activity.

Affect. Studies that interpreted changes in PFA as reflecting changes in affective valence focused on PFA activation post-exercise. Seven studies report significant changes in PFA induced by exercise. While most of them report an increase in PFA (Hicks et al., 2018; Woo et al., 2009, 2010; Xiao et al., 2020), one study reports the opposite finding (Chen et al., 2016): in 12 athletes with intellectual disabilities PFA decreased after a 20 min walking session. These controversial findings are supplemented by three studies that failed to find a significant change in PFA after exercise (Crabbe et al., 2007; Lattari et al., 2016; Petruzzello & Tate, 1997). All these studies have in common, that they observe a change in PFA and interpret this observation as a change in affect. However, only three studies actually tested this assumption by looking at associations between changes in PFA and changes in affect. For example, Petruzzello and Tate (1997) investigated differences in extreme groups in regards to PFA and anxiety post-exercise. Their findings are in line with the study by Petruzzello and Landers (1994) that examined the correlation of the change in PFA and change in affective state as well as the study by Moraes et al. (2011) that correlated post-exercise PFA and anxiety: all three studies showed an negative association between PFA and anxiety level in response to exercise. Since anxiety is an affective state high in arousal and of negative valence, arousal and valence cannot be differentiated.

Motivation. PFA activation right before or during exercise was theorized to be reflective of motivational factors. For example, Maszczyk et al. (2019) aimed to identify patterns of motivational intensity by assessing PFA right before bench press trials at different percentages of one-repetition-maximum (1-RM). They found differences between elite and novice powerlifters in regards to PFA with elite powerlifters varying their motivation (i.e., increasing and decreasing PFA) efficiently to optimize performance. While has clearly interpreted their results in terms of motivation, the other two studies assume both, an involvement of affective and motivational processes. Chen et al. (2019) reported increases in PFA right before successful performance in golf putting and interpreted their findings in light of effective regulation of motivational and affective states relevant for performance. Similarly, Kerick et al. (2000) found a positive correlation of PFA right before a shot in rifle shooting and shot scores depending on the feedback condition. In the low feedback condition, PFA was positively correlated with shot scores and in the high feedback condition, it was positively correlated with shot score variance. The regulation of motivational and affective states might be responsible for the findings: individuals that manage to increase motivation or decrease negative affect after receiving negative feedback are more successful. All three studies suggest a regulatory role of PFA. No contradictory results have been reported for PFA activation before exercise. Regarding PFA during exercise, results are similar: all three studies report significant increases in PFA that have been interpreted as increased approach motivation (i.e. motivational direction) to succeed in the task (Bixby et al., 2001; Broelz et al., 2019; Steinberg et al., 2017). However, Broelz et al. (2019) provides the only immediate association by correlating the change of PFA with measures of approach and avoidance motivation. In particular, athletes high in motivational persistence showed an increase in left-hemispheric PFA.

Performance. Some of the studies that investigated a motivational role of PFA also provide direct or indirect implications for an involvement in performance variables. All four studies report significant results and can be further differentiated in motor performance (Chen et al., 2019; Kerick et al., 2000; Maszczyk et al., 2019) and cognitive performance (Steinberg et al., 2017). For motor performance, two studies found direct associations of objective performance measures (i.e., successful golf putts and rifle shots) with PFA activation (Chen et al., 2019; Kerick et al., 2000). However, an association with subjective performance was not supported (Kerick et al., 2000). The other two studies found differences between elite and novice athletes with PFA changes in elite athletes indicating more efficient or successful performance (Maszczyk et al., 2019; Steinberg et al., 2017). For cognitive performance, success is reflected in increased cognitive control (i.e., increased PFA) during breath holding in elite freedivers (Steinberg et al., 2017).

Table 2

PFA Activity

	Authors	Year	Population & Sample size	Exercise type[a] & Mode	PFA location	PFA interpretation	Psychological variables[b]	Results (PFA)	Performance association
Athlete	Chen, Ryuh, Donald & Rayner	2021	Athletes with intellectual disabilities (*n* = 18)	Badminton; 50 min/session, 2 sessions/week, 5 weeks	F4-F3, F8-F7, Fp2-Fp1 (average)	Affective valence	Depression via SDS, Self-efficacy via ESES	↑PFA after 5-week training program	None
Non-athlete	Cantisani et al.	2015	Patients with major depressive disorder & healthy adults (*n* = 39)	Physical activity via wrist actigraph; 24h activity level	F4-F3, F8-F7, Fp2-Fp1 (average)	Motivational direction	Depression via HDRS	Positive correlation of PFA and activity level in patients	None
	Deslandes et al.	2010	Elderly with major depressive disorder (*n* = 20)	Walking; 35 min/session, 1 session/week, Aerobic, 12 months	F4-F3, F8-F7	Affective valence	Depression via BDI, HDRS, MADRS	No correlation of PFA and depression, No change in PFA after 12 months exercise intervention	None
	Hall & Petruzzello	1999	Older adults (*n* = 41)	Physical activity via Physical Activity Scale for the Elderly	F4-F3	Affective valence	Trait anxiety via STAI-T, Dispositional affect via PANAS, Depression via GDS, Satisfaction with life via SWLS	PFA predicted dispositional positive affect, PFA predicted negative affect in low activity group, PFA predicted affective valence and satisfaction with life in high active group	None
	Hall, Ekkekakis, Landuyt & Petruzzello	2000	Students (*n* = 42)	Walking; 10 min, Self-paced	F4-F3	Affective valence & Motivational direction	Affect via ADACL, Anxiety via STAI-S, Perceived effort via RPE	PFA did not predict affect or anxiety after exercise, PFA predicted perceived effort during exercise and walking speed	Motor
	Hall, Ekkekakis & Petruzzello	2007	Students (*n* = 30)	Walking; Until volitional exhaustion, High intensity	F4-F3	Affective valence	Affect via ADACL	PFA predicted tiredness and calmness after exercise	None
	Hall, Ekkekakis & Petruzzello	2010	Students (*n* = 30)	Walking; 5 min, Low, medium and high intensities	F4-F3, F8-F7	Affective valence	Affect via ADACL	PFA (F4-F3) predicted energetic arousal following low and high intensity exercise, and following cool down after high intensity exercise, PFA (F8-F7) predicted energetic arousal at 20 min post cool down	None
	Hong et al.	2020	Adolescents with internet addiction (*n* = 50)	Running, jump rope and basketball; 90 min/session 1 session/week, Aerobic, 6 sessions	F4-F3, F8-F7	Affective valence & Motivational direction	Internet addiction via YIAS, Depression via BDI, Anxiety via BAI	↑PFA (F4-F3 & F8-F7) after 14 week of physical activity (6 sessions) additional to cognitive behavioural therapy (8 sessions)	None
	Lattari et al.	2018	Patients with panic disorders (*n* = 10)	Walking; 25 min, Aerobic, 12 sessions	F4-F3	Affective valence	Panic disorder via PDSS, Feeling of distress via SUDS, Anxiety via BAI, Depression via BDI	No change in PFA after 12 exercise sessions	None
	Petruzzello & Landers	1994	Students (*n* = 19)	Walking; 30 min, Aerobic	F4-F3	Affective valence	Anxiety via STAI-S	PFA predicted anxiety post-exercise	None
	Petruzzello & Tate	1997	Students (*n* = 20)	Cycling; 30 min, Moderate and high intensity	F4-F3	Affective valence	Affect via ADACL, Anxiety via STAI-S	PFA predicted positive affect immediately post-exercise, PFA predicted post-exercise anxiety PFA did not predict anxiety and affect during exercise	None
	Petruzzello, Hall & Ekkekakis	2001	Students (*n* = 67)	Walking; 30 min, Aerobic	F4-F3	Affective valence	Affect via ADACL	PFA predicted energetic arousal 20 min post-exercise, PFA predicted energy post-exercise in the high-fit group, Difference between extreme PFA groups in regards to change in and persistence of energy post-exercise	None
	Schneider, Graham, Grant, King & Cooper	2009	Adolescents (*n* = 98)	Cycling; 30 min, Moderate and high intensity	F4-F3	Affective valence	Affective valence via FS	PFA predicted affect post-exercise after moderate exercise (when performed first)	None

