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From Appraisal and Attention to Affective Experience: Genetic, Social and Exercise-based Influences on Emotional Evaluation and Psychophysiological Reactions

Kumulative Dissertation

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M. Sc. Friedrich Florian Meixner
geboren in Memmingen

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Amtierende Dekanin:	Prof. Dr. Anke Huckauf
Gutachter/in:	1. Prof. Dr. rer. nat. Cornelia Herbert
	2. apl. Prof. Dr. phil. Markus Kiefer
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Abstract

Experiencing an affective, emotional state upon encountering novel stimuli is dependent on the nature of the stimulus as well as the appraisal of the stimulus by the perceiving individual. Contemporary views on stimulus processing consider appraisal to be the underlying mechanism determining the subjective affective outcome, as it is experienced by the individual. This thesis had the objective of contributing to the understanding of appraisal processes in healthy participants, with a special focus on self- versus other-reference of the experienced stimuli. To this extent, the experimental His-Mine paradigm (Herbert, DFG HE5880/3-1) has been repeatedly employed, assessing the emotional evaluation of positive, negative, and neutral words, combined with self- or other-reference.

In the first study, associations between genetic markers (OXTR polymorphisms rs53576 and rs2268498) and emotional evaluation have been investigated, demonstrating a possible relationship in the form of an interpretation bias in the appraisal of neutral words, i.e., ambiguous stimuli devoid of valence information (Meixner, Montag, & Herbert, 2019). While the usually found self-positivity bias did not interact with participants' genotype, rs53576-A+/rs2268498-C+ carriers displayed a less positive, and more negative interpretation bias in the appraisal of neutral stimuli, depending on self- or other-reference of the stimuli.

In the second study, romantic relationships have been examined as a possible factor changing the appraisal of self- and other-related emotional information, even in the absence of explicit partner-related instructions. It could be shown that the self-positivity bias persisted in a romantic relationship. However, participants in a romantic relationship evaluated positive, other-related stimuli more often in a valence-congruent fashion, and therefore akin to positive, self-related stimuli (Meixner & Herbert, 2018).

In the third study, the influence of acute aerobic exercise with varying attentional focus on the evaluation of self- and other-related emotional stimuli has been tested. Results suggested that while aerobic exercise is an affective experience influencing mood and subjective exertion, this did not transfer into subsequent emotional evaluation, ruling out effects of mood-congruent processing. However, it could be shown that the attentional focus instruction led to slower reaction times in the subsequent emotional evaluation paradigm compared to the exercise condition without attentional focus instruction, possibly caused by the increased demands of the additional attention task. The direction of the self-reported attentional focus during exercise proved to be related to the self-positivity bias in subsequent emotional evaluation: An internal

focus of attention on bodily stimuli during the aerobic exercise was associated with a larger difference between the number of valence-congruent answers in positive, self-related compared to positive, other-related words, and vice versa for an external focus of attention (Meixner & Herbert, 2022).

Lastly, in the fourth study, the psychophysiological effects of acute aerobic exercise with different attentional focus have been examined. It could be shown that instructed attentional focus did not influence affective experience of exercise, perceived exertion, or physiological parameters, such as heart rate variability (HRV), and pre-ejection period (PEP). Follow-up analyses, however, hinted at a possible relationship between self-reported attentional focus and psychophysiological parameters (Meixner & Herbert, 2021).

Taken together, the presented studies and their results illustrate associations of factors which differ on their time scale, on stimulus appraisal and affective experiences: Stable factors, such as genetics, long-term factors such as romantic relationships and short-term influences, such as acute aerobic exercise with varying attentional focus on stimulus appraisal have been investigated. In sum, these findings contribute to uncovering the relationship of biopsychological influences, emotional evaluation, and affective experiences in the appraisal process of verbal and bodily stimuli.

Zusammenfassung

Affektives, emotionales Erleben als Reaktion auf neuartige Reize wird beeinflusst von den Eigenschaften des Reizes, aber auch von der Bewertung der wahrnehmenden Person. Aktuelle Theorien zur Reizverarbeitung nennen die Bewertung eines Reizes als essenzielle Komponente, die dem subjektiven affektiven Erleben eines Individuums zugrunde liegt. Diese Dissertation wurde mit dem Ziel angefertigt, das Verständnis dieser Bewertungsprozesse in gesunden Stichproben zu verbessern, mit speziellem Augenmerk auf den Selbst- oder Fremdbezug der erlebten Reize. Dabei wurde das experimentelle His-Mine Paradigma (Herbert, DFG HE5880/3-1) mehrfach verwendet, mit dem die emotionale Evaluation positiver, negativer und neutraler Worte, gekoppelt mit Selbst- oder Fremdbezug erfasst werden kann.

In der ersten Studie wurden Zusammenhänge zwischen genetischen Markern (OXTR Polymorphismus rs53576 und rs2268498) und emotionaler Evaluation untersucht. Die Ergebnisse stützen einen möglichen Zusammenhang in Form eines Interpretationsbias bei der Bewertung neutraler Worte, also ambiger Reize, die keine Valenzinformationen beinhalten (Meixner, Montag, & Herbert, 2019). Der übliche Befund eines Self-Positivity Bias war unabhängig vom Genotyp der Teilnehmenden nachzuweisen. Träger der rs53576-A+/rs2268498-C+ Allele zeigten jedoch einen weniger positiven, eher negativen Interpretationsbias in der Bewertung neutraler Reize, in Abhängigkeit von deren Selbst- und Fremdbezug.

In der zweiten Studie wurden romantische Beziehungen als ein möglicher Einflussfaktor untersucht, der die Bewertung von selbst- und fremdbezogenen Reizen verändern könnte. Es wurde geprüft, ob sich dies sogar in Abwesenheit von expliziten, partnerbezogenen Instruktionen zeigen lässt. Die Ergebnisse zeigten, dass der Self-Positivity Bias in einer romantischen Beziehung insgesamt erhalten bleibt, aber Teilnehmende in einer romantischen Beziehung positive, fremdbezogene Stimuli häufiger als valenzkongruent, und somit vergleichbar zu positiven, selbstbezogenen Stimuli bewerten (Meixner & Herbert, 2018).

In der dritten Studie wurde der Einfluss von akuter sportlicher Aktivität im aeroben Bereich mit verschiedenem Aufmerksamkeitsfokus auf die Evaluation selbst- und fremdbezogener emotionaler Reize erforscht. Aerobe sportliche Aktivität erwies sich als eine affektive Erfahrung und beeinflusste Stimmung sowie die subjektive Anstrengung. Diese Effekte übertrugen sich jedoch nicht auf die Evaluation emotionaler Reize, was einer stimmungskongruenten Verarbeitung im verwendeten experimentellen His-Mine Paradigma

widerspricht. Es konnte jedoch gezeigt werden, dass eine Instruktion zur Aufmerksamkeitsfokussierung zu langsameren Reaktionszeiten im nachfolgenden Evaluationsparadigma führte, was auf die erhöhten Anforderungen durch die parallele Aufmerksamkeitsfokussierung zurückzuführen sein könnte. Die selbstberichtete Richtung der Aufmerksamkeit zeigte einen Zusammenhang mit dem Self-Positivity Bias in der emotionalen Evaluationsaufgabe: Je stärker Teilnehmende ihre Aufmerksamkeit auf internale Reize während der sportlichen Aktivität fokussierten, desto größer war die Differenz zwischen valenzkongruenten Antworten auf positive, selbstbezogene Worte und positive, fremdbezogene Worte. Je ausgeprägter Teilnehmende external fokussierten, desto geringer war diese Differenz (Meixner & Herbert, 2022).

Zuletzt wurden in der vierten Studie zusätzlich die psychophysiologischen Effekte von sportlicher Aktivität mit verschiedenem Aufmerksamkeitsfokus untersucht. Es konnten hierbei keine Zusammenhänge von affektivem Erleben sportlicher Aktivität, der subjektiven Anstrengung und physiologischen Parametern, wie der Herzratenvariabilität (HRV) und der Präejektionsperiode (PEP), und dem instruierten Aufmerksamkeitsfokus während der Aktivität gezeigt werden. Sekundäre Analysen deuteten jedoch auf einen möglichen Zusammenhang zwischen selbstberichtetem Aufmerksamkeitsfokus und psychophysiologischen Parametern hin (Meixner & Herbert, 2021).

Zusammengefasst beleuchten die dargestellten Studien und Ergebnisse die Beziehungen diverser Einflussfaktoren der emotionalen Evaluation von Reizen und affektivem Erleben verschiedener zeitlicher Ausdehnung: Zeitstabile genetische Faktoren, Langzeitfaktoren, wie romantische Beziehungen, sowie kurzzeitige Einflüsse, wie akute sportliche Aktivität, wurden erforscht. Die berichteten Befunde leisten einen Beitrag, unser Verständnis der Zusammenhänge zwischen biopsychologischen Einflüssen, emotionaler Evaluation und affektivem Erleben in den Bewertungsprozessen von verbalen und körperlichen Reizen zu verbessern.

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List of Abbreviations

CO	cardiac output
CPM	component process model of emotion
HR	heart rate
HRV	heart rate variability
ICG	impedance cardiography
LVET	left-ventricular ejection time
mRNA	messenger RNA
OXTR	oxytocin receptor (gene)
PEP	pre-ejection period
SNP	single nucleotide polymorphism
SV	stroke volume

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Part I

Synopsis

1 Introduction

"You've got a promotion" - "We're expecting a child" - "I love you". All these sentences can elicit incredibly broad ranges of affective experiences, ranging from immense joy, happiness or gratitude to envy or jealousy, to simple indifference. Depending on the context in which and from whom these verbal stimuli are perceived, be it on the subway train from a stranger's mouth, at home from a close other person, or at work, the ensuing emotional reaction is substantially different. Of course, this is not limited to verbal stimuli. A racing heart, sweating palms and shortness of breath might be appraised as signs of a threatening malady if they are perceived at rest. They might also be appraised as warning signs of a panic attack if they are perceived in the context of a situation that is evaluated as potentially threatening. At the same time, if these exact same physical symptoms are perceived during physical activity, the perceiving person might not even think twice about these symptoms, appraising them merely as temporary by-products of her favourite activity. Between different people, dispositional traits might also influence the appraisal of a given stimulus. Even within one person, the reaction towards the exact same stimulus input might greatly differ with changing mood, energy levels or acute previous experiences: A great opportunity in one's job might be perceived as something overwhelming and threatening, or as a new challenge and an opportunity to grow, depending simply on how much one has slept the night before and if he/she had a hurtful fight with his or her significant other the prior morning. This also illustrates how an affective experience, once formed, might ripple through a person's day, a whole week, a year, with this chain reaction possibly impacting their whole life. Taken together, it seems evident that an affective experience is the end-product of a process which is influenced by multiple factors. These factors can include the valence of the stimulus, the (self-) reference of a stimulus input, as well as personal disposition, mood, experience and many more. This is the basic assumption of all *appraisal theories of emotion*, which aim to explain how an emotional episode, and an affective experience is formed.

This thesis has been motivated by the investigation of influences on the appraisal process of external (verbal) and internal (bodily) stimuli. A special focus is placed on how the perceiver's self interacts with stimulus inputs to prompt different emotional evaluations and affective outcomes. Long-term (dispositional) and short-term (situational) influences on the process from perceiving a stimulus to an affective experience, such as genetic variations, romantic relationships, and physical activity, constituted the main research questions of the presented articles. In the following Introduction, a contemporary view on the concept *emotion* is

presented, followed by brief overview on *appraisal theories of emotion*. Subsequently, a description of the self's role in stimulus appraisal is presented, as well as previous research on factors tying into the appraisal of self- and other-related information, followed by the value of biopsychological methods in the quest for objective information on affective experiences, and closing with a theoretical comparison of stimulus appraisal of verbal input versus bodily sensations.

1.1 What's in a Name? Describing Emotion, Mood, and Affect

Emotion, *mood*, and *affect* are influences on human lives which cannot be overstated, and yet their definition has been object to multiple explanation attempts and re-conceptualizations by emotion psychology. One of the conceptual difficulties lies in their differentiation from each other. Due to the trouble of properly defining *emotion* in terms of biologically vs. socially constructed phenomena, instincts, action tendencies, sensations or feelings, Russell (2003) argued to move the (laypersons') term *emotion* out of scientific discussion and instead focus on its basic elements. He points out that most of the so-called 'basic' emotions are complex reactions to events and probably already a blend of an affect and an implied cognitive structure, e.g., the joy *about something* or the anger *at something*, i.e., indicating an object or reference. Russell (2003) describes *Core Affect* as a primary concept, "a neurophysiological state that is consciously accessible as a simple non-reflective feeling that is an integral blend of hedonic (pleasure-displeasure) and arousal (sleepy-activated) values" (p.147). Core affect can therefore be described on two dimensions (valence and arousal) and is primarily object-free, but might be attributed to an object, leading to *attributed affect*. *Mood* is defined as a secondary concept and as a prolonged core affect, also object-free. According to Russell, an *emotional episode* (i.e., what is commonly referred to as a single occurrence of a basic emotion such as *fear*, *joy*, or *anger*) is prototypically constructed as a series of components. This includes an *antecedent event*, i.e., the occurrence of any kind of stimulus, which is then analysed in terms of its *affective quality*, followed by alterations in *core affect*, *attributional* and *appraisal* processes, leading to *instrumental action* and *physiological* or *expressive changes*. The episode closes with a *subjective conscious experience*, *emotional meta-experience*, i.e., self-perception of one's own affective experience, processes of *emotion regulation* and, in certain circumstances, looping into re-evaluation or re-appraisal. In this thesis, the term *affective experience* will be used to describe the experience of a *core affect*, encompassing its possible changes caused by antecedent events or occurring stimuli, depending on their *affective quality*. However, the

perceived affective quality of an object or stimulus might greatly differ, both intra- and interindividually.