Note. a. Walking and running are summarized under "Walking", b. Abbreviations stand for: SDS = Self-rating depression scale, ESES = Exercise self-efficacy scale, BDI = Beck depression inventory, HDRS = Hamilton depression rating scale, MADRS = Montgomery-Asberg depression rating scale, STAI-T = State trait anxiety inventory-trait; PANAS = Positive affect negative affect scale, GDS = Geriatric depression scale, SWLS = Satisfaction with life scale, ADACL = Activation deactivation adjective check list, STAI-S = State trait anxiety inventory-state, RPE = Rating of perceived exertion, YIAS = Young internet addiction scale, BAI = Beck anxiety inventory, FS = Feeling scale

Table 3

PFA Activation

	Authors	Year	Population & Sample size	Exercise type[a] & Mode	PFA location	PFA interpretation	Psychological variables[b]	Results	Performance association
Athlete	Broelz et al.	2019	Cyclists (elite, *n* = 19)	Cycling; Maximum effort, 2 trials	F4-F3, F8-F7, Fp2-Fp1 (average activity)	Motivational direction	Motivational direction via BIS/BAS	↑PFA during exercise after taking a placebo ergogenic aid, Positive correlation of change in PFA and BAS, Negative correlation of change in PFA and BIS, BAS drive and BIS predicted the level of change in PFA during exercise	None
	Chen, Kelsey, Mulvey & Ringenbach	2016	Athletes with intellectual disabilities (*n* = 12)	Walking; 20 min, Moderate intensity	F4-F3	Affective valence	Affective state via RPE	↓PFA after exercise compared to baseline, Negative correlation of change in PFA and RPE	None
	Chen et al.	2019	Golfers (elite, *n* = 20)	Golf putting; 40 putts	F4-F3	Affective valence & Motivational direction	none	Gradual ↑PFA before successful putts, ↑PFA before successful putts compared to unsuccessful putts	Motor
	Maszczyk et al.	2019	Power lifters (novice & elite, *n* = 16)	Bench press; 100%, 125% and 150% of body mass	F4-F3	Motivational direction	none	↑PFA before lifting 35-55% of 1RM and ↓PFA before 55-85% and 95-100% of 1RM in novices, ↑PFA before lifting up to 70% and for 95-100% of 1RM and ↓PFA for 75-90% of 1RM in elites	Motor
	Steinberg, Pixa & Doppelmayr	2017	Divers (novice & elite, *n* = 20,)	Freediving; 2 min (novice) or 4 min (elite)	F4-F3	Motivational direction	none	↑PFA increases at 3 min and 4 min of breath holding in experts compared to baseline	Cognitive
Non-athlete	Bixby, Spalding & Hatfield	2001	Students (*n* = 27)	Cycling; 30 min, Low and high intensities	F4-F3, F8-F7	Motivational direction	Mood via VAMS and PANAS	↑PFA(F8-F7) during exercise at both intensities compared to baseline	None
	Crabbe, Smith & Dishman	2007	Students (*n* = 34)	Cycling; 30 min, Moderate intensity	F4-F3	Affective valence	Affective state via SAM	No change in PFA in response to affective pictures after exercise compared to control	None
	Hicks, Hall, Staines & McIlroy	2018	Young adults (*n* = 12)	Cycling; 30 min, Aerobic	F4-F3	Affective valence	Perceived effort via RPE	↑PFA at 22-38min post-exercise	None
	Kerick, Iso-Ahola & Hatfield	2000	Students (*n* = 18)	Rifle shooting; 40 shots, 4 times	F4-F3	Motivational direction	Affect via PANAS, Psychological momentum via SPQ	Positive correlation of PFA right before shot and shot scores when receiving low performance feedback and shot score variance when receiving high performance feedback, No correlation of PFA and subjective performance ratings	Motor
	Lattari et al.	2016	Young adults (*n* = 20)	Cycling; 20 min, Self-paced or prescribed	F4-F3	Affective valence	Affect via FS and FAS, Perceived effort via RPE	No change in PFA post-exercise dependent on exercise condition	None
	Moraes et al.	2011	Young & elderly (*n* = 29)	Cycling; 20 min, Aerobic	F4-F3	Affective valence	Anxiety via STAI-S, Mood via POMS, Perceived effort via RPE	Negative correlation of PFA post-exercise and anxiety in young individuals	None
	Petruzzello & Landers	1994	Students (*n* = 19)	Walking; 30 min, Aerobic	F4-F3	Affective valence	Anxiety via STAI-S	Negative correlation of change in PFA and change in anxiety from pre- to post-exercise	None
	Petruzzello & Tate	1997	Students (*n* = 20)	Cycling; 30 min, Moderate and high intensity	F4-F3	Affective valence	Affect via ADACL, Anxiety via STAI-S	No change in PFA in response to exercise condition, Difference between extreme change in anxiety groups in regards to PFA post-exercise in high intensity condition, Difference between extreme PFA groups post-exercise in regards to change in anxiety in high intensity condition	None
	Woo, Kim, Kim, Petruzzello & Hatfield	2009	Students (*n* = 16)	Walking; 15, 30 and 45 min, Moderate intensity	F4-F3	Affective valence	Affect via POMS	↑PFA following 30 min exercise compared to baseline	None
	Woo, Kim, Kim, Petruzzello & Hatfield	2010	Students (*n* = 13)	Walking; 30 min, Low, moderate and high intensity	F4-F3	Affective valence	Affect via POMS	↑PFA following 30 min exercise compared to baseline at all three intensity levels	None

Xiao, Long, Gao, Qin & Liu	2020	Students (*n* = 66)	Cycling; 20 min	F8-F7	Affective valence	Affect via PAD-P	↑PFA during negative and neutral picture viewing post-exercise compared to picture viewing pre-exercise	None

Note. a. Walking and running are summarized under "Walking", b. Abbreviations stand for: BIS/BAS = Behavioral inhibition and activation system, RPE = Rating of perceived exertion, VAMS = Visual analogue mood scale, PANAS = Positive affect negative affect scale, SAM = Self-assessment manikin, SPQ = Subjective performance questionnaire, FS = Feeling scale, FAS = Felt arousal scale, STAI-S = State trait anxiety inventory-state, POMS = , ADACL = Activation deactivation adjective check list, PAD-P = Pleasure arousal dominance scale-pleasure

Discussion

To date, all prior approaches to review studies on PFA in the sport and exercise context have focused on affective processes only. However, the functional connectivity of the PFC in performance relevant processes, including affect and motivation, suggest an involvement of PFA that goes beyond this affective perspective. In this scoping review, we comprehensively reviewed 27 scientific papers on the role of PFA in sports and exercise with a particular focus on athletic performance. The reviewed research shows mixed results regarding the psychological responses (i.e., affective and motivational states) to exercise and exercise induced changes in PFA. Additionally, it reveals that research investigating the direct relationship between PFA and athletic performance is scarce. However, the retrieved studies provide some first indications that adaptive changes in PFA could be indicative of superior performance.

PFA and affect

In PFA research, affect has been the main variable of interest (for a recent review see Reznik & Allen, 2018). Also, in the sports and exercise context, the majority of studies involving PFA focused on affect. On the one hand, studies on PFA activity showed that PFA can predict positive and negative affect in response to exercise with a higher probability of predicting arousal compared to valence. The strongest support was found for energetic arousal, which was negatively associated with PFA (Hall et al., 2010; Petruzzello, 2001). On the other hand, studies on PFA activation showed that changes in PFA in response to exercise can occur. There are first indications that these changes might be associated to changes in anxiety. In fact, support for this assumption comes from studies that link increases in PFA to decreases in anxiety (Moraes et al., 2011; Petruzzello & Landers, 1994; Petruzzello & Tate, 1997).

With the exception of energetic arousal where the relationship is reversed, these findings are supported by PFA models that associate a higher relative left-hemispheric activity and activation with approach motivation and positive affect (Davidson, 2004; Harmon-Jones & Gable, 2017). However, they can also be interpreted in light of AIM. AIM associates PFA with the downregulation of positive and negative affective states or approach and withdrawal motivation respectively (Grimshaw & Carmel, 2014). Given that exercise can be accompanied by unpleasant sensations, such as muscle pain (Miles & Clarkson, 1994) or fatigue (Davis & Bailey, 1997), individuals with a higher-relative left-hemispheric activity might be able to downregulate this negative affect in order to focus on the task. This downregulation effort could also be reflected in increased left-hemispheric PFA activation and positive affect post-exercise and therefore, explain the results for PFA activity and PFA activation. Additionally, this cognitive perspective on PFA can explain the unexpected findings regarding energetic arousal (i.e., negative association with PFA). High arousal levels can be harmful for cognitive processes, such as attention (Lenartowicz et al., 2013) or memory (Mather & Sutherland, 2011), and limit the functioning of cognitive control (Cudo et al., 2018; Demanet et al., 2011). Therefore, their downregulation is crucial for cognitive control to function effectively. This counts for both, controlling physical movements (Koch et al., 2009; McPherson & Vickers, 2004) and affective states (Ochsner & Gross, 2005; Ochsner et al., 2012). Therefore, higher levels of energetic arousal might be a consequence of regulatory failure associated with a lower left-hemispheric activity or activation as predicted by AIM.

Studies on transient effects of exercise on PFA are complemented by studies that investigate long-term changes in PFA. Aiming for long-term adaptations in PFA is not a novel idea. For example, Kerson et al. (2009) have shown that neurofeedback training to reduce relative right frontal activity can lead to adaptations in PFA and subsequent reductions in anxiety in anxious patients. However, the present review does not provide clear support for long-term changes in PFA induced by regular exercise: while half of the studies has found increases in PFA (Chen et al., 2021; Hong et al., 2020), the other half has not found any changes (Deslandes et al., 2010; Lattari et al., 2018). One remarkable distinction between the four studies is the duration of the individual exercise sessions. Studies that have found changes in PFA have chosen more than double the duration for each individual session compared to studies, which could not find any differences. The number of sessions, however, did not seem to play a role.

A dose-response relationship could account for some of the inconsistencies. Davidson (1998) has suggested that individuals differ regarding their threshold of responding to a stimulus of a certain intensity. While some individuals already respond to stimuli of low intensities, others may need a more intense stimulus to show the same response. Therefore, choosing longer durations of exercise sessions might ensure that a greater amount of participants respond to the stimuli, which makes changes in PFA more likely.

Understanding the association between PFA and affect is particularly important when it comes to promoting physical activity and increasing exercise adherence. Affective state post-exercise is an important indicator for exercise adherence. The experience of positive affect promotes engagement in physical activity and contributes to sustained exercise participation (Lewis et al., 2002; McCarthy, 2011). Also, regular exercise enhances physical and mental health (Penedo & Dahn, 2005). For example, individuals suffering from depression tend to have a higher relative right-hemispheric PFA (Thibodeau et al., 2006). Therefore, regular exercise could help to alleviate symptoms of depression by inducing a more adaptive PFA.

PFA and motivation

Motivation is an important construct in sport and exercise research. It has been shown to be related to increased athletic performance (Gillet et al., 2012; Gillet et al., 2013) and exercise adherence (Richard et al., 1997). Motivation is therefore considered as important for athletic success as well as mental and physical health. According to Self-determination theory (Deci & Ryan, 2000) autonomous motivation, which refers to the engagement in an activity based on pleasure or volition, can lead to positive affect and optimal performance. The present review shows, that PFA serves as an indicator of motivation or motivational regulation with a higher relative left-hemispheric activity at baseline predicting higher levels of motivation (PFA activity; Cantisani et al., 2015) and a higher relative left-hemispheric activation before (Chen et al., 2019; Kerick et al., 2000; Maszczyk et al., 2019) and during exercise (Bixby et al., 2001; Broelz et al., 2019; Steinberg et al., 2017) reflecting increased motivation (PFA activation). Although the evidence is consistent, there is no conceptual clarity because only one study actually associated changes in PFA with immediate measures of motivation (Broelz et al., 2019). Critique can be also raised regarding sample size with the majority of studies reporting a sample size of 20 and smaller. Therefore, results and their interpretations must be viewed with caution. However, the findings are in line with the predictions of the Motivational Direction Model that links a higher relative left-hemispheric activity and activation to increased approach-motivation (Harmon-Jones & Gable, 2017) and extent this perspective by suggesting a regulatory role. This regulatory role is in line with neurophysiological findings that show an involvement of the PFC in the regulation of motivation and affect in line with internal goals and motivational incentives by exerting cognitive control (Kouneiher et al., 2009; Miller & Cohen, 2001).

PFA and performance

For athletes and coaches, it is important to understand what determines successful performance in order to identify means for performance enhancement. For example, neurofeedback (Mennella et al., 2017) or biofeedback (Allen et al., 2001) training could help athletes to learn how to adapt their PFA flexibly in order to prepare for upcoming challenges.