1.2 Stimulus Appraisal as the Underpinning of Affective Experiences

In contrast to Russell's (2003) previously described prototypical emotional episode, *appraisal theories of emotion* usually define the estimation of an object's *affective quality* as an appraisal process as well. For example, one of the earlier appraisal theories, Lazarus' transactional model of stress and coping (Lazarus, 1991) describes two main layers of appraisal. After an initial sensory perception filter, a primary appraisal determines if the stimulus is positive, dangerous, or irrelevant. The secondary appraisal then encompasses an analysis of available resources to react to the stimulus. If this appraisal concludes a state of insufficient resources, feelings of stress might emerge. In the case of sufficient resources, feelings of challenge might arise. Either way, this guides the subsequent appraisal of coping potential (i.e., changing the situation or changing the relation to the situation, e.g., actions of approach or withdrawal). The process concludes with reappraisal of the stimulus to evaluate if one's goal has been met. Notably, the primary appraisal of a stimulus is different to Russell's (2003) terms, wherein the pure and emotionally uninfluenced perception of a stimulus' *affective quality* is formulated as a separate step.

Building upon the model by Lazarus (1991), the *component process model of emotion* by Scherer et al. (CPM; Grandjean & Scherer, 2008; Sander, Scherer, & Grandjean, 2008; Scherer, 2001) describes a multi-level sequential check of a stimulus' relevance, its implications, one's coping possibilities, and its normative significance. These sequential checks are influenced by processes of attention, memory, motivation, implications, and self-concept. As a product, individual responses in the autonomous physiology, action tendencies, motor expression and subjective feelings emerge, which also serve as reciprocal feedback for reappraisal. The parallelism of these two appraisal theories of emotion with Russell's description of the genesis of an emotional episode is obvious, and not surprising given Russell's explicit attempt to formulate an integrative theory including prior models and research findings. Figure 1 illustrates the key components of these contemporary appraisal theories of emotion. All three models share the concept that in the case of any event, a cascade of successive evaluations takes place, each influenced by intraindividual parameters, while also acknowledging the importance of physiological reactions in the emotional experience.

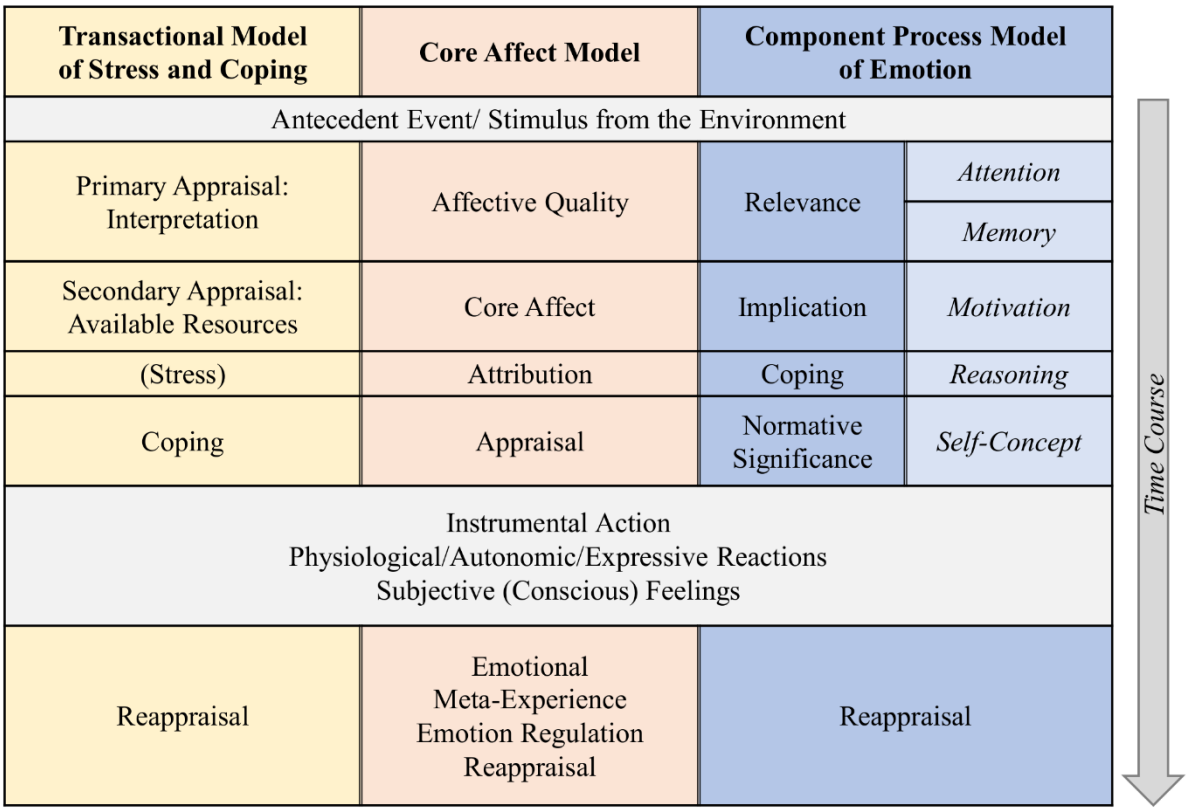


Figure 1. Contemporary theories on the appraisal processes leading to affective and instrumental consequences after a stimulus encounter. From left to right, the Transactional Model of Stress and Coping (based on Lazarus, 1991), the Core Affect model (based on Russell, 2003), and the Component Process Model of Emotion (based on Grandjean & Scherer, 2008; Sander, Scherer, & Grandjean, 2008; Scherer, 2001).

1.3 The Role of the Self in Stimulus Appraisal

Each of the presented theories of stimulus appraisal encompass the concept of the self in one way or another. In the Transactional Model of Stress and Coping, the primary appraisal comprises goal-relevance, goal-congruence, and ego-involvement, and secondary appraisal includes blame or credit for oneself or other, implying personal consequences (Lazarus, 1991). In the CPM, the self is implied to be important for relevance detection at early, as well as self-concept checks at later stages of appraisal (Grandjean & Scherer, 2008; Sander, Scherer, & Grandjean, 2008; Scherer, 2001). In Russell's model of Core Affect (2003), the self is only explicitly mentioned in later stages such as emotional meta-experience, or emotion regulation. However, since it is an integrative theory, appraisal is only included in brevity. Therefore, Russell's model is still compatible to the former two theories regarding the involvement of the self.

In the presented models, it might be implied that a stimulus needs to be self-related to be considered relevant, i.e., the self being incorporated in the earliest of stimulus evaluation checks. However, it is not explicitly and sufficiently articulated as an influencing factor in any of the presented, contemporary theories. Yet, the self seems to be deeply linked to appraisal processes, starting from relatively early stages of information processing. Self-related information is almost always preferentially processed (e.g. Blume & Herbert, 2014; Esslen, Metzler, Pascual-Marqui, & Jancke, 2008; Symons & Johnson, 1997; Zhou et al., 2010) and mnemonically superior (self-reference effect in memory; Symons & Johnson, 1997). Additionally, the evaluation of the stimulus' *affective quality* – positive ones in particular – is also deeply related to personal relevance, especially to the self. For example, there exists a notable difference in emotional evaluation depending on the reference in verbal stimuli. By exchanging the pronoun in front of a noun (e.g. 'my/his'; German: 'meine/seine'), the personal relevance of the ensuing noun (e.g. 'joy', 'sadness'; German: 'Freude', 'Trauer') might drastically change, as it is evident in the well-documented *self-positivity bias* (e.g. Fields & Kuperberg, 2016; Fossati et al., 2003; Herbert, Herbert, Ethofer, & Pauli, 2011; Meixner & Herbert, 2018; Meixner, Montag, & Herbert, 2019; Weis & Herbert, 2017). Neuropsychological experiments also show that any personal reference influences early information processing ('my/his' vs. article 'the') whereas explicit self-reference improves processing at later stages of stimulus appraisal ('my' vs. 'his', Herbert, Herbert, et al., 2011), possibly differentiating self-relevant from other-relevant information. Given these previous results the involvement of the self in multiple – early and late – stages of the appraisal process of emotion can be assumed.

1.4 The Self in a Relationship

Relying on the previously described results, it is obvious how important the self is to affective experiences. But what happens to affective experiences if the self or its boundaries are subject to change? For example, in close interpersonal relationships, the self seems to be expanding by the respective other: according to the *self-expansion model* by Aron and colleagues (Aron, Aron, Tudor, & Nelson, 1991; Aron, Mashek, & Aron, 2004), this includes the successive integration of resources, perspectives and identity of the close other into one's own self (Aron & Aron, 1986). A partner might feel ashamed if a significant other does something shameful, resources might be spent more freely on close other persons, and lastly even their traits might be confused with one's own (Aron et al., 1991). In terms of appraisal theories of emotion, this could be interpreted as follows: stimuli relating to another person are being appraised similarly to self-related stimuli, regarding their implications and consequences. This similarity in

processing could also be shown using neuroimaging methods: In fMRI and MEG experiments, overlapping neural activation of self- and other-related processing could be demonstrated, depending on the degree of closeness to the other, e.g. a romantic partner compared to friends, or own children vs. acquainted children (Bartels & Zeki, 2004; Tiedt et al., 2014; Vanderwal et al., 2008), suggesting a neural correlate of reduced self-other boundaries.

Therefore, if the self can be influenced by close interpersonal relationships, it would be insightful to examine participants living in a romantic relationship. That way, additional knowledge on the stability of any biases in self-related processing, such as the self-reference effect or the self-positivity bias might be acquired.

1.5 Beyond the Characteristics of Stimuli: Interpretation Biases

As initially described, stimulus appraisal and the resulting affective experience are not always determined by the objects' innate qualities. There might be conditions leading to strong biases in stimulus appraisal, possibly even to the extent of twisting and shifting it into the opposite end of the valence dimension. An event which is inherently positive, such as a friend winning a competition, might still lead to negative affective responses such as envy or jealousy. Conversely, something innately negative as someone else experiencing pain, might elicit paradoxical feelings of joy, depending on the relationship to the suffering person, something aptly described by the Germanism *Schadenfreude*. An extreme form of misinterpretation, i.e., stimulus appraisal highly deviating from an object's innate qualities, can be observed in the study of psychiatric disorders. Conclusions from clinical populations might also be relevant for participants with sub-clinical symptomatology, since most psychiatric disorders are merely defined by reaching thresholds on continuous scales. Therefore, although findings from patients acutely suffering from psychiatric disorders might not be fully generalizable, they might still grant insight into the appraisal processes in 'healthy' subjects.

In psychiatric disorders, stimulus appraisal might be significantly altered by interpretation biases. In major depressive disorders, for example, the self-positivity bias is shifted towards a self-negativity bias (Herbert et al., 2014). Additionally, interpretation biases could be shown in anxiety disorders and social phobia (Amir et al., 2005; Huppert et al., 2003; Moser et al., 2012). Ambiguous stimuli, such as neutral words, are evaluated in a valence-incongruent, but possibly mood-congruent fashion. Interestingly, these cognitive interpretation biases might be attenuated by a single session of physical exercise (Clarke et al., 2018). But not only affective disorders influence stimulus appraisal. There is also evidence that borderline personality disorder (Winter

et al., 2015) is associated with a negative evaluation bias in self-related, positive stimuli. Similarly, psychotic disorders accompanied by a disturbed sense of self seem to be associated with less accuracy in the evaluation of self- or other-related stimuli (Herbert, Hesse, & Wildgruber, 2018), suggesting increased difficulty evaluating words with any personal relevance.

While the study of affective experiences through quasi-experimental designs comparing, e.g., participants with different degrees self-expansion in their life, or different psychiatric disorders are enlightening, they often do not grant any insight into causal relationships. In psychiatric disorders, for example, any found associations might be either due to the disorder causing altered stimulus appraisal, or due to the altered stimulus appraisal creating specific vulnerabilities (i.e., a self-negativity bias leading to a vulnerability for depressive disorders). In interpersonal relationships, love and entering a relationship might influence the processing of other-related information. Alternatively, certain habitual styles of processing other-related information might make entering and maintaining an interpersonal relationship much easier. A strong experimental approach, and further long-term studies are necessary to identify clarifying cause-and-effect relationships.

1.6 Biopsychological Perspectives on Affective Experiences

Another often-discussed difficulty in emotion research is the emphasis on subjective measurements, e.g., self-report data, neglecting the fact that most of the time, only the end-product of an appraisal process reaches subjective awareness. The processes on the way to the end-product are mostly inaccessible and unconscious. As LeDoux (2000) aptly put it, "[emotion researchers] remained focused on subjective emotional experience. [...] emotion researchers need to figure out how to escape from the shackles of subjectivity if emotion research is to thrive" (p.156). If physiological measures correspond to specific psychological reactions, then affective experiences can also be described objectively through emotion-specific physiological markers. Therefore, besides long-term study of these relationships, the biopsychological perspective might aid in revealing the underlying processes of stimulus appraisal. Extending our knowledge by diverse, objective physiological parameters could greatly increase our understanding of the complete process from perceiving a stimulus to an affective experience.

For example, physiological correspondences to psychological states can be studied by assessing hormonal changes during an affective experience. Vice versa, hormones can also be administered and their effect on behaviour and affective experience subsequently measured.