Studies measuring performance parameters are sparse. However, the few existing studies provide first evidence for a role of PFA in performance with a higher relative left-hemispheric PFA preceding (Chen et al., 2019; Hall et al., 2000; Kerick et al., 2000; Maszczyk et al., 2019) or accompanying (Steinberg et al., 2017) successful performance. According to the interpretations of the observed effects within the studies, there is unison regarding the expected mechanism of enhanced performance: increased levels of (approach) motivation facilitate performance. Additionally, studies differentiating experts and novices show that the adaptive regulation of affective and motivational states is crucial for both, cognitive and motor performance. Experts regulated their affective and motivational levels in response to upcoming tasks, which is reflected in their flexible patterns of PFA activation (Maszczyk et al., 2019; Steinberg et al., 2017). Accordingly, these findings can be interpreted in terms of self-regulatory mechanisms with a higher relative left-hemispheric PFA reflecting effective self-regulation, which is an important indicator of athletic performance (Robazza et al., 2016; Robazza et al., 2004). For example, Steinberg et al. (2017) assessed changes in PFA in elite and novice freedivers during breath-holding and observed increased left-hemispheric PFA activation in elite freedivers after 3 min of breath holding. This activation could be reflecting sustained regulatory control necessary to withstand the respiratory drive but also to stay motivated towards the goal of holding their breath for 4 min. However, since none of the studies under review assessed self-regulation specifically, the immediate associations between PFA, self-regulation and performance remain to be fully explored and tested in future research.

Limitations

The present scoping review has some limitations that need to be pointed out. First of all, scoping reviews provide a broad summary of the studies on a specific topic (Levac et al., 2010). Therefore, they do not assess bias, report sizes of effects or aim at appraising the quality of the studies, which is commonly done in systematic reviews (Aromataris & Pearson, 2014) and meta-analysis (Field & Gillett, 2010). Instead, the principal aim is to map out the evidence (Munn et al., 2018). Given that sample sizes were generally low in most studies, a meta-analytic approach might have been valuable in providing an evaluation of the results reported.

Second, the inherent nature of scoping reviews also requires the strict limitation of search criteria matched with the specific research question. Accordingly, some studies were excluded although they might have provided added value. This includes studies that assessed PFA in prefrontal regions other than F4-F3 and F8-F7. Furthermore, studies that solely reported absolute alpha power values of the individual hemispheres were excluded. Some studies provided information on both, absolute and relative power. These studies were included in the review, but only results for relative values were mapped out in the summary of evidence. However, as suggested by Allen et al. (2004), analyzing the individual contributions of the hemispheres can enhance the understanding of the underlying mechanisms of PFA.

Third, due to the small number of studies that were conducted with a sample of athletes as well as their diversity, it was not possible to draw differential conclusions for the role of PFA in athletes. Particularly, results regarding PFA and affect are mainly based on studies with a non-athlete sample. Research on PFA in other contexts has shown that considerable differences between populations can exist (e.g. Gotlib et al., 1998; Nelson et al., 2012). According to these findings and considering the differences reported between experts and novices within the present review, a differential consideration might provide valuable insights.

Conclusions

The present scoping review aimed at mapping out studies about PFA in the sport and exercise context including associations with affective, motivational and performance-related variables. In particular, evidence for a role of PFA that goes beyond affective processes was sought. Findings are inconsistent with some studies providing evidence for an association of affective and motivational self-regulation with PFA and changes in PFA. Also regarding performance, first indications are given that associate adaptive changes in PFA with successful performance. Our scoping review complements the previous systematic reviews by providing a broader overview including outcomes and associations other than affect.

Despite of some limitations, the present review allows to deduct areas for future research. These should focus on linking motivational outcomes directly to measures of motivation and aim at assessing the role of self-regulatory mechanisms explicitly. This would allow for a more comprehensive interpretation of the results and help to advance the general understanding of PFA in affective and motivational processes as well as to evaluate the interactions with cognitive control processes. Comparing experts and novices could be a suitable means. Generally, higher sample sizes would be advisable to follow good scientific practice.

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5 General discussion

The aim of the present thesis was to investigate the role of PFA in dealing with negative states induced by failure. It focused primarily on affective and behavioral (i.e., performance) outcomes in a university, a general and a sports setting. The findings advanced the understanding of the interpretation of PFA and highlighted its relevance for performance. The first study observed changes in affective state and cognitive performance based on resting baseline PFA. It identified a role of PFA in downregulating negative affective states subsequent to a failure experience in a university setting. Furthermore, it showed that PFA is involved in cognitive performance during the persistence of negative affective states. It thereby contributes to the growing number of studies supporting an association of PFA with situational affect regulation and is one of the first studies to highlight an involvement in cognitive performance. However, the question arose whether the performance relevance was specific to cognitive performance only. In order to gain a more holistic picture of PFA, the second study extended these findings by including a trait perspective of PFA. It associated resting baseline PFA with a measure of trait affect regulation, namely AOF. AOF assesses the ability to downregulate negative affect in everyday life. It hereby contributed to the debate on the inconsistent findings regarding BAS/BIS (i.e., trait affect reactivity) and further supported a role of PFA in the ability to downregulate negative affect subsequent to failure in particular and personality variables in general. Since AOF is not only associated with the ability to downregulate negative affect, but also with the ability to concentrate on new activities, further tentative evidence for a role in performance-related processes was provided. Based on the findings of the second study, which revealed an association between PFA and affect regulation across a variety of situations (i.e., ability to downregulate negative affect), it was assumed that similar associations might be found in the sport and exercise context. Therefore, the third project aimed to provide a broad overview on the role of PFA in the sport and exercise context with a particular focus on athletic performance. It thereby picked up on the question regarding the generalizability of the performance relevance raised by study 1. The scoping review mapped out previous studies in the field. Results showed that the evidence is not consistent but point towards a role of PFA in the regulation of affective and motivational states prior, during or after physical activity. Most interestingly, the evidence suggests that adaptive regulation of these states (indicated by a higher relative left-hemispheric PFA) benefits athletic performance and is therefore in line with our findings regarding cognitive performance. Thus, the present thesis supports evidence that suggests an interpretation of PFA in light of regulatory processes that target affect as well as motivation and influence performance. Importantly, these associations were shown across different settings. The following sections integrate the findings with current knowledge, put them into a greater context and highlight areas for future research.

5.1 Prefrontal asymmetry's role in affect and motivational regulation

From a theoretical perspective, all studies consistently support the assumptions of the AIM, which can be seen as a regulatory approach to PFA: the left PFC inhibits processing of negative or withdrawal related stimuli and the right PFC inhibits processing of positive or approach related stimuli. Affective stimuli act as distractors and take up cognitive resources. Therefore, efficient inhibition of affective stimuli enables successful goal pursuit and hence, performance (Grimshaw & Carmel, 2014). PFA's involvement in the flexible regulation of affect is also supported by neurophysiological models of affect regulation that suggest a close interaction between affective and cognitive processes (Ochsner & Gross, 2005; Ochsner et al., 2004). This interaction becomes evident in the control function of the PFC. It resolves ambiguity in line with an individual's goals (Miller & Cohen, 2001).

When talking about affect, one should also consider motivation. Both are highly related (Bradley et al., 2001). In PFA research, motivation has been integrated in terms of approach and avoidance motivation, which describe motivational directions that guide our actions (Harmon-Jones et al., 2013). However, the concept of motivation is not only characterized by motivational direction but also by intensity and persistence (Heckhausen & Heckhausen, 2006). While intensity reflects the effort a person exerts (i.e., how hard someone tries) to attain a goal, persistence describes the maintenance of the effort (i.e., how long someone tries). Although, research on PFA has mainly focused on motivational direction, PFA might also be related to the intensity (Harmon-Jones et al., 2010) and persistence (Tomarken & Keener,

1998) of motivation. This notion is supported by the findings of the present thesis: On the one hand, motivational intensity might be reflected in an increased level of effort, which was reported to be related to PFA within the review article. On the other hand, better performance on the second task related to PFA in the first study might serve as an indicator of sustained motivation to perform well in the task.

More specifically, the results suggest that PFA is involved in the regulation of motivational processes, which is essential for successful goal attainment and task execution (Heckhausen & Heckhausen, 2006) and in line with previous perspectives (Tomarken & Keener, 1998). This assumption is also supported by neurophysiological evidence. While subcortical structures such as the dopamine system (including the nucleus accumbens, caudate nucleus, putamen and ventral tegmental area) and the limbic regions (including the hypothalamus, amygdala and insular cortex) are responsible for the generation of motivation and the processing of reward information respectively, the PFC (including OFC, dlPFC and ACC) integrates reward information with internal goals to control goal-directed behavior (Kouneiher et al., 2009; Reeve & Lee, 2012). Additionally, there is research on the laterality of motivational functions, such as motives (Schultheiss et al., 2021), motivational direction (Brookshire & Casasanto, 2012; Rutherford & Lindell, 2011) or motivational persistence (Hosoda et al., 2020; Westfall et al., 2014).

Accordingly, findings contribute to the debate on the functional interpretation of PFA and suggest an involvement of PFA in regulatory processes, including affect and motivation, instead of reactive processes implied in BAS and BIS. When talking about affective and motivational self-regulation, the superordinate concept of volition should be considered.

5.2 Volition and action control

Volition refers to self-regulating one's mental state, which entails the self-regulation of affective, motivational and cognitive processes (Kuhl, 1994b). Accordingly, volitional processes are required when external or internal obstacles appear that hinder goal pursuit (Beckmann & Kossak, 2018). The interaction of motivational and volitional processes during goal pursuit is further elaborated in the Rubicon Model of Action Phases (Heckhausen, 1987, 1989). The model consists of several phases that describe the how and why of goal pursuit. It describes a temporal sequence of motivational and volitional phases that include two major transitions. The first refers to intention building and marks the transition between a motivational deliberation phase (pre-decisional phase) and a volitional planning phase (pre-actional phase). The second is called intention initiation and describes the transition from planning to enacting (actional phase). It directs which of the intentions will be enacted on. This is followed by a final motivational evaluation phase (post-actional phase). Accordingly, each phase is characterized by motivational or volitional regulation processes that ensure information processing in line with the respective phase (Heckhausen, 1989). Within the model intentions play a main role and have been described as "arrangements that people make with themselves about what to do in a particular situation" (p. 336, Jostmann & Koole, 2010).

5.2.1 Intentions

As indicated in the previous paragraph, the translation from intentions into actions is supported by volitional processes. These volitional processes might depend on PFA as it is involved in affect and motivational regulation. A similar perspective is taken by Hewig (2018) who suggests that PFA reflects the strength of an intention within the volitional phase of action. The strength of an intention represents the affective-motivational component of intentions and is vital for the transition to the pre-actional phase. Within the pre-actional phase, regulatory processes become relevant in order to suppress distracting information and continue goal pursuit in line with the predominant intention (Heckhausen & Heckhausen, 2006). This temporal or regulatory perspective of PFA has also been implied by others (Miller & Tomarken, 2001; Tomarken & Keener, 1998). They state, for example, that PFA is related to affective processes "involved in the guidance of goal-directed behavior over time" (p.509, Miller & Tomarken, 2001). Further support for an association between intentionality and PFA comes from studies confirming Gainotti's (2005, 2007) model of hemispheric lateralization which links the left hemisphere to verbal cognitive and conscious processing as well as intentionality. For example, Ross and Pulusu (2013) support the theory by showing that the left PFC is mainly involved in the intentional control of facial expressions. Future research might investigate the role of PFA within different phases of the goal pursuit process (i.e., motivational and volitional phases) and to identify its distinctive association with volitional processes.

5.2.2 Action and state orientation

Individuals differ regarding their efficiency in applying regulatory processes during goal pursuit, which is reflected in the personality dimensions of action and state orientation (Kuhl, 1994b, 2001). Action and state orientation are individual difference variables that are based on the Theory of Action Control (Kuhl, 1983, 2001) and can be described as a volitional mode characterized by flexible self-regulation (Kuhl, 1994b). Within the Theory of Action Control, action control refers to volitional processes that shield current or initiated intentions against competing motivational tendencies and lead to the forming and implementation of intentions. Based on this construct, action and state orientation deal with the perseverance of affective states and are directly related to affect regulation (Koole & Coenen, 2007). Hence, action and state orientation become particularly relevant in high demanding situations where action control regulates cognition, affect, and behavior and thereby reflects how well someone is able to use their mental capacities (Jostmann & Koole, 2010). While action-oriented individuals succeed in pursuing their goals (i.e., intentional action) even when facing affective distractions by disengaging from these affective experiences and co-occurring thoughts, state-oriented individuals are unable to regulate their affective states effectively and therefore tend to ruminate instead of focusing on their goal pursuit (Koole & Jostmann, 2004; Kuhl, 1994b). This counts for both, the downregulation of negative affect and upregulation of positive affect. Importantly, despite the communalities between action and state orientation (regulation) and BAS/BIS (reactivity), which are often conceptualized in terms of extraversion and neuroticism (see Wacker et al., 2010), differences between the constructs have been highlighted empirically: action orientation is able to predict the change of affect instead of the initial affective reaction and explains the change of affect even when controlling for the initial reaction (Brunstein, 2001). Findings from article 2 support this view by revealing a significant correlation between AOF and BAS/BIS as well as significant associations between AOF and

PFA when controlling for BAS/BIS and thereby highlight the differentiation between the constructs and the regulatory perspective of PFA.

Furthermore, previous research has linked action orientation to PFA (Düsing et al., 2016; Harmon-Jones & Harmon-Jones, 2002; Harmon-Jones et al., 2008; Harmon-Jones et al., 2008). For example, Harmon-Jones et al. (2008) experimentally induced an action-oriented mindset in half of their participants after they had to make a difficult choice. The subsequent EEG analysis showed that PFA increased in those that were manipulated, with a higher left-hemispheric PFA indicating an action-oriented mindset. Re-ratings of the choice alternatives were more in favor of their chosen alternative as compared to the initial rating, which shows that they regulated their affect effectively. Additionally, theoretical considerations support a role of PFA in action and state orientation. As noted above, action and state orientation become particularly relevant under high demanding conditions, which trigger the efficient use of psychological resources in action-oriented individuals in order to exert action control (Jostmann & Koole, 2010). This is in line with the notion of the Diathesis-Stress Model of PFA (see chapter "Prefrontal asymmetry and affective phenomena"), which states that PFA will manifest itself only in response to a challenge (i.e., demanding condition), otherwise differences between individuals with a high and low PFA are not apparent. Since the present research has focused on AOF (i.e., downregulation of negative affect) only, it does not provide a complete picture regarding action and state orientation and PFA. Therefore, future research should investigate if PFA is associated with this aspect specifically, or with action orientation in general. This could be done by assessing the relationship with the other two subscales, which goes beyond the topic of dealing with failure and involves the upregulation of positive affect.