The most prominent example for this might be the involvement of the stress hormone cortisol in the stress reaction cascade. Oxytocin, also termed the ‘love hormone’ or ‘bonding hormone’, proved to be a promising candidate regarding the processing of information which is either related to the own or to another person (Bakermans-Kranenburg & van IJzendoorn, 2013; Kumsta & Heinrichs, 2013; MacDonald & MacDonald, 2010). However, the exact mechanisms behind any behavioural effects or affective changes after intravenous/intranasal administration is still debated, with most of the criticism deriving from the uncertainty regarding central nervous availability of the administered substance, regarding both time and amount (Leng & Ludwig, 2016; Striepens et al., 2013; Van IJzendoorn & Bakermans-Kranenburg, 2012). Therefore, and to furthermore study influences of the oxytocinergic system on affective experience or behaviour on a longer time scale, it might be feasible to employ a related biopsychological method: the research on genetic associations with behaviour.

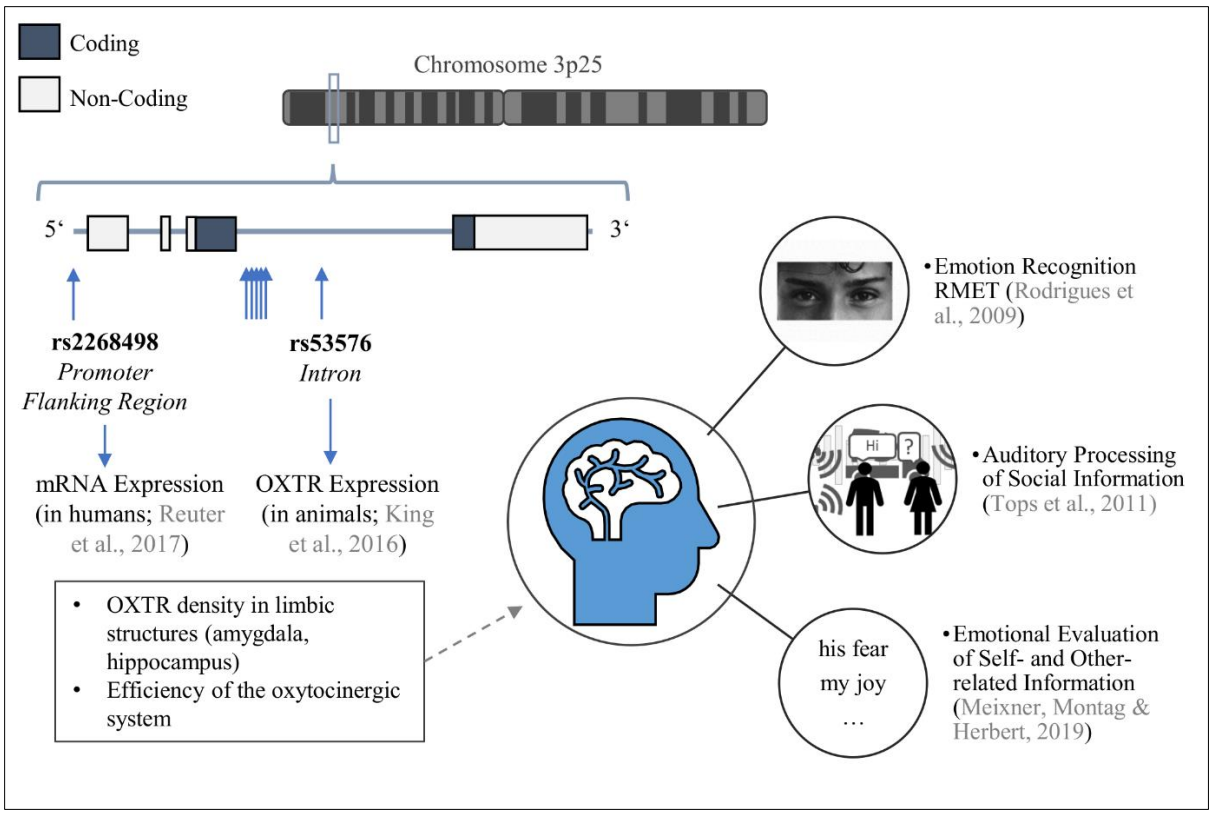
Another classical method to investigate the biopsychological perspective on affective experiences is the examination of peripheral physiological parameters and their manipulation-dependent changes. Almost all affective experiences are accompanied by physiological changes, as predicted by both Russell’s model (2003) and appraisal theories of Lazarus (1991) or Scherer (Grandjean & Scherer, 2008; Sander et al., 2008; Scherer, 2001). Therefore, besides hormonal or genetic correlates of behaviour, acute cardiovascular correlates to affective experience can grant objective insight into psychophysiological processes associated with stimulus appraisal. In the following section, a perspective on genetic influences on stimulus processing is presented, followed by an overview of cardiovascular changes towards affective experiences.

1.6.1 Genetic Influences on the Processing of Self- and Other-Related Emotional Stimuli

Research on behavioural neurogenetics has led to an increased understanding of human information processing in the last decades. It could be shown how specific single nucleotide polymorphisms (SNPs), such as the rs53576 or rs2268498 of the oxytocin receptor gene (OXTR) on the chromosome 3p25, are associated with social information processing (Melchers et al., 2015), emotional information processing (Melchers et al., 2013), and empathic concern (Smith et al., 2014). Although not necessarily a *determining* factor, DNA, and its accompanying influences – albeit modified by epigenetic processes – remain the same throughout our lives. Therefore, evaluating the effects of genetic variations on behaviour might grant insight into the

starting point of personal and behavioural development. In the following section, an attempt to describe the translation from SNPs into behaviour and affective experience is given.

Figure 2. Illustration of a possible pathway from genetic variations (SNPs) on the oxytocin receptor gene (OXTR rs53576, rs2268498) to behavioural outcomes.



Depending on their position on the chromosome, SNPs influence the final gene product. In the case of rs2268498, being located on the promoter flanking region, this means influencing the mRNA expression through regulation of the transcription process, which has previously been demonstrated in humans (Reuter et al., 2017). In contrast, rs53576 is located on an intron, which are usually not transcribed. Actually, the functionality of rs53576 in humans has yet to be proven, but animal studies suggest that SNPs on an intron might also regulate genetic transcription and therefore influence gene expression (King et al., 2016). Depending on the genetic variant, oxytocin receptor expression, i.e. density, might vary in the limbic system, e.g. amygdala or hippocampus (Bakermans-Kranenburg & van IJzendoorn, 2013; Landgraf & Neumann, 2004; MacDonald & MacDonald, 2010). Although receptor density does not equal availability of neurotransmitters, it might still indicate a more efficient oxytocinergic system. And since brain structures such as the amygdala have previously been associated with functionality in social and emotional information processing (e.g. Herbert et al., 2009; Herbert, Herbert, & Pauli, 2011), it seems reasonable to assume that the OXTR expression in this region

might influence the behavioural outcomes in domains of empathy, emotion recognition and affective evaluation (Figure 2; Study I).

1.6.2 Specificity of Cardiovascular Changes towards Affective Experiences

Emotion research has greatly benefitted from efforts to confidently differentiate affective states by means of specific psychophysiological reaction patterns. Kreibig (2010) reviewed multiple studies from the last decades on physiological reactions after affective states have been induced. Depending on the emotion, the overall pattern of physiological changes might be rather specific, but changes in a single physiological parameter might be ambiguous, e.g., elevations in heart rate. These can be associated with multiple affective states, ranging from positive to negative valence, such as anger, anxiety, happiness or surprise (Kreibig, 2010). However, if multiple physiological markers are assessed, affective states might be identified more clearly and discerned from one another.

To illustrate this, the following section covers the general physiological reactions towards any stimuli capable of eliciting an affective experience, e.g., the presence of an arousing, emotional stimulus, a mentally stressful task or challenging physical activity. Obviously, there is a multitude of interconnected physiological reactions related to affective experiences, ranging from endocrinological responses to skin conductance, to cardiovascular, to respiratory short-term adaptations. In this thesis, the focus is placed on acute cardiovascular reactions in relation to affective experiences.

1.6.3 Physiological Reactions Accompanying Appraisal Processes

Given an affective experience with an ensuing action tendency (e.g., approach or withdrawal), i.e., a mental or physical stressor, the autonomous nervous system responds by mobilizing necessary resources to enable appropriate reactions. Depending on the appraisal of the stimulus and/or the situation, this could mean approaching a pleasant stimulus or withdrawing from an unpleasant stimulus. In the terms of Lazarus (1991), this would be the consequence of a secondary appraisal concluding with insufficient resources and a need for action, making the use of coping strategies, such as approach, withdrawal or emotional regulation, necessary. The Component Process Model of Emotion (Grandjean & Scherer, 2008; Sander et al., 2008; Scherer, 2001) summarizes these responses as action tendencies, motor expression and physiological responses, also acknowledging their feedback effects on attention, memory, motivation, reasoning and self-concept, and influence on the re-appraisal of the stimulus.

Regardless of the theoretical model, the autonomous nervous system (ANS) is heavily involved in mobilizing resources to react to a given stimulus.

Generally, the initial reactions to physical versus mental stressors are comparable. At first, the sympathetic nervous system is activated, while the parasympathetic nervous system withdraws its influence to meet possible environmental demands placed on the individual. Central command signals from higher brain structures are signaling the required muscles to accomplish a certain movement (i.e., physical activity such as running, cycling, or instrumental actions such as approach/withdrawal responses), but also elicit a signal cascade to the medullary cardiovascular center. The latter further signals the baroreceptors as well as both branches of the autonomic nervous system, the *sympathicus* and the *parasympathicus*, via the (para-) sympathetic ganglia, to react to the stressor. For example, in the case of sympathetic activation, this mainly leads positive inotropic influences increasing stroke volume, cardiac output and the heart's contractility, as well as vasomotor effects. It is worth mentioning, however, that sympathicus and parasympathicus are intricately intertwined and that there are substantial interactions between their influences. Although there are several end-organ responses which are measurable (e.g. heart rate variability, HRV; or systolic time intervals, STI), and can deliver insight into physiological correlates to affective responses, as well as the balance of the (para-) sympathetic activity, their interconnection impedes an easy interpretation (for a detailed review on cardiovascular regulation during exercise and recovery, see Michael, Graham, & Davis, 2017).

However, there are certain parameters being more specifically influenced by one of these branches, as could be shown in pharmacological blockade studies (Cacioppo et al., 1994). For example, the systolic time interval (STI) of the pre-ejection period (PEP), which is a measure of the heart's contractility and expressed as the time from the beginning of the left ventricular depolarization to the aortic valves' opening, ejecting oxygenated blood, is mainly influenced by sympathetic, but not parasympathetic activity. Other systolic time intervals such as the left-ventricular ejection time (LVET; the time from opening to closing of the aortic valves) or other contractility parameters such as the PEP:LVET ratio have been used to assess sympathetic activity but could be shown to be influenced by parasympathetic activity as well (Cacioppo et al., 1994), making their interpretation questionable. Psychophysiologically, PEP has previously been associated with effortful coping (Kelsey, 2012), heart rate reactivity to stress (Cacioppo, Uchino, & Berntson, 1994) and reactivity to rewarding situations (Richter & Gendolla, 2009).

Other reactions towards stressors, such as changes in heart rate variability (HRV) indices are considered to mainly reflect parasympathetic influences. These indices include but are not limited to time-based parameters such as the Root Mean Square of Successive Differences (RMSSD) or Respiratory Sinus Arrythmia (RSA), or frequency-based parameters such as high-frequency (HF) and low-frequency (LF) components of the power spectrum as well as their normalized units (HFnu, LFnu, or LF/HF ratio). Although widely used to measure sympatho-vagal balance, the interpretation of HFnu, LFnu and LF/HF ratio has been subject to debate recently (e.g., Billman, 2013; Heathers, 2014). However, frequency-based parameters in their raw units (e.g., HF) or time-based parameters, such as the RMSSD, are indicators of the ability of the parasympathicus to regulate the heart as a reaction to the presence or absence of stressors. For a review on HRV and systolic time intervals, see Michael, Graham and Davis (2017). HRV has also been widely associated with self-reported feelings of stress during (socially) challenging situations (Boesch et al., 2014; Lischke et al., 2018; Pulopulos et al., 2018), self-regulatory strength (Geisler et al., 2010; Segerstrom & Nes, 2007), mental health (Beauchaine & Thayer, 2015), as well as fitness level (Buchheit & Gindre, 2006). It is even considered to be a predictor of mortality (Hillebrand et al., 2013; Nolan et al., 1998; Villareal et al., 2002). Figure 3 depicts general cardiovascular reactions towards a given stressor, i.e., sympathetic activation and parasympathetic deactivation, illustrating measurable cardiovascular indices which can aid in identifying objective physiological parameters in correspondence to affective experiences.

Strong reactions of the sympathetic branch of the ANS might therefore be associated with an increased physiological activation, preparing the individual to enact on action tendencies such as approach or withdrawal. As predicted by the biopsychosocial model of challenge and threat, a further differentiation between situations which are either appraised as challenging or threatening (see also the *Transactional Model of Stress and Coping*; Lazarus, 1991) can be made using parameters influenced by vasoconstriction (Blascovich & Mendes, 2010; Tomaka et al., 1997), e.g. cardiac output (CO). Since a metabolically demanding situation such as physical activity usually requires vasodilation to be executed properly, this model is only specified for non-metabolically demanding situations (Blascovich & Mendes, 2010). However, while vasoconstriction might clearly differentiate between challenging and threatening

situations, this effect might still be visible to a lesser extent in situations with physical demands, if they do not require maximum effort from the participants (Study IV).