5.2.3 Personality Systems Interaction Theory

Action Control Theory has further developed into a functional approach to personality, the Personality Systems Interaction Theory (PSI theory; Kuhl, 2000). Since PFA has been discussed in light of personality functions, a short glance at PSI is warranted. PSI theory does not only integrate different theoretical approaches to personality but also evidence from neuroscience. It aims to describe human action, decision-making and experience by integrating motivation, affect, cognition, and behavior (Kuhl, 2000, 2001). Since PSI theory is rather complex and its details go beyond the scope of the present thesis, only the potential relation to the present findings and PFA will be outlined in the following (for further information regarding PSI theory see Kuhl, 2000, 2001).

When applying PSI theory to the present findings regarding PFA, the notion of the Diathesis-Stress Model of PFA (i.e., PFA indicates a vulnerability) is of interest. Under normal conditions individuals with a higher relative right-hemispheric PFA might rely more on their Extension Memory while individuals with a higher left-hemispheric PFA tend to rely on their Intention Memory because the systems have been associated with the right and left PFC respectively (Baumann et al., 2005; Kuhl & Kazén, 1999). Both systems allow for affect regulation, with self-maintenance (or self-regulation) being associated with the Extension Memory and self-control with the Intention Memory (Kuhl, 2001). These two modes can be differentiated based on whether they operate automatically (self-maintenance) or voluntarily (self-control). However, under demanding conditions access to the Extension Memory is blocked if individuals remain in a negative state. Therefore, individuals with a higher relative right-hemispheric PFA might find it more difficult to regulate their affective state compared to individuals with a higher relative left-hemispheric PFA: when individuals with a higher relative left-hemispheric PFA find themselves in demanding conditions with no access to their Extension Memory, they could still rely on cognitive control processes originating from the Intention Memory. This might allow them to downregulate negative affect and hence, to function adequately.

To sum up, PFA might be an indicator of volitional control or the strength of an intention and serve as an objective measure that can be applied in addition to self-report questionnaires, such as the Action Control Scale (Kuhl, 1994a). Support for this assumption comes from the evidence of this dissertation project. In the first study, the successful downregulation of negative affect in participants with a higher relative left-hemispheric PFA might reflect the volitional phase in preparation for the second performance test. This observation could also be interpreted in light of action orientation (or PSI theory more generally): action-oriented individuals are able to cope with a demanding situation, where an action-oriented mindset is important to successfully downregulate negative affective state and ensure successful goal pursuit. In the second study, PFA was associated with AOF when controlling for individual difference in affective reactivity, which supports an involvement of PFA in volitional processes more explicitly. Finally, the third study suggests a role of PFA in the flexible adaptation of affective and motivational states. Additionally, a higher relative left-hemispheric PFA, indicating adaptive changes, preceded or accompanied successful task execution in accuracy tasks. This is in line with research on action and state orientation in sport and exercise that suggest action orientation is beneficial in performance situations where accuracy is important (Gröpel, 2016). Therefore, it might be interesting to see if the association of PFA with performance varies between tasks, such as between accuracy and endurance tasks.

In the following, the rather theoretical consideration regarding PFA and volition will be complemented by the more practical perspective on PFA and resilience.

5.3 Resilience in face of adversity

Volition is an important factor when it comes to dealing with failure or setbacks because it enhances the capacity for goal-pursuit (see AOF). This in turn is indicative of resilience (Masten & Obradović, 2006). The adaptive regulation of affective states, particularly of negative affect is one of the core elements of resilience (Montpetit et al., 2010). While several definitions of resilience exist, the construct has been widely defined as positive adaptation in face of adversity (Luthar et al., 2000). Accordingly, high levels of resilience have been associated with well-being (Mayordomo et al., 2016), life satisfaction (Mak et al., 2011), mindfulness (Pidgeon & Keye, 2014) and physical health (Yi et al., 2008) whereas low levels of resilience have been linked to depression (Ristevska-Dimitrovska et al., 2015), anxiety (Hjemdal et al., 2011), stress (Hjemdal et al., 2011), post-traumatic stress disorder (Horn et al., 2016) and loneliness (Marchini et al., 2021), among others.

5.3.1 Parallel between prefrontal asymmetry and resilience

Several factors suggest a close relationship between resilience and PFA. First, the Diathesis Stress Model of PFA describes PFA as an indicator of individual differences that "are conceptualized as diatheses that alter a person's vulnerability or resilience toward developing psychopathology" (Davidson, 2000, p. 1209). Therefore, Davidson (1998) has referred to PFA as an affective style (i.e., individual differences in affect reactivity and regulation), which he called resilience. Second, several researchers have linked PFA to positive reactions to stressful (Davidson et al., 1999; Düsing et al., 2016; Koslov et al., 2011; Quaedflieg et al., 2015) and trauma-related events (Curtis & Cicchetti, 2007; Meyer et al., 2014). For example, Quaedflieg et al. (2015) measured PFA and the neuroendocrine response before and after exposing their participants to an acute stressor. Their results showed that a higher relative left-hemispheric activity at rest predicted smaller increases in cortisol, an important biological stress marker. Third, from a neurophysiological perspective, both constructs are associated with the neural processes of affect regulation. For resilience, evidence suggests an involvement of several neural circuits. These mainly include the neural circuitry of fear, reward and affect regulation (Feder et al., 2009). In regards to affect regulation, resilience has been associated with factors such as limbic reactivity to negative stimuli or altered cortico-limbic connectivity (Drabant et al., 2006) with a particular focus on the functional coupling of the amygdala and PFC (Ochsner et al., 2004; Southwick & Charney, 2012). As indicated within the introduction (see chapter "Prefrontal asymmetry and affective phenomena"), the same mechanisms are suggested to explain the function of PFA (Davidson, 2000). Finally, from a theoretical perspective, an overlap between the two constructs can be observed: both have been conceptualized as state and trait. While research on PFA has shown that it is a trait with a high degree (i.e., 40% to 50%) of situational variability (Hagemann et al., 2005) and that is subject to brain plasticity (Davidson, 1994), resilience is also often viewed as a trait with the majority of theories describing it as a dynamic process that varies depending on the context and across time (Jacelon, 1997). It is important to note that resilience has shown to differ between domains

(Vanderbilt-Adriance & Shaw, 2008), which has not been investigated in PFA research but might be likely due to the high situational variability of PFA.

The present thesis further supports the close relationship between PFA and resilience, which is a relevant factor in dealing with failure (Johnson et al., 2017). Dealing with failure is an adverse event that causes negative affect, such as frustration and sadness (Johnson, Gooding, et al., 2011; Johnson et al., 2008; Nummenmaa & Niemi, 2004). Therefore, positive adaptation in face of failure (i.e., resilience) does include the downregulation of negative affect while still having the cognitive resources to function effectively (Johnson et al., 2008). This was particularly evident in study 1 and study 2: PFA was associated with the efficient downregulation of negative affect and an absence of performance loss in face of an adverse situation. Following the Bi-dimensional Framework for resilience research (Johnson, Wood, et al., 2011), which states that resilience factors change the likelihood of a negative outcome when exposed to risk factors (Johnson et al., 2016), PFA could be a resilience factor that increases (in case of a higher relative right-hemispheric PFA) or decreases (in case of a higher relative left-hemispheric PFA) the likelihood of adverse events leading to long-term negative outcomes. These considerations allow for practical implications concerning, among others, resilience in sport and the measurement of resilience.

5.3.2 Resilience in sports

As suggested in the initial example, athletes encounter numerous challenging situations where they have to withstand pressure or deal with adverse events. In addition to non-sport-related life events, these challenging situations include important competitions (i.e., expectations and self-presentation), nominations for elite squads (i.e., rivalry), difficulties in skill development (i.e., preparation) or injuries, which all entail important consequences (Mellalieu et al., 2009). Therefore, resilience is relevant to sustain high performance as well as good mental health (Hosseini & Besharat, 2010). However, resilience in sport differs from more "traditional" perspectives on resilience, because it is mainly concerned with enhancing performance instead of maintaining normal functioning (Fletcher & Sarkar, 2012).

So far, interventions to enhance resilience in the sport domain have focused on fostering optimism skills (i.e., evaluation of assumptions, disputing strategies and de-catastrophizing techniques; Schinke et al., 2004), exposure to increased pressure (Kegelaers et al., 2021), strength-based education (i.e., enhancing access to internal and external resources; Chandler et al., 2020), practicing gratitude (Gabana, 2017), biofeedback training combined with positive feeling states (Miller & France, 2020) or providing coping skills (Sullivan et al., 2021). For example, Kegelaers et al. (2021) conducted an intervention with female basketball players. They have used eight training sessions with increased pressure coupled with an introductory workshop on resilient qualities and regular reflection sessions after each session. The pressure induction consisted of a simulation training of the final two minutes of a game and a free throw exercise. Mental, physical or environmental demands were increased successively. A mixed methods design showed that the intervention helped to develop resilient and psychosocial qualities. Despite the positive findings, the general effectiveness of resilience interventions in sports are unclear due to a lack of systematic reviews on the topic (Sarkar & Fletcher, 2016).

Feder et al. (2009) suggests that neurophysiological knowledge could inform new intervention modalities. Considering the close relationship between PFA, affect regulation and resilience, as well as the results of article 3 that suggest an association of PFA and adaptive processes in the sport context, future interventions could target PFA. This could be achieved, for example, through neurofeedback training (Allen et al., 2001; Mennella et al., 2017; Quaedflieg et al., 2016) or mindfulness training (Davidson et al., 2003), which have shown to alter PFA in the long term. Even short term manipulations such as unilateral hand contractions (Harmon-Jones, 2006; Schiff & Lamon, 1994) have the potential to change PFA and thereby could help athletes to deal with acute challenges more adaptively. Accordingly, future research on resilience interventions could benefit from taking a PFA perspective.

Additional to the unclarity of intervention efficacy, concerns have been raised regarding the measurement of resilience (Sarkar & Fletcher, 2014). This concern is not only present in the sport context but also regarding resilience in general (Luthar et al., 2000).

5.3.3 Assessment of resilience

The assessment of resilience has been subject of debate. Accordingly, substantial variations in scales have been observed (Windle et al., 2011). This is partly due to a lack of consensus regarding definitions and other discrepancies such as the conceptualization of resilience as a stable trait or dynamic process. Additionally, the multidimensional nature of resilience suggests that the competences in face of adversity differ based on the domain in which resilience is observed (Luthar et al., 2000). Hence, Luthar et al. (2000) suggest that resilience research needs to become integrative and multidisciplinary.

Following their suggestion, subjective approaches using self-report questionnaires could be complemented by objective measures, such as assessing physiological indicators. These can be used across different domains and might therefore serve as a general measurement tool. However, so far the measurement of most physiological indicators is rather complicated and time-consuming and therefore, in most cases, not feasible. These include, the extraction of genetic markers such as the serotonin transporter gene (5-HTTLPR; Stein et al., 2009), assessing the responsiveness of neurotransmitter systems such as the noradrenergic system (Charney, 2003) or measuring hormonal indicators such as the release of the corticotropin-releasing hormone as well as its receptor activity (De Kloet et al., 2005). Compared to these indicators, PFA is relatively simple to assess and can be measured in the field if portable devices such as the NeXus-10 MKII (Mind Media B.V.; Herten, Netherlands) are used. Therefore, measuring PFA could be a suitable means to assess resilience (i.e., positive adaptation in face of adversity) in a more objective manner complementing or even substituting the use of self-report questionnaires. Research on the immediate relationship between PFA and resilience is needed to assess suitability of PFA as an indicator of resilience.

5.4 Future research perspectives

Research on PFA has been conducted extensively. However, a functional understanding of the phenomenon has not been reached with researchers investigating a broad range of variables and findings being inconsistent. The current thesis analyzed its association with the downregulation of negative affect following failure and affective and motivational processes in the sport an exercise context. Findings and other research suggest a shift in the understanding of PFA away from a reactivity and towards a regulatory perspective. Since the differentiation between reactivity and regulation is not an easy one (Gross et al., 2011b), one of the major challenges will be to find means to distinguish the two constructs experimentally. As done in the present thesis, this methodological challenge could be solved by observing the temporal dynamics of affective (or motivational) processes or by measuring reactivity and regulation at the same time and directly comparing their individual contributions as was done in article 2.

Considering that PFA showed associations with both, affect and motivational regulation, a potential approach for future research might be to view PFA from an overarching perspective. As neurophysiological research shows, no single brain region is responsible for only one task. Instead, regions such as the PFC serve a diverse range of functions (Miller et al., 2013). Therefore, it is highly unlikely that PFA is an indicator of one function only but rather might be associated with a broader construct incorporating various functions (Grimshaw & Carmel, 2014). In terms of psychological constructs and as suggested previously, volition might be a promising candidate. Following this approach, it would be interesting to see if PFA is also associated with volitional regulatory processes other than affect and motivational regulation. For example, neurophysiological evidence showed that the PFC is involved in the regulation of attention (Daffner et al., 2000; Kondo et al., 2004; Rossi et al., 2009), which is also an important aspect of goal-oriented behavior (Asplund et al., 2010). So, does PFA play a role in attention regulation as well? Findings from article 1 and article 3 could be seen as support. Attention regulation is highly relevant for the maintenance of good performance in face of distractors such as affective states (Vast et al., 2010; Wurm et al., 2004). Furthermore, distraction, defined as a shift in attention, has been proven effective in reducing negative affect (McRae et al., 2010). Accordingly, a higher relative left-hemispheric activity could also be reflective of enhanced attentional control in face of affective distractors (or stimuli) and hence, better cognitive and motor performance and reduced negative affect. Future research could build on these assumptions and investigate the immediate association between PFA and attention regulation.

Additional to this holistic perspective, several other topics emerged based on the research conducted within the present thesis. These will be outlined in the following and focus on the advancement of the underlying mechanisms and functional interpretation of PFA as well as practical consideration.