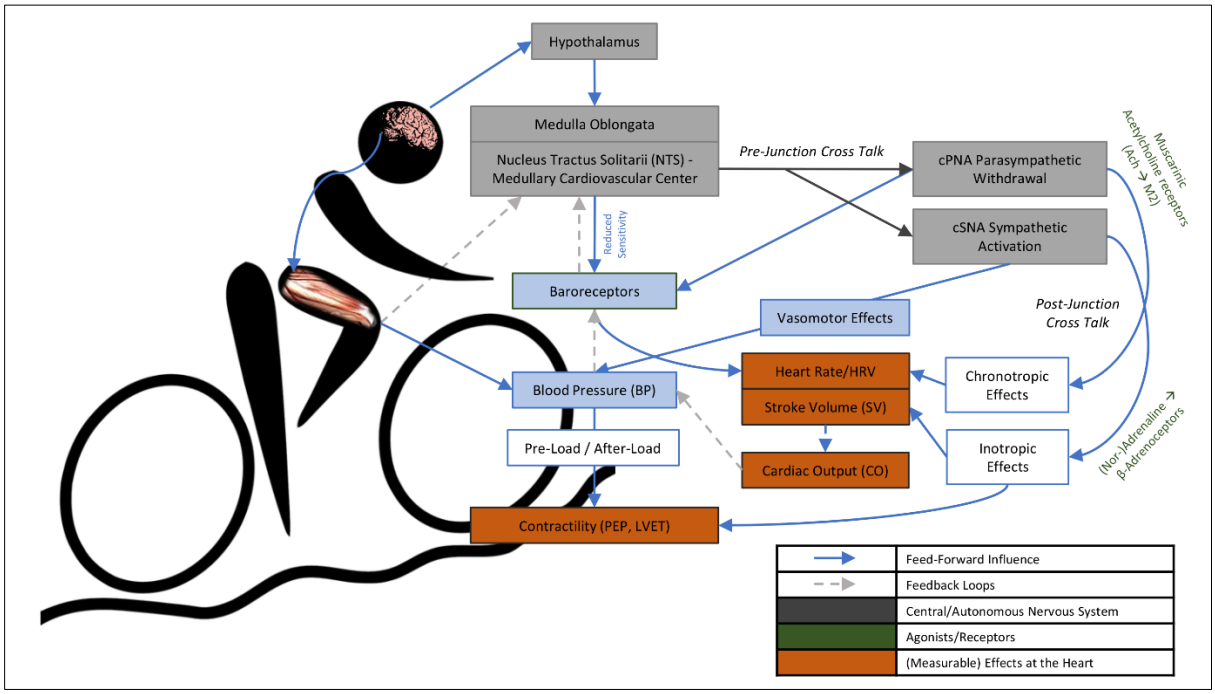


Figure 3. Cardiovascular responses to a given stressor. Structures of the central/autonomous nervous system are depicted, agonists/receptors, and end-organ effects as well as mediating feed-forward and feedback mechanisms.

Impedance cardiography (ICG) as a non-invasive measurement of psychophysiological processes can be used to identify autonomic processes (ANS) in reaction to psychological elements (e.g. Kreibig, 2010; Shiota, Neufeld, Yeung, Moser, & Perea, 2011). It utilizes changes in thoracic impedance which are associated with cardiovascular changes to calculate parameters such as heart rate (HR), heart rate variability (HRV), pre-ejection period (PEP), left-ventricular ejection time (LVET), stroke volume (SV), cardiac output (CO), and respiration rate. These parameters can then be used to examine sympathetically or parasympathetically influenced physiological correlates of affective experiences, as consequences or 'by-products' of stimulus appraisal.

1.7 Physiological Reactions as an Object of Appraisal

Most research on stimulus appraisal is based on the perception of external stimuli, typically from the visual or auditory domain. However, internally, or self-generated stimuli could theoretically also prompt appraisal processes leading to affective experiences.

It must be noted that appraisal theories of emotion and specifically the models described in the beginning of this introduction do not explicitly postulate stimulus appraisal regarding physical symptoms in general, neither as a result of stimulus appraisal nor as a result of voluntary physical activity. Unfortunately, there does not seem to be a model yet explaining appraisal of stimulus input originating from perception, interoception, and proprioception. Rather, concurrent appraisal theories of emotion are focused on the perception (i.e., exteroception) of stimuli, not yet fully integrating concepts of interoceptive or proprioceptive awareness.

Aside from classical viewpoints, e.g., the James-Lange theory of emotion, physiological reactions are usually considered accompanying symptoms to affective experiences. However, they are also experienced by the individual, albeit via proprioceptive or interoceptive, instead of perceptive processes. Consequently, these physiological changes might become the *object* (i.e., stimulus input, or antecedent event) of an appraisal process themselves. This might be especially relevant in situations which primarily elicit physiological reactions, e.g., sports or physical activity in general.

The Dual Mode Theory (Ekkekakis, 2003, 2009) postulates that affective responses to exercise are a result of the interaction of cognitive processes (e.g. goals, attributions, self-presentation) and interoceptive inputs from the body, such as feedback from the muscles (i.e. lactate) or the state of ventilation. In some instances, the cognitive process might influence the appraisal of bodily symptoms. For example, physical symptoms such as lack of breath and a burning sensation in the muscles might be interpreted as negative shortly before the end of an important race. In a training context, however, these symptoms might be appraised as something desirable, since they signal training with a high workload, promising increased performance, as well as chances of winning a race in the long run (see also Lazarus, 1991). Therefore, physical stimuli are, to some extent, comparable to other types of stimulus input (e.g. verbal, or auditory stimuli) and the way they are being processed according to the CPM (Grandjean & Scherer, 2008; Scherer, 2001, see also Figure 1), particularly in the later stages of stimulus appraisal, which is compatible to the Dual Mode Theory (Ekkekakis, 2003, 2009). Early stages of stimulus appraisal, however, are not comparably described. Yet, appraisal of physical symptoms also bears some resemblance to early appraisal stages as postulated by the CPM, even though the specific pathways of interoceptive and exteroceptive input might be considerably different (Craig, 2002). For example, intense physical sensations could be shown to capture attention to a degree where it is difficult or even impossible to focus on anything else (e.g. Hutchinson & Tenenbaum, 2007). Furthermore, physical sensations can also be considered highly self-relevant, since stimuli such as burning, painful muscles, elevated heart rate and shortness of

breath might be signals of something dangerous to avoid, e.g., injury during overexertion. Physical stimuli are also differently appraised in post-exercise memory, depending on attention (Cioffi & Holloway, 1993) or pleasantness (Zenko et al., 2016). Equally, they might be differently appraised depending on the *memory* of previous experiences (Cioffi & Holloway, 1993). They can further influence *motivational processes* to cope with the task at hand (i.e., aborting a race due to feelings of excessive fatigue or pain). They can also have an influence on *reasoning*, i.e., in the face of imminent injury, inferred from proprioceptive or interoceptive processes. And, finally, they might also have a *normative significance*, e.g. if a display of fatigue or pain is considered to be shameful or threatening to one's reputation (see also Ekkekakis, 2003, 2009). Physiologically, this might be evident in a decreasing cardiac output (CO) due to the increased vasoconstriction associated with negative, stressful experiences. In the end, this appraisal process might lead to *instrumental actions*, such as withdrawal from the activity, returning into a zone of manageable intensity, where muscle pain is not dominant anymore, or an increased effort to manage a given, physical task. Therefore, the perception and appraisal process of physical sensations, e.g., during exercise, might be considered comparable to classical views of stimulus appraisal.

Research in sports psychology often utilizes attentional focus in (quasi-) experimental designs to investigate the effects of an increased focus on the self, or an increased focus on the environment or other factors on participants behaviour and affective experience. This research has brought forth many insights into the relationship of attentional focus and performance (movement economy, e.g. in golfers, runners, and cyclists; Hill, Schücker, Hagemann, & Strauß, 2017; Pelleck & Passmore, 2017; Schücker et al., 2016; Schücker, Schmeing, & Hagemann, 2016), and affective experiences during and after exercise, such as feelings of joy, energization or tranquillity versus feelings of fear, anxiety or excessive fatigue (Brick et al., 2014; Lind et al., 2009). Interestingly, this means that physical activity seems to be capable of changing people's *core affect* on both axes of the circumplex model of affect, valence, and arousal. Positive feelings, as well as negative feelings might be induced, both ranging from high- (e.g., threat or performance-anxiety vs. invigoration) to low-arousing feelings (e.g., fatigue vs. tranquillity after the physical activity), depending on factor such as intensity, attentional focus, mode of exercising or the environment.

Physical activity is therefore an ideal method, close to everyday life, to induce various affective experiences, varying on both dimensions of the circumplex model of affect, valence, and arousal. Additionally, physiological responses to physical activity are well-documented.

Measuring the accompanying physiological changes depending on the situation or the attentional focus, it could therefore be analysed if and how cardiovascular reactivity to physical activity adapts when the affective experience of the activity changes, e.g., by manipulating attention towards internal or external stimuli.

However, monitoring and controlling the intensity of the activity is also critical in an experimental design: Physical activity at moderate intensity endogenously generates perceivable physical sensations, which can be attended to, but do not demand full attentional focus. Compared to highly intense activities, moderate intensity presumably creates freedom in the appraisal of physical sensations, since their appraisal is not limited to being something hazardous, e.g., pain during high-intensity training.

1.8 Aims and Outline of the Present Thesis

The present thesis has been pursued with the aim of investigating multiple factors influencing or being associated with affective experiences. An affective experience is not only evident in subjective measures assessing positive or negative affect, but also in the resulting judgment of a present stimulus' affective quality, i.e., emotional evaluation. To acknowledge the interaction of self- vs. other-related information and emotional content while maintaining a) a strong experimental approach and b) comparability across studies, the His-Mine paradigm (Herbert, DFG HE5880/3-1; Blume & Herbert, 2014; Herbert, Herbert, Ethofer, et al., 2011; Herbert et al., 2018; Herbert, Pauli, & Herbert, 2011; Weis & Herbert, 2017; Winter et al., 2015, 2018), i.e., an established paradigm measuring emotional evaluation of verbal stimuli varying in valence and self-reference via reaction times and valence-congruency of responses, has been repeatedly employed (Study I-III). To provide a consistent narrative, ranging from the longest-term to short-term influences, the studies are presented in the following sequence: Firstly, genetic variations on the OXTR gene have been investigated to identify long-time stable influential factors on stimulus appraisal (Study I). Secondly, romantic relationships as self-chosen, long-term factors have been examined for their possible associations with self- and other-related affective evaluation (Study II). Lastly, acute physical activity as a short-term influence on affective experiences and ensuing affective evaluation has been studied with respect to different attentional focus instructions (internal vs. external; Study III), with an emphasis on the interplay of affective and physiological reactions (Study IV).

2 Summary of the Present Studies

2.1 Affective Language, Interpretation Bias and its Molecular Genetic Variations: Exploring the Relationship between Genetic Variations of the OXTR Gene (rs53576, rs2268498) and the Emotional Evaluation of Words Related to the Self or the Other.

Study I: Meixner, Montag, & Herbert (2019)

In behavioral neurogenetics, two well-studied SNPs related to interpersonal information processing are the OXTR rs53576 and the OXTR rs2268498. Both have been associated with proficiency in interpersonal information processing, e.g., in the reading-the-mind-in-the-eyes task (RMET; Rodrigues, Saslow, Garcia, John, & Keltner, 2009). It has been proposed that their influence on behavior might be exerted via different oxytocin receptor densities, e.g., in limbic brain structures such as the amygdala or the hippocampus (see also Figure 2). Regarding the SNP rs53576, GG carriers are usually associated with more proficient processing of interpersonal information, compared to A+ carriers. Comparably, participants with the TT variant of the rs2268498 SNP could also be shown to exhibit advantageous outcomes in interpersonal information processing, compared to C+ carriers (Melchers et al., 2013, 2015; Walter et al., 2012). This study has been conducted to identify associations between genetic variations on the OXTR gene with emotional evaluation of words with self-, other- or no reference. It has been the first experimental approach to investigate how verbal, emotional stimuli are appraised, depending on the stimulus reference and participants' genotype.

N=149 healthy participants have been recruited, completing the His-Mine paradigm (Blume & Herbert, 2014; Herbert, Herbert, Ethofer, et al., 2011; Herbert et al., 2018; Herbert, Pauli, et al., 2011; Meixner & Herbert, 2018; Weis & Herbert, 2017; Winter et al., 2015, 2018), in which participants were presented 180 pronoun-noun combinations of positive, negative and neutral valence, varying in personal reference. Regarding rs53576, results indicated a tendentially less positive interpretation bias for neutral stimuli in A+ carriers compared to GG carriers, especially if presented with other-reference or without any reference. Regarding rs2268498, C+ carriers compared to TT carriers also exhibited a less positive interpretation bias in the evaluation of neutral stimuli, most pronounced in the categories of self-referenced stimuli and stimuli without personal reference. The self-positivity bias, however, was unaffected by participants' genotype. The results support an association of genetic variations on the OXTR gene (rs53576,

rs2268498) and the evaluation of neutral, ambiguous words, depending on their self- or other-reference.

2.2 Whose Emotion Is It? Measuring Self-Other Discrimination in Romantic Relationships during an Emotional Evaluation Paradigm.

Study II: Meixner & Herbert (2018)

The association of long-term factors, such as interpersonal relationships, and affective experiences, has been examined in a quasi-experimental study. Participants in a romantic relationship were compared to single participants, regarding their emotional evaluation of self- and other-related words in the His-Mine paradigm (Blume & Herbert, 2014; Herbert, Herbert, Ethofer, et al., 2011; Herbert et al., 2018; Herbert, Pauli, et al., 2011; Weis & Herbert, 2017; Winter et al., 2015, 2018). Participants in romantic relationships were neither married, nor engaged nor had any children, and were in these relationships for M = 26.8 months (SD = 19.64).

Results indicated that in a romantic relationship, other-related positive stimuli are processed more often in an accurate, valence-congruent fashion compared to single participants. This indicates a reduced self-positivity bias in the number of valence-congruent answers, but not at the cost of longer reaction times. However, the self-positivity bias has not been eliminated in participants in a romantic relationship. The results extend previous findings of partner-related stimuli being processed comparably to self-related stimuli in a romantic relationship: Even in the absence of explicit partner-related instructions, participants did evaluate positive, other-related stimuli more often in a valence-congruent fashion and therefore comparably to positive, self-related stimuli. This suggests a generalized effect beyond the self-expansion predicted by the model of Aron et al. (1991; 2004). Analyses beyond the scope of the published paper of Study II (Meixner & Herbert, 2018), further confirmed an interpretation bias (see also Meixner et al., 2019; Study I) for participants in a romantic relationship: When in a relationship, participants evaluated neutral words referencing an unknown other, more often as positive, compared to single participants. Furthermore, the effects of a romantic relationship on the evaluation of other-related positive stimuli were not moderated by relationship duration, nor by self-reported intrusive thinking. This suggests an effect of romantic relationships irrespective of the progression of a long-term relationship, on emotional evaluation of positive, other-related information.

2.3 Acute aerobic exercise and attentional focus influence the self-positivity bias in emotional evaluation. Evidence from an experimental study.

Study III: Meixner & Herbert (2022)

Physical activity is widely regarded as an effective means to increase positive mood (Penedo & Dahn, 2005; Szabo, 2003; Yeung, 1996), and alleviate symptoms of affective disorders, such as major depressive disorder or anxiety disorders (Anderson & Shivakumar, 2013; Blake, 2012; Dunn, Trivedi, & O'Neal, 2001; Mammen & Faulkner, 2013; Paluska & Schwenk, 2000; Stanton & Reaburn, 2014; Ströhle, 2009; Woll & Bös, 2004). Besides other conditions of physical activity, attentional focus has been suggested as a substantial influence on perceived exertion and resulting affect (Blanchard et al., 2004; LaCaille et al., 2004). Although many studies have employed experimental manipulations of attentional focus in the past, there has been some criticism based on the adherence to attentional focus instructions (for recent reviews see Brick, MacIntyre, & Campbell, 2014; Lind, Welch, & Ekkekakis, 2009). This non-adherence might be related to the (un-)pleasantness or the added mental demands of an attentional focus. It has been hypothesized that the direction of the attentional focus during physical activity (e.g., focus on internal versus external stimuli) influences the self-specificity of the affective experience caused by the activity, and consequently emotional evaluation of self-related words in the His-Mine paradigm.

N=30 female, novice participants (i.e., not regularly engaged in performance sports, nor preparing for a sports competition). The experiment has been realized as a repeated-measures, within-subject design, with each participant completing all four conditions: In one session, an internal, task-relevant focus has been instructed, other sessions included an external, task-irrelevant focus and aerobic exercise without any attentional focus instructions, and a physically inactive control condition. To ensure and allow deliberate shifts of attentional focus, intensity has been kept moderate (60-70% of participants' maximal heart rate), and attentional focus instructions have been verbally reinforced every 30 seconds.

Results gave limited support to the hypothesis: It could be shown that instructing any attentional focus seems to be a fatiguing and demanding task, which was evident in significantly longer reaction times after physical activity with any attentional focus instructions. Instructed attentional focus did not influence subsequent emotional evaluation of self- or other-related stimuli in the His-Mine paradigm, neither in reaction times nor in number of valence-congruent answers. However, participants' self-reported attentional focus was associated with the self-

positivity bias, e.g., the more participants focused internally (internal-irrelevant focus of attention, e.g., daydreaming), the greater was the difference in valence-congruent evaluations of positive, self-related, versus positive, other-related stimuli. Conversely, the more participants focused externally (external-irrelevant focus of attention, e.g., changes in brightness, scenery, environment), the smaller the difference between valence-congruent evaluations of positive, self-related, versus positive, other-related stimuli. The presented results demonstrate the acute effects of attentional focusing on internal versus external stimuli on affective experience and the subsequent evaluation of self- and non-self-related emotional stimuli.

2.4 Does Attentional Focus Influence Psychophysiological Responses to an Acute Bout of Exercise? Evidence From an Experimental Study Using a Repeated-Measures Design.

Study IV: Meixner & Herbert (2021)

In this study, the effect of attentional focus on positive and negative affect, subjective exertion and accompanying psychophysiological changes were studied. This study has been done in combination with the previously described Study III, i.e., design, experimental manipulations, and sample were identical, but the following analyses regarding psychophysiological data differed in objective, research questions, analytic methods, and conclusions from the previously mentioned study. Impedance cardiography (ICG) has been employed as a non-invasive measurement of cardiovascular changes during/after aerobic exercise with different types of attentional focus. Each experimental session included a passive baseline measurement of psychophysiological parameters. Additionally, each participant completed an inactive control condition.

It has been hypothesized that an unfavorable attentional focus leading to more negative affect and perceived exertion (i.e., internal-relevant, e.g., Blanchard et al., 2004; LaCaille et al., 2004) might also be associated with an increased sympathetic activation during the activity. It has also been proposed that the additional demands of a second, unfamiliar task, i.e., attentional focusing for novices, resembles a psychophysiological burden for the participants which would be evident in self-report measures but also in an increased sympathetic reactivity and later parasympathetic reactivation after the exercise.

Results indicated that instructed attentional focus did not influence the sympathetic or parasympathetic (re-) activation. Explorative analyses, however, hinted at associations between participants' self-reported internal-irrelevant attentional focus (e.g., daydreaming) and self-

reported exertion, as well as cardiovascular markers such as PEP. Interestingly, self-report data from these analyses pointed towards less subjective exertion with increasing internal attentional focus, whereas physiological data showed higher sympathetic activation (e.g., PEP and HR recovery). Taken together, during aerobic exercise of comparable intensity and comparable stimulus inputs (i.e., environment, force production), attention towards internal vs. external sources of stimuli could potentially lead to altered psychophysiological reactions. In terms of appraisal processes, this suggests that simply directing attention internally or externally – without any instruction to re-appraise physical sensations – can not only modify affective, but possibly even cardiovascular responses in the exercising person.

3 Discussion and Future Directions

In this thesis, four experimental studies have been described, illustrating influences on, and associations with affective experience. Genetic variations, as a stable, long-term factor could be associated with interpretation biases in the emotional evaluation of neutral stimuli, depending on self- or non-self-reference (Meixner et al., 2019; Study I). Living in a romantic relationship as a self-chosen, but enduring long-term factor has been associated with increased valence-congruent responses towards other-related positive stimuli, compared to single participants (Meixner & Herbert, 2018; Study II). Acute aerobic exercise with different attentional focus as a short-term factor was associated with changes in affect, perceived exertion, emotional evaluation and psychophysiological reactions, which were, however, independent of instructed attentional focus, but rather influenced by actual attentional focus (Meixner & Herbert, 2021, 2022; Study III, Study IV).

Initially, appraisal has been introduced as a key factor in determining the affective experience resulting from any stimulus encounter. It has been proposed that the construct of the self is underrepresented in the appraisal theories of emotion, given its importance to the experience of affect. The presented experiments aimed at extending previous knowledge on stimulus appraisal and particularly its relationship to the processing of self- vs. other-related information. Further, utilizing physical activity, it has been investigated if emotional evaluation is also affected by a prolonged attentional focus on internal compared to external stimuli during aerobic exercise. Lastly, psychophysiological markers during and after a mood-affecting activity, i.e., aerobic exercise, have been assessed via impedance cardiography to measure physiological correlates of affective experiences, as well as the effects of attentional focusing on cardiovascular reactivity to a physical stressor.

3.1 Genetic Markers Associated with an Interpretation Bias in Emotional Evaluation

The first study, associating genetic variations with an interpretation bias, has been a first step in understanding the extent to which OXTR SNPs might influence evaluation of verbal, self- and other-related stimuli. Depending on their personal reference, neutral words grant interpretative freedom regarding their affective quality, which was evident in a less positive interpretation bias for certain allele carriers (rs53576-A+, rs2268498-C+). However, some things need to be considered when interpreting these findings: Applying an interpretation bias to a neutral stimulus took participants generally longer compared to valence-congruent answers. Because of this incomparability, attribution of the found effects might be difficult. Apparently,

evaluating a neutral word as positive or negative requires more or simply longer processes compared to valence-congruent judgments. This might even include complete loops of re-appraisal: While some participants might have appraised a stimulus intuitively and, following instructions, based on their gut feelings, other participants might have ignored their initial affective response, i.e., not translating it into behavioral outcomes such as the necessary button press. Instead, they might (re-)appraise the stimulus in an elaborate, possibly more cognitive fashion before deciding on his/her evaluation of the stimulus' affective quality. Future experiments restricting response windows might grant additional insight if the effects of genetic variations on interpretation biases persist in conditions where reaction times are controlled across categories and participants.

It should also be noted that an interpretation bias has usually been researched in psychiatric disorders, such as depression or anxiety (Amin et al., 1998; Amir et al., 2005; Berna et al., 2011; Huppert et al., 2003; Moser et al., 2012; Wisco & Nolen-Hoeksema, 2010). It might therefore be enlightening to replicate the findings in a sample suffering from depressive or anxiety disorders. Interestingly, there have also been some findings associating genetic variations on the rs53576 with increased depression scores (Saphire-Bernstein et al., 2011) and reduced positive affect (males only; Lucht et al., 2009), which would be in line with an expected association between rs53576, depressive symptomatology and a negative interpretation bias. Regarding causation, it might be argued that a negative interpretation bias is not only a symptom of depressive disorders but could also be a vulnerability factor, as has been suggested in Beck's cognitive theory of depression (Beck, 1967).

3.2 Romantic Love as an Influence on the Appraisal of Self- and Other-Related Stimuli

In the second presented study, relationship status could be associated with different emotional evaluation of self- and other-related stimuli. While the self-positivity bias seems to be largely unrelated to relationship status, positive other-related stimuli are evaluated more often as valence-congruent by participants currently living in a romantic relationship compared to single participants.

It could be argued that the analysis and results of Study I contradict the interpretation of Study II, since what is being considered the measured or 'desirable' response in Study I has been considered valence-incongruent and therefore similar to an 'error' in Study II. However, the His-Mine paradigm allows for all these interpretations at the same time. Comparable to Study II, an altered evaluation of other-related stimuli is also hypothesized in Study I, depending on

genotype, but only the hypothesis regarding the interpretation bias was supported by the data. The equivalency of the interpretation of valence-congruent and -incongruent responses is also reflected by the instructions of the His-Mine paradigm: participants are explicitly instructed to base their responses on their gut feelings, and that there are no right or wrong answers, i.e., they are not explicitly told to give only valence-congruent answers. Therefore, the response format of the His-Mine paradigm prevents the application of elaborate models integrating response accuracy and reaction times, such as the diffusion model (Ratcliff & McKoon, 2008) or its variant, the EZ diffusion model (Wagenmakers et al., 2007), since responses in the His-Mine paradigm cannot be dichotomized into correct or incorrect without losing valuable information on the appraisal process outside of the stimulus' obvious properties.

It might be argued that the reported effects of Study II do not specifically support the self-expansion model by Aron et al. (1991; 2004), since the task instructed to think about a virtual third person, and not the romantic partner. The self-expansion model does not explicitly propose any generalizing effects of the self-expansion towards unrelated third persons. This would change the interpretation from a self-expansion encompassing the other person to an interpretation of the self-other boundaries becoming blurred in general. While this might be true, an open question at the end of the experiment revealed that participants - although instructed otherwise – did indeed think about their partner (Meixner & Herbert, 2018). This is indicative of the intrusive nature of partner-related cognitions in a romantic relationship (Fisher, 2004). However, the word 'relationship' was included in the title of the study, and therefore visible in the informed consent and in the advertisements. To test the robustness of the effects, the study has been replicated specifically without any wording, information, or any behavior that would suggest romantic relationships to be the topic of the experiment. In a sample of N=122 participants, the effects were in line with the reported findings and there was still a significant amount of intrusive thinking (Meixner & Herbert, in preparation). Conversely, explicitly instructing participants to think about their partner or a close friend (Meixner & Herbert, in preparation) also led to increased valence-congruent responding to other-related, positive stimuli. The latter provides stronger support for the self-expansion model, but the published Study II suggests an effect on other-related positive stimuli in general.

If intrusive thinking is another factor to consider, then relationship duration might also be an important influence, since intrusive thinking as a facet of *mania* (i.e., obsessive thoughts and behaviors regarding the partner; Lee, 1977) seems to be associated with relationship duration: Research from Acevedo & Aron (2009) suggested that the seeming decline in passionate feelings over the course of a romantic relationship might simply be due to its measurement.