5.4.1 Theoretical perspectives

First, research on PFA and regulatory processes rarely differentiates between voluntary and automatic regulation. Given the timeline and break time activities of article 1, an involvement in voluntary affect regulation might be assumed, but the data did not allow for any conclusions. In addition, as suggested previously, propositions made by PSI theory could be interpreted in favor of an involvement of PFA in voluntary instead of automatic affect regulation. From a neurophysiological perspective, Phillips et al. (2008) suggest a general model of both, voluntary and automatic affect regulation. Within their model, on the one hand, a medial prefrontal cortical system serves as a feedforward pathway that entails automatic regulatory processes. On the other hand, a lateral prefrontal cortical system acts as a feedback pathway providing voluntary control. Once affective states and behaviors are generated by the amygdala, ventral striatum and thalamus, both neural systems are activated. For automatic affect regulation this includes activity in the hippocampus (and parahippocampus), OFC, dorsal and ventral ACC, as well as dorsomedial PFC (dmPFC). While the ventral ACC and dmPFC are also implicated in voluntary affect regulation, the dlPFC and vlPFC are the main regions of the lateral feedback system. This model is based on their original model (Phillips et al., 2003; see article 1 for further details) and further supports the assumption that PFA, as it is measured in the dlPFC and vlPFC, is involved in voluntary regulation. Future PFA research on the differentiation of voluntary and automatic affect regulation could also help to advance research on the neurophysiology of affect regulation.

Second, similar to the differentiation between voluntary and automatic affect regulation studies could investigate the differential associations with individual affect regulation strategies. Up to date only few studies have investigated the link between PFA and individual strategies (e.g., Choi et al., 2016; Papousek et a., 2017) and have mainly focused on cognitive reappraisal. Neurophysiological research has shown that different affect regulation strategies engage different subregions of the PFC and limbic area, as well as additional cortical areas involved in cognitive and sensory processing. Reappraisal, which aims to change the interpretation of a stimulus, is the cognitively most complex strategy and also the most prevalent in neurophysiological research of affect regulation (Ochsner et al., 2012). On the one hand, cognitive reappraisal shows an increased activation of the dorsal ACC and medial and lateral PFC, which are involved in conflict monitoring, mental representations and goal-attainment respectively (Botvinick et al., 2004; Miller, 2000; Mitchell, 2009; Ochsner et al., 2002). On the other hand, subcortical regions, such as the amygdala and OFC, are deactivated. This shows that reappraisal changes the activity of subcortical regions that are responsible for affective processing by engaging the PFC (Ochsner et al., 2002; Ochsner et al., 2004). In particular, activity in the left vlPFC and dlPFC is increased and activity within the left OFC and right amygdala is decreased (Kim & Hamann, 2007; Ochsner et al., 2004; Urry et al., 2006), which corroborates the findings from PFA research mentioned above. However, an involvement of the dlPFC has also been suggested in distraction with a differential activation of subregions (Kanske et al., 2011). Accordingly, future research could investigate if PFA is also related to affect regulation strategy other than cognitive reappraisal. It is important to note that the present thesis has mainly focused on the downregulation of negative affect. Therefore, future research should complement this perspective by focusing on the upregulation of positive affect as well. This would not only advance the functional understanding of PFA but also potentially offer new areas for interventions: practicing affect regulation strategies regularly could change PFA.

5.4.2 Practical perspectives

Third, practical implications of PFA in the domain of sport have been provided by article 3. These suggest that PFA is a promising candidate for improving athletes' performance and well-being by supporting an adaptive dealing with challenging situations. However, research on PFA in the domain of sport is still in its infancy. Accordingly, future research is required to fully understand its applicability and to deduct the utility of interventions. For this purpose, immediate measures of affect or motivation should be included to allow for a clearer interpretation of the results. Also, considering athletes' frequent exposure to failure and hence, potentially a reduced sensitivity to negative events, future research needs to ensure that the situation is demanding in order to be able to detect relevant effects.

Fourth, finding interventions to alter PFA has not been one of the aims of the present thesis. First insights are provided by article 3, which suggest that aerobic exercise might be suitable to achieve long-term adaptations in PFA. Other research has also suggested mindfulness (Davidson et al., 2003; Moynihan et al., 2013; Shanok et al., 2019), neurofeedback (Allen et al., 2001; Kerson et al., 2009; Mennella et al., 2017; Peeters et al., 2014; Quaedflieg et al., 2016) or positive psychology (Xu et al., 2018) to be effective interventions. Since systematic reviews are suitable means to "establish the quality of evidence, and to address any uncertainty or variation in practice" (Munn et al., 2018, p.2), a systematic review is warranted to show the efficacy of interventions, inform best practices and potentially allow for the deduction of new interventions.

Ultimately, considering the construct of resilience and its close relationship with PFA, the topic of domain-specificity arises. It would be interesting to see if PFA varies systematically based on the domain. Particularly when it comes to interventions, this knowledge would be highly relevant: interventions might need to be tailored to the specific domain as is suggested in resilience research (Vanderbilt-Adriance & Shaw, 2008).

6 Conclusion

The present thesis has investigated PFA as a potential factor in dealing with failure. The results of the studies have shown that PFA is associated with affect regulation as well as cognitive performance in face of adversity. Additionally, reviewing the literature of PFA in sport and exercise revealed further associations with motivational processes and athletic performance. A higher relative left-hemispheric PFA seems to allow for adaptive dealing with challenges, which benefits goal pursuit and hence, performance. Accordingly, PFA could be a suitable means to differentiate between athletes that can handle failure situations easily compared to those for whom the situation is enduring and impeding. While the former tend to have a higher relative left-hemispheric PFA, the latter are more likely to be dominant in the right PFC.

Findings point towards a general association of PFA with volitional processes and put forth parallels with the construct of resilience. Future research investigating the explicit associations with PFA could advance the understanding of the functional interpretation and underlying mechanisms of PFA. Furthermore, implications of the current thesis could help researchers and practitioners in the area of sports, as well as other areas, to understand the phenomenon of dealing with failure, to develop new interventions and to learn what determines successful performance.

7 References

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8 Attachment

8.1 List of publications and submissions

Haehl, W., Mirifar, A., & Beckmann, J. (under review). Regulate to facilitate: A scoping review of prefrontal asymmetry in sport and exercise. *Psychology of Sport and Exercise*.

Heim-Ohmayer, P., Freiberger, A., Gedik, M., Beckmann, J., Ziehfreund, S., Zink, A., *Hähl, W. & *Schielein, M. C. (2021). The impact of stigmatization of psoriasis, atopic dermatitis and mastocytosis in different areas of life - A qualitative interview study. *Skin Health and Disease*, e62.

Haehl, W., Mirifar, A., Quirin, M., & Beckmann, J. (2021). Differentiating reactivity and regulation: Evidence for a role of prefrontal asymmetry in affect regulation. *Biological Psychology*, *162*, 108107.

Beckmann, J., Ehmann, M., Kossak, T. N., Perl, B., & Hähl, W. (2021). Volition in sports. *Zeitschrift für Sportpsychologie*, *28*, 84-96.

Haehl, W., Mirifar, A., Luan, M., & Beckmann, J. (2020). Dealing with failure: Prefrontal asymmetry predicts affective recovery and cognitive performance. *Biological Psychology*, *155*, 107927.

Pfundmair, M., Erk, W., & Reinelt, A. (2017). “Lie to me”—Oxytocin impairs lie detection between sexes. *Psychoneuroendocrinology*, *84*, 135-138.

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8.2 Reprint permissions

Article 1 & 2: Biological Psychology

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