According to the authors, the usually employed instruments assessing passionate love also measure mania. Since mania is declining with increased duration of a relationship due to increased intimacy, subjective security, and feelings of companionship, this might explain the apparent decline in passionate love scale scores over the course of a relationship. Although relationship duration has not been identified as a moderating factor in the presented Study II – relationship duration ranged from one month to seven years – further studies might examine longer relationships, i.e., couples that have been in a relationship for more than 10, or 20 years. Additionally, different qualities of a relationship, as might be caused by marriage or children, might be taken into consideration to further elaborate the long-term influences of romantic relationships on the appraisal of self- and other-related information.

It also needs to be acknowledged that the reported Study II has been quasi-experimental in nature. Clear causation can therefore not be inferred from the findings. While it might be possible that other-related, positive stimuli are evaluated differently after entering a romantic relationship, participants with more valence-congruent evaluations of positive, other-related stimuli might also get into and maintain a romantic relationship more easily, since this evaluation pattern could translate into actual behavior, e.g., being emotionally more responsive towards information concerning the partner. This, in turn could be appreciated by the respective other, possibly increasing the probability of the couple staying together. Future studies could therefore conduct longitudinal examinations of emotional evaluation, passionate love, and processes of entering (and leaving) romantic relationships. Additionally, including OXTR SNPs such as rs53576 or rs2268498 could be included to monitor genotype-dependent changes in emotional evaluations or relationship status over time, since a more ‘efficient’ OXTR polymorphism and therefore favorable oxytocinergic system might influence relationship behavior in general, as oxytocin has also been classified as the ‘love hormone’ (Bakermans-Kranenburg & van IJzendoorn, 2013; Kumsta & Heinrichs, 2013; MacDonald & MacDonald, 2010). However, re-analyzing data from Study I (Meixner et al., 2019), it was evident that neither relationship status, nor Passionate Love Scale (PLS) scores, were associated with the examined SNPs.

3.3 Physical Activity, Attentional Focus and Emotional Evaluation

Physical activity, as a possible affective experience, has been examined regarding its effect on subsequent emotional evaluation. While instructed attentional focus did not influence perceived exertion, affect and emotional evaluation, self-reported attentional focus has been associated with these parameters. However, focusing on internal-irrelevant stimuli conceptually contains

exemplary items as daydreaming, solving math problems or imagining music. The self-report measure used in this study also listed these as examples. Therefore, 'internal-relevant stimuli' cannot be considered a homogenous category: daydreaming is an extensive term and might even be considered similar to mind-wandering, a state that has been considered the default mode of functioning in humans and highly associated with a sense of self (Davey et al., 2016; Raichle et al., 2001; Scheibner et al., 2017). Math problems, on the other hand obviously resemble a second task, whereas imagining music can theoretically contain anything from melancholy to joyous, upbeat songs, possibly influencing mood and physical performance (Boutcher & Trenske, 1990; Moss et al., 2018). If future studies repeat the reported experiment in a comparable design, it might be fruitful to experimentally manipulate attentional focus to be directed towards internal-irrelevant stimuli, possibly even directly comparing those three categories.

Furthermore, it cannot be excluded that there is an effect of disobedience. Theoretically, participants receive an instruction to focus on something which is expected to be uncomfortable for them, e.g., muscle sensations. Therefore, they might simply focus on something more beneficial to them, i.e., they employ a distracting strategy. However, since attentional focus has been reinforced every 30 seconds, attention has always been dragged back to the object of the instruction. It is possible that the effects associated with the actual attentional focus during the activity are either due to task disobedience or rapid switching between instructed and preferred focus of attention. Future quasi-experimental studies could help to entangle these associations by explicitly pre-selecting participants with certain habitual attentional focus styles, refraining from instructing a specific attentional focus which might be unfamiliar or uncomfortable for the participant. Alternatively, it might be sensible to assess actual attentional focus as standard procedure in research on attention in physical activity. This could either be realized via self-report after the activity (Wininger & Gieske, 2010) or explicitly asking participants during the activity about the direction of their attentional focus (e.g., Hutchinson & Tenenbaum, 2007).

Moreover, a stronger conceptual integration of attention research coming from cognitive psychology and sports psychology is critical to evaluate effects of attentional tasks during physical activity. For example, the employed taxonomy with dimensions of task-relevance and location (internal-external) can also be criticized: To name one example, one does not strictly need to monitor his/her muscle sensations to successfully cycle on a bicycle ergometer, but it would still be classified as an internal, task-relevant focus of attention. This serves to illustrate the different conceptions of 'task-relevance' between disciplines (see also the Introduction to

Study III). Concepts from cognitive psychology, such as vigilance or task-switching might aid in describing the specifics of an attentional focus with greater precision, to ultimately gain an accurate estimate of the difficulty of these attentional focus tasks. With that in mind and as a first step, the presented design could be enhanced by implementing additional conditions without physical activity, but with specific attentional focus instructions, to assess the isolated difficulty of the attentional focus tasks during inactivity.

3.4 Physical Activity, Attentional Focus and (Appraisal of) Physiological Reactions

Following up on the proposal described in the introduction, physical activity might be considered an internal source of stimuli which can be theoretically appraised akin to external stimuli such as words or pictures. Physiological changes required for physical activity lead to experienceable changes, such as an increased heart rate, breathing, muscle tension due to increased blood flow, sweating and overall exertion. Previous models have already suggested the idea that physiological changes are also stimuli being subject to an appraisal process (e.g. dual mode theory; Ekkekakis, 2003, 2009). The outcome of this appraisal process might then determine if the physical activity is being interpreted negatively, i.e., exhausting, painful or even harmful, or positively, i.e., refreshing and invigorating.

Therefore, while physical sensations might be considered comparable to verbal stimuli in that sense, there is also a major difference. In verbal processing, stimulus properties such as semantic content, contrast, font size, or word length are entirely in the hands of the experimenter. During physical activity, however, the physical stimuli in question emerge from the individual itself and therefore, their qualities potentially differ remarkably across participants. Therefore, contemporary research is mostly restricted to (quasi-)experimental settings, measuring self-report data about physical sensations, and analyzing their relationship to parameters of interest – cost-effective, non-invasive possibilities to induce a generally comparable physical sensation in two individuals are not readily available. A promising, experimental possibility lies, however, in direct (para-) sympathetic activation, e.g., in pharmacological blockade studies, or in electronic exercise equipment, giving direct feedback and thus approximating comparable exercise execution.

Additionally, interindividual differences in interoceptive abilities might also influence the way physical sensations are perceived and subsequently appraised. Maintaining an attentional focus towards internal-relevant symptoms, such as force production of the quad muscles (e.g., Schücker et al., 2016) might not be equivalent to being aware of it. Interoception grants access

to bodily information and might be – comparable to intact visual/auditory systems being needed for corresponding perception – a prerequisite to being able to focus attention on sensations originating from the body. This might especially be relevant in the internal focus condition, where participants were asked to focus on their own bodily sensations. In Study III/IV, this aspect has been acknowledged by assessing self-reported interoceptive awareness with the MAIA scale (Mehling et al., 2012). Results demonstrated that self-reported interoceptive abilities were not associated with the adherence to the instructed attentional focus in the respective experimental conditions. Nonetheless, future studies might implement other established measures of interoceptive abilities not relying on self-report data, such as the heartbeat detection task (see also Hill et al., 2017). Extending the idea of a possible influence of interoceptive abilities, other personality factors might also aid in the uncovering of the mechanisms of appraisal. Comparable to the interpretation bias demonstrated in psychiatric disorders, such as depression or anxiety, personality factors such as self-consciousness or reinforcement sensitivity might influence perception, appraisal and reporting of physical symptoms, as has previously been suggested (Hall et al., 2005; Pennebaker & Skelton, 1978).

Unfortunately, appraisal processes are hard to directly observe. Like the amount of intrusive thinking in romantic relationships, it is also difficult to directly measure appraisal of bodily symptoms. Emotional evaluation or self-reported affect as a result of physical activity deliver subjective estimates on how participants feel regarding a specific stimulus, and in general. However, investigating all stimulus evaluation checks leading up to this experience, i.e., attention allocation, memory, relevance, or pleasantness detection (see Figure 1; Grandjean & Scherer, 2008; Sander, Scherer, & Grandjean, 2008; Scherer, 2001) in a single experimental attempt would require significant experimental complexity and additional equipment, such as eye tracking or electroencephalography. Additionally, some stimulus evaluation checks might even remain undisclosed to the participant itself, thus being unavailable via self-report instruments. Therefore, the presented findings regarding affective experiences and psychophysiological reactions need to be considered *not* as direct measures of, but rather as *results* of stimulus appraisal.

Interestingly, the OXTR polymorphism might also be linked to cardiovascular control in physical activity. It could be shown in an animal study that the Nucleus Tractus Solitarii, the cardiovascular command center signaling for cardiovascular adaptation is also very dense in oxytocin receptors (Vela et al., 2010). Oxytocin can also directly influence the reactions to physical activity by influencing blood pressure as well as the cortisol response to the physical

stressor (Cardoso et al., 2013), which could possibly explain why it is so popular to exercise with one's romantic partner.

3.5 Gender Effects and Stimulus Reference

In the His-Mine paradigm employed in Studies I and II, only the masculine pronoun 'his' has been used in stimulus presentation. In the German language 'her' ('ihr/ihre') is easily mistaken for 'your' (second person singular; polite address 'Ihr/Ihre'). Since the article-noun combinations ('der/die/das') have been extensively evaluated in previous research and Study I and II, Study III/IV employed female pronouns instead of articles as a stimulus category. It could be shown that female or male pronouns do not systematically alter response behavior in the His-Mine paradigm. It must be noted, however, that gender was not without influence on emotional evaluation: Although unrelated to the reported effects or the self-positivity bias in the presented studies, female and male participants did react differently to positive/negative and female/male pronoun-noun combinations (see Study II; Meixner & Herbert, 2018).

3.6 Conclusion

Taken together, the presented studies' findings demonstrate multiple contributing factors of affective experience. Firstly, molecular genetic markers could be associated with an interpretation bias in the appraisal of self- and other-related words. Secondly, romantic love proved to be associated with an altered processing of other-related stimuli, possibly indicating a substantial change in the self and its boundaries upon entering a romantic relationship. Lastly, physical activity with specific attentional focus did influence the self-positivity bias depending on the direction attention has been focused during the activity. All in all, it can be stated that the attention and thought contents during a task influence the appraisal of stimuli at hand. On one level, the focal object influences affective responses, and on a second level, the object of focus influences the appraisal of other present stimuli. Regardless of whether this might be the romantic partner during the His-Mine paradigm, or the attentional focus during the physical activity fluctuating, or intrusively entering consciousness during aerobic exercise. The presented experiments could increase our understanding of influences on affective experiences and appraisal processes, but there are still many mechanisms and effects to discover. Future studies could follow up on the discovered results by varying stimulus material, experimental manipulations, and the assessment of additional physiological parameters. In the long run, an integrated view on the appraisal of external and internal stimuli, and its influential factors, might be gained. In turn, this could soon be leading us to unified theoretical models with predictive

qualities across multiple situations and stimulus types. In other words – it would enable us to accurately predict affective, behavioral, and physiological reactions regardless of whether it's a phrase such as "We're expecting a child" or a bodily sensation, given the knowledge of selected influential factors. The presented studies of this thesis hopefully proof to be one of many bricks upon which these models are to be built.

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Part II

Original Research Articles

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[1] The authors contributed equally to this article.

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Affective Language, Interpretation Bias and Its Molecular Genetic Variations: Exploring the Relationship Between Genetic Variations of the OXTR Gene (rs53576 and rs2268498) and the Emotional Evaluation of Words Related to the Self or the Other

Friedrich Meixner[1†], Christian Montag[2,3] and Cornelia Herbert[1†]*

[1] Applied Emotion and Motivation Psychology, Institute of Psychology and Education, Ulm University, Ulm, Germany, [2] Molecular Psychology, Institute of Psychology and Education, Ulm University, Ulm, Germany, [3] The Clinical Hospital of Chengdu Brain Science Institute, MOE Key Lab for Neuroinformation, University of Electronic Science and Technology of China, Chengdu, China

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***Correspondence:**
Cornelia Herbert
cornelia.herbert@uni-ulm.de

[†] These authors have contributed equally to this work

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Several studies have demonstrated links between oxytocin and socio-emotional information processing. Regarding the frequently studied single nucleotide polymorphism (SNP) rs53576 and the less studied, functional polymorphism rs2268498 of the oxytocin receptor (OXTR) gene, previous research suggested that their variants might be associated with different proficiency in the processing of social information. Differences between the genotype variants are not restricted to non-verbal stimulus processing but have also been reported in the verbal domain. Moreover, there is evidence that oxytocin expression influences empathic communication and language development during childhood, indicating that language-based theory-of-mind abilities may be affected by interindividual differences in OXTR genotypes as well. The present study therefore investigates whether two prominent SNPs of the OXTR gene (rs53576 GG vs. A+; rs2268498 TT vs. C+) also play a role in the affective evaluation of verbal stimuli varying in emotional valence and in self-other reference. Participants (N = 149 Caucasian participants, 104 females; A+: n = 80, GG: n = 69; C+: n = 98, TT: n = 51) were presented a series of written, self-, other-, and unreferenced words of positive, negative, and neutral valence and asked to affectively evaluate each word pair as positive, negative, or neutral by button press. In line with previous research, reaction times and accuracy (number of valence-congruent responses) showed a self-positivity bias (i.e., preferential processing of self-related positive words), which, however, was unaffected by participants' genotype. Regarding affective

evaluation of neutral words (interpretation bias), A+ carriers displayed a weaker positive interpretation bias compared to GG carriers in the other– and unreferenced stimulus categories. C+ carriers showed a weaker positive interpretation bias than TT carriers in the self-reference condition and in the other-reference condition. These effects were independent from participants' gender. The present results suggest that the OXTR genotype and hence participants' genetic oxytocin sensitivity may cause an interpretation bias in the spontaneous appraisal of neutral words.

Keywords: OXTR, social cognition, language, self, emotional evaluation, rs53576, interpretation bias

INTRODUCTION

Oxytocin is a neuropeptide of the brain. In mammals, oxytocin has been shown to play a role in social bonding, attachment and the formation of interpersonal and maternal relationships. Because of its strong associations with bonding and mating behavior, it has been labeled the "love hormone" (Bakermans-Kranenburg and van IJzendoorn, 2013), which might be an oversimplification, because oxytocin is involved in several processes related to social cognition (Ebstein et al., 2010; MacDonald and MacDonald, 2010; Kumsta and Heinrichs, 2013). Regarding its influence on socioemotional behavior, oxytocin cannot only act peripherally as a hormone, but also centrally as a neuropeptide and neuromodulator. It is mainly synthesized in the central structures of the paraventricular (PVN) and the supraoptical nuclei (SON) of the hypothalamus, projecting to the pituitary gland, from where oxytocin is subsequently released into the bloodstream. Moreover, the PVN has various neural projections to brain areas involved in the processing of social and emotional information such as the amygdala and the hippocampus, i.e., limbic brain structures also possessing a rich number of oxytocin receptors (OXTRs) (Landgraf and Neumann, 2004; MacDonald and MacDonald, 2010; Bakermans-Kranenburg and van IJzendoorn, 2013).

To investigate the effects of oxytocin on human behavior, the following two experimental approaches have been employed most frequently in previous research: (a) measuring or manipulating oxytocin levels by administrating oxytocin intranasally or intravenously to determine its direct impact on human behavior and (b) measuring genetic individual differences in single nucleotide polymorphisms (SNPs) located in the genome on the chromosome 3p25 and related to the coding of the OXTR gene. Basically, SNPs are the most common form of genetic variation in humans.

Regarding intranasal administration of oxytocin, an increase in positive self-attribution in men (Colonnello and Heinrichs, 2014), increased trust (Kosfeld et al., 2005), increased attention to positive social information (Ditzen et al., 2009; Domes et al., 2013), as well as an attenuated neural reactivity in the amygdala and the visual cortex (fusiform gyrus) towards threatening face cues (Kanat et al., 2015) could be shown repeatedly following experimental oxytocin administration. This supports the role of oxytocin in socio-emotional signal and information processing.

Oxytocin and Its Genetic Variations in the Oxytocin Receptor Gene (OXTR rs53576, rs2268498)

Regarding individual differences in the SNPs of the OXTR gene a plethora of studies in humans already reported associations with social behaviors and social information processing. In these studies, two SNPs – rs53576 and rs2268498 – emerged as very promising genetic candidates contributing to individual differences in social information processing. Although located on an intron region of the OXTR gene and therefore not expressed in the final messenger RNA, the SNP rs53576 has been investigated very frequently in previous studies. The SNP rs53576 can occur in three different allele variants called AA, AG, and GG. Regarding the distribution of these three variants in the general population, the literature shows a trend towards higher prevalence of GG carriers, particularly in European-American samples (Kim et al., 2010) in which the distribution of AA, AG, and GG carriers roughly corresponds to percentages of 12% (AA), 38% (AG), and 50% (GG), respectively. While some studies report no differences between different ethnic groups in the occurrence of GG/GA/AA-allele-carriers (e.g., Rodrigues et al., 2009) in Korean, Korean-American and European-American samples (Kim et al., 2010), other studies found the above reported frequency distributions only in European-American samples. Because of the genotype's skewed distribution, the three different variants have been clustered into A+ (AA/AG) and GG carriers in many previous publications. However, a direct influence of these variations (A+ vs. GG) on OXTR functionality has yet to be proven in humans (for animals, see for example King et al., 2016). Nevertheless, from an evolutionary perspective, the different genetic variations in the OXTR gene might have adaptive value for human behavior as well, i.e., in some situations one variant of the genotype might be superior compared to the other genotype variant and vice versa in other situations.

In line with these speculations, previous studies which investigated the relationship between individual variations in the rs53576 genotype and behavior found that A+ carriers score lower on positive affect (male A+ carriers only; Lucht et al., 2009), show lower non-verbal intelligence (Lucht et al., 2009), less support seeking when in distress (Kim et al., 2010), lower dispositional empathy (Rodrigues et al., 2009), higher depression scores (Saphire-Bernstein et al., 2011), increased harm avoidance (females only; Wang et al., 2014), and global

deficits in the processing of social information compared to the GG genotype. For example, Rodrigues et al. (2009) could demonstrate increased scores in the "Reading the Mind in the Eyes" test (RMET) in GG carriers compared to carriers of the A+ genotypes. The RMET is considered to be a reliable measure of accurate emotion recognition. Thus, GG carriers seem to be more accurate in the recognition of emotions expressed by other people. Besides differences in emotion recognition, GG carriers have also been found to show lower physiological and dispositional stress reactivity compared to A+ carriers (Rodrigues et al., 2009) and to be more sensitive towards social exclusion (McQuaid et al., 2015). Again, this implies that GG carriers might be more sensitive in the processing of socio-emotional information compared to A+ carriers. In accord with these findings, other studies (e.g., Smith et al., 2014) reported higher levels of empathic concern and sympathetic arousal, as measured by increased electrodermal activity, in GG carriers as opposed to A+ carriers during the perception of harm dealt to another person. For more complex effects of OXTR rs53576 on empathy please see a recent molecular genetic association study with data from China and Germany (Montag et al., 2017). As with studies employing intranasal administration of oxytocin, some molecular genetic studies dealing with the OXTR gene also report gender-based differences (e.g., Lucht et al., 2009; Wang et al., 2014; Feng et al., 2015). For example, Feng et al. (2015) investigated individual variations in OXTR rs53576 together with intranasal application of oxytocin in a functional imaging study while participants performed a reciprocal cooperation game. The authors report increased activation of the left ventral caudate nucleus in male GG carriers after intranasal oxytocin treatment compared to decreased activation in female carriers, possibly suggesting an inverted U-shape curve of the dose–response relationship between central oxytocin, which is higher in females at baseline levels, and the neural activation in reward-related structures such as the left ventral caudate nucleus following reciprocated cooperation.

Although rs53576 might be one of the most studied OXTR polymorphisms with respect to differences in socio-emotional information processing, recent research also highlights a role of the OXTR rs2268498 polymorphism. In contrast to the rs53576, the SNP rs2268498 is located in the adjacent area of the OXTR gene's promoter region. Genetic variations of both the promoter and exon regions of a gene can exert direct influence on a functional level and by this alter the gene product in terms of different enzyme activity (as observed for the prominent COMT Val158Met polymorphism; see review by Montag et al., 2012) or on receptor density (as has been demonstrated for the DRD2/ANKK1 Taq Ia polymorphism; for a discussion see Comings, 1999). In line with this, in humans genetic variations in the SNP rs2268498 have already proven to be functional (Reuter et al., 2017). The SNP rs2268498 also occurs in three different genotype variations: CC, CT and TT, respectively, and akin to the SNP rs53576, its distribution in the population varies (Caucasian samples showing 20.1% CC, 52.1% CT, and 27.7% TT; Montag et al., 2017). Although the genotype status of the SNPs rs53576 and rs2268498 can covary (e.g., being A+ carrier might also be associated with being C+; Laursen et al., 2014), previous studies investigating variations in both SNPs suggest that their relationship with social behavior may not be mutually interchangeable. Individual variations in rs2268498 have been associated with autism spectrum disorder (Montag et al., 2017), differences in interpersonal perception (Melchers et al., 2015), differences in emotion recognition skills (Melchers et al., 2013) and other social abilities related to perspective taking, such as moral judgment (Walter et al., 2012). Moreover, recent genetic imaging studies found differences in C+ vs. TT carriers in resting state connectivity between amygdala subregions and fusiformis/inferior occipital cortex (Zimmermann et al., 2018), supporting the functional relationship between variations in this SNP in neural pathways critical for automatic processing of socio-emotional information including the processing of verbal emotional content (e.g., Herbert et al., 2009).

Influence of OXTR Polymorphisms on Verbal Affective Information Processing

While many previous genetic studies investigated non-verbal social and affective processing, the above illustrated relations between oxytocin and social behavior on the one hand and oxytocin-related genotype differences and social behavior on the other hand may not be restricted to differences in non-verbal social and affective processing, but could also hold true for linguistic and auditory processing of social and emotional information: for example, in a very recent study (Pfundmair et al., 2016), it could be shown that oxytocin (intranasal application) facilitates the comprehension of affective verbal communication. Regarding OXTR polymorphisms, Tops et al. (2011) analyzed differences between A+ and GG carriers in self-reported difficulties in hearing and understanding others in noisy environments. In line with the previous literature, GG carriers displayed greater efficiency in the processing of interpersonal information compared to carriers of the A+ genotype. Thus, the latter two studies suggest a link between oxytocin or individual variation in OXTR genotypes and social information processing during verbal communication. However, the results of these studies are based solely on questionnaire data, underlining the necessity to employ experimental paradigms that consist of linguistic stimuli to better understand how the processing of social and emotional information particularly related to semantics and language could be influenced by OXTR polymorphisms.

Regarding the interplay between OXTR genotypes and language processing, research on autism spectrum disorder has accumulated some evidence that autism-related difficulties in interpersonal information processing and in theory-of-mind (ToM) abilities – especially in those ToM abilities requiring language comprehension and higher-order cognitive and semantic understanding – can be positively influenced by intranasal/intravenous oxytocin applications (Hollander et al., 2007; Dadds et al., 2014). It has been hypothesized that the amygdala, an OXTR-dense area of the brain, plays an important role in the processing of emotional and social information and in the development of autism spectrum disorders (Baron-Cohen et al., 2000; Janak and Tye, 2015; Herrington et al., 2016).

Moreover, regarding language processing, there is increasing evidence from emotional word processing studies (for an overview, see Herbert et al., 2018a) that in the brain and the body, language is closely linked to emotions and emotional word processing is associated with changes in neural activation of emotional brain structures: for instance, during reading, words of emotional content and of high self-relevance have been found to elicit changes in neural activity in the amygdala, the insula and related emotional brain structures involved in the recognition and evaluation of affective and personally relevant information (e.g., ventromedial prefrontal cortex; Herbert et al., 2009, 2011b).

Verbal Affective Information Processing: Self-Positivity Bias and Positive/Negative Interpretation Bias

In healthy individuals, the processing of neutral and emotional verbal stimuli is indeed already well-documented in a wealth of studies (e.g., see Herbert et al., 2018a, for an overview): in particular, it has been shown that when exposed to verbal stimuli, healthy participants display a bias for self-referenced information (e.g., Esslen et al., 2008; Zhou et al., 2010; Blume and Herbert, 2014) and often also a positivity bias (e.g., Herbert et al., 2008, 2009; Augustine et al., 2011). These observations are well in line with the well-known self-reference effect (Symons and Johnson, 1997) and the observation of self-serving attributional biases in affective processing (Mezulis et al., 2004). Interestingly, when words possess both emotional content and self-reference, processing of self-related emotional words reveals a self-positivity bias on a behavioral and a neural processing level (Fossati et al., 2003; Herbert et al., 2011a; Fields and Kuperberg, 2016; Weis and Herbert, 2017; Meixner and Herbert, 2018). This suggests that the combination between positive emotional valence and self-reference significantly increases the personal relevance of the meaning of a stimulus and consequently enhances the reaction towards it. In other words, when healthy participants are presented a series of emotional and neutral words that are related either to their own self or the self of another person and asked to judge these words in terms of their emotional valence and concomitant feelings, they judge positive words more often as positive and thus as valence-congruent when related to the self as compared to when related to another person. Moreover, they are faster in this decision than in their decisions to self-related neutral or negative words (e.g., Weis and Herbert, 2017; Meixner and Herbert, 2018). Although quite robust, this self-positivity bias can be subject to inter- and intraindividual variations: it can be significantly extended from the first person to the third person in individuals experiencing a romantic relationship (e.g., Meixner and Herbert, 2018; Quintard et al., 2018), whereas in participants with mental disorders, this self-positivity bias may be significantly attenuated, absent or even changed towards a negativity bias (Herbert et al., 2014, 2018b; Winter et al., 2015, 2018). So far, however, one can only speculate how variations in OXTR genotypes might influence these interpretation biases.

Yet a further example for biases in affective evaluation and interpersonal communication is the so-called *interpretation bias*, i.e., the tendency to interpret semantically ambiguous and neutral information in a positive or negative way. So far, the interpretation bias has been studied most frequently in association with depressive symptomatology (Wisco and Nolen-Hoeksema, 2010; Berna et al., 2011) and social anxiety (Amin et al., 1998; Huppert et al., 2003; Amir et al., 2005), showing a strong tendency towards negatively biased evaluation in healthy individuals as well as in patients scoring high on anxiety and depressive disorder. Regarding depressive symptoms, Wisco and Nolen-Hoeksema (2010) found evidence for a negative interpretation bias that is dependent on the specific type of "other" (i.e., an unknown vs. a familiar other person). Since close others might be more integrated in one's self-concept and considering previous findings on behavioral differences related to OXTR genotypes outlined under the sections "Oxytocin and Its Genetic Variations in the Oxytocin Receptor Gene (OXTR rs53576, rs2268498)" and "Influence of OXTR Polymorphisms on Verbal Affective Information Processing," an interpretation bias (positive or negative) could also be present in healthy individuals varying in OXTR genotypes when evaluating neutral stimuli differing in self-other reference.

Theoretically, processing of interpersonal information is a dynamic process that comprises different stages of information processing. According to the Component Process Model of Emotions (CPM) by Scherer (2001), several appraisal steps are completed in a sequential fashion while encountering stimuli varying in emotional content and in personal relevance. At first, stimuli are appraised for their novelty and their personal relevance for the own person including an intrinsic pleasantness check of the stimulus' content in terms of its unpleasantness or pleasantness. Secondly, the implications or consequences a stimulus or an event has for the person are assessed. In a third step, the own person's coping potential is considered, which is then followed by an evaluation of its normative significance with respect to one's own self-concept or to certain social norms. Difficulties in interpersonal processes and in the processing of socio-emotional information (be it non-verbally or verbally conveyed), as have been demonstrated for certain OXTR genotypes (see the sections "Oxytocin and Its Genetic Variations in the Oxytocin Receptor Gene (OXTR rs53576, rs2268498)" and "Influence of OXTR Polymorphisms on Verbal Affective Information Processing"), might be caused by unfavorable appraisal in any of those steps, leading to a cascade of false interpretations, which are based on wrong assumptions. This might further lead up to unjustified behavior that might provoke harsh reactions from surrounding others. However, to properly assess the mechanism of these genotype-related deficits, separate evaluation of any step of stimulus appraisal is crucial.

Aim and Hypotheses

The aim of this study was to investigate the interplay between verbally conveyed social information processing and OXTR genotypes. In particular, and extending previous research, we thought to elucidate the role of individual differences in the OXTR genotypes (rs53576 – GG vs. A+; rs2268498 – C+ vs. TT) in affective evaluation of verbal stimuli varying in emotional valence and in self-other reference. Regarding the mechanism underlying the interplay between genes, affect and

language, we were particularly interested in whether affective stimulus appraisal – in particular the appraisal of self-relevance including the intrinsic pleasantness check as proposed by the CPM (Scherer, 2001) – would be significantly affected by individual differences in the OXTR genotype. Recent studies investigating the time course of stimulus appraisal for words varying in emotional valence and in self-reference suggest that for linguistic stimuli an interaction between stimulus valence and stimulus reference occurs at later stages of information processing that are associated with in-depth elaboration of the stimulus meaning. This supports the notion that appraisal of self-relevance occurs temporally after each information (appraisal of the emotionality of the word and appraisal of its self-reference) has been checked and integrated (Herbert et al., 2011a,c; Fields and Kuperberg, 2016). Accordingly, on a behavioral level (e.g., Weis and Herbert, 2017; Meixner and Herbert, 2018), affective evaluation of words varying in both emotional content and in self-reference should elicit considerably longer reaction times necessary for the sequence of elaborations associated with the appraisal of the word's personal relevance. Differences in the appraisal of the word's personal relevance related to individual differences in the OXTR genotypes (rs53576 – GG vs. A+, rs2268498 – C+ vs. TT) may manifest in differences in response accuracy as well as in differences in reaction times.

Moreover, since previous genetic studies focused mainly on the effects of oxytocin on the processing of positive and/or negative stimuli, the present study also examined whether affective evaluation of neutral stimuli varying in self-other reference will differ as a function of individual differences in OXTR genotypes. Neutral stimuli are devoid of any emotional quality. Thus, when appraised according to their personal relevance and when presented with or without self-other reference, their content may become susceptible to an *interpretation bias*, facilitating valence-incongruent judgments, e.g., evaluating neutral stimuli either as positive or as negative.

The relationship between individual differences in OXTR genotypes and affective evaluation of verbal stimuli varying in emotional and neutral content and in self–other reference has not been investigated before. Therefore, the following hypotheses can be based only on the results of previous genetic studies outlined in detail above. In accord with these studies, it could be expected that individual differences in both OXTR genotypes (rs53576 and rs2268498) might contribute to differences in affective evaluation of self- vs. other-related emotional and neutral verbal stimuli. Given that A+ carriers have been shown to exhibit greater difficulties in the categorization of other-related stimulus categories compared to GG carriers, A+ carriers should show significantly less response accuracy (i.e., valence-congruent answers) and increased reaction times in the affective evaluation of other-related words compared to GG carriers. Moreover, it could be hypothesized that A+ carriers would also tend to evaluate semantic stimuli of neutral content differently from GG carriers, probably exhibiting an *interpretation bias,* evident in valence-incongruent judgments to neutral words varying in self-other reference. Regarding individual variations in rs2268498, behavioral results are still scarce. However, due to the possible functional role of this SNP, it seems reasonable to test the same hypotheses for carriers of C+ vs. TT as well.

MATERIALS AND METHODS

Participants

Recruitment and Genotype Distribution

Participants were recruited via mailing lists and advertisements around the city of Ulm and the campus of Ulm University, Germany, where all measurements took place. In line with previous OXTR genetic studies, inclusion criteria for participation were carefully chosen to exclude possible confounding factors. Therefore, participants of the present study could take part in the study only if they were Caucasian, heterosexual, 18–30 years of age, neither married nor engaged ever in their lifetime and if they had no children. In addition, to be included in the current data analysis, participants had to be either already registered in the Ulmer genetic database led by the Department of Psychology and Education, Molecular Psychology at the University of Ulm, Germany or become a voluntary member thereof. For the present study, N = 175 volunteers, all members or willing to register in the genetic database could be included in the present data analysis. The N = 175 participants could be taken from a larger sample of N = 359 participants, who over the period of 2 years all took part in behavioral experiments employing the His-Mine paradigm and the same set of stimuli and the same set of questionnaires and exclusion and inclusion criteria. Participants included in this larger project including the participants of the current data analysis all gave informed consent and received course credit or 10 euros in return for their participation. Consent obtained from all participants was both written and informed and the project and individual study and experimental design were approved by the local ethics committee of Ulm University.[1]

One participant had to be excluded from the present sample due to having reported suffering from attention deficit syndrome; two participants had to be excluded due to having reported treatment for acute psychiatric disorders. Although not reporting diagnosis of clinical depression, n = 6 participants had to be excluded due to self-reported depression on the Beck-Depression Inventory indicating medium-to-severe depressive symptomatology (BDI scores > 20). In addition, n = 17 participants had to be excluded since they reported being non-native speakers of German and/or being left-handed or ambidextrous.[2]

The remaining sample of participants included in the analysis comprised N = 149 healthy adults (104 females, 44 males,

[1]https://www.uni-ulm.de/einrichtungen/ethikkommission-der-universitaet-ulm/

[2]Regarding handedness, exclusion of left-handers might not have been necessary because participants were instructed to reply with their dominant hand and therefore, left- or right-handedness seem not to bias the behavioral results in the His-Mine Paradigm (e.g., Meixner and Herbert, 2018). However, since an association between oxytocin and testosterone levels on the one hand and testosterone in pregnancy and handedness on the other hand cannot be ignored and has occasionally been reported in the literature, left-handers were excluded from the analysis to guarantee a homogenous sample.

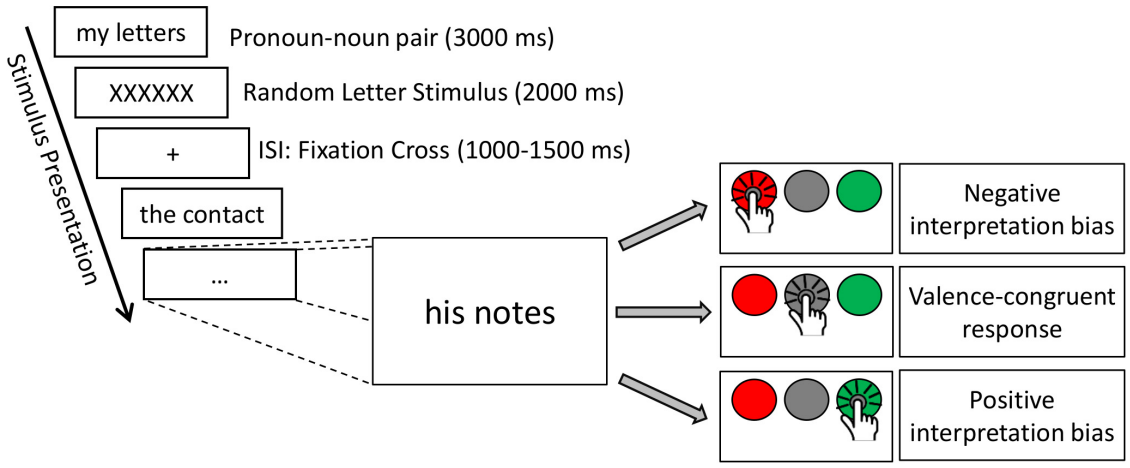


FIGURE 1 | Time course of the experimental paradigm with different response types, illustrating positive, and negative interpretation biases.

1 unspecified), with a mean age of M = 22.19 years, SD = 2.52, all right-handed and native speakers of German.

Genotype distribution in the final sample was in Hardy–Weinberg equilibrium for both SNPs (rs53576: χ^2 = 0.20, p = 0.65; rs2268498: χ^2 = 1.47, p = 0.22), corresponding to AA: n = 17, AG: n = 63, GG: n = 69, and CC: n = 32 CT: n = 66 or TT: n = 51) and was in line with reports from previous studies (e.g., Walter et al., 2012; Melchers et al., 2013; Montag et al., 2017). Also, in line with previous studies was the conjunct distribution of both SNPs [A+/C+: n = 72; A+/TT: n = 8; GG/C+: n = 26; GG/TT: n = 43; $\chi^2(1)$ = 45.05, p < 0.001]. Because of the skewed distributions and in accord with previous research (e.g., Rodrigues et al., 2009; Saphire-Bernstein et al., 2011; Tops et al., 2011; Feng et al., 2015), AA/AG-genotypes as well as CC/CT-genotypes were combined into one group of A+ carriers or C+ carriers, resulting in comparable group sizes of n = 80 (A+) and n = 69 (GG) participants for the SNP rs53576 and n = 98 (C+) and n = 51 (TT) participants for the SNP rs2268498. In the following analyses, A+ genotypes will be compared with the GG genotype and the C+ genotypes will be compared with the TT genotype. The A+ and GG-genotype distribution as well as the C+ and TT genotype distribution did not differ by gender, [A+/GG: $\chi^2(1)$ = 0.006, p = 0.938; C+/TT: $\chi^2(1)$ = 0.108, p = 0.742].

Genetic Sampling

All genetic sampling was done non-invasively via buccal swaps. DNA extraction was performed on MagNA Pure 96 using a commercial extraction kit (Roche, Mannheim, Germany). Genotyping was performed on a Cobas Z 480 Light Cycler via detection of melting curves. The simple probes were designed by TIB MolBiol (Berlin, Germany).

Materials

In the present study, a modified version of the affective His-Mine paradigm was used (Herbert et al., 2011a,c, 2018b; Blume and Herbert, 2014; Winter et al., 2015, 2018; Weis and Herbert, 2017). The affective His-Mine paradigm consists of emotional and neutral nouns that are paired with possessive pronouns of the first or third person as well as with articles (Herbert et al., 2018b; Meixner and Herbert, 2018) or negated pronouns (Weis and Herbert, 2017) devoid of any personal reference. As shown in **Figure 1**, in the present study the experimental design consisted of three different self-reference and emotion conditions: self-related and other-related[3] emotional and neutral pronoun-noun pairs (e.g., my fear, my happiness, my office) and emotional and neutral article-noun pairs devoid of self- or other-reference. In total (see also Meixner and Herbert, 2018), 60 nouns were included with 20 nouns per emotional valence category (positive, negative, and neutral). These 60 nouns were the same for each reference category (self-, other-, and no reference) to reduce stimulus variance across stimulus categories. Nouns were matched according to normative ratings of valence and arousal. Nouns and ratings were taken from our own word corpus (e.g., Herbert et al., 2006, 2008; Kissler et al., 2006, 2007) providing for 469 German adjectives and 311 German nouns emotional valence and emotional arousal ratings on the 9-point Self-Assessment Manikin (SAM; Bradley and Lang, 1994) and for concreteness on 9-point Likert scales. Affective ratings of this word corpus are also provided in other standardized German datasets of affective words, using slightly different procedures and rating scales (e.g., see Berlin Affective Word List, BAWL-R, Võ et al., 2009). In addition, nouns were also matched for linguistic dimensions, e.g., word length and word frequency to avoid confounding effects with linguistic dimensions. Thus, the final sample of word material differed only in valence and arousal, i.e., positive and negative words eliciting higher arousal than neutral nouns, and positive, negative, and neutral nouns differing significantly in valence from each other, as can be seen in **Table 1**.[4]

[3]We employed only the male pronoun "his" (German: sein/seine). In the German language, "her" (ihr/ihre) is almost indiscernible from "their" (Ihr/Ihre) and was therefore not included due its possible ambiguity.

[4]The full list of stimuli is available from the corresponding author upon request.

TABLE 1 | Descriptive statistics of the different word categories used in this study.

	Valence	Arousal	Concreteness	Length	Frequency
Positive	7.31 (*0.72*)[a]	4.68 (*0.74*)[a]	4.68 (*0.70*)[a]	5.75 (*1.71*)[a]	263.15 (*283.53*)[a]
Neutral	5.34 (*0.67*)[b]	2.43 (*0.97*)[b]	4.05 (*1.83*)[a]	6.35 (*1.35*)[a]	227.00 (*253.77*)[a]
Negative	2.56 (*0.53*)[c]	4.77 (*0.69*)[a]	4.33 (*0.89*)[a]	6.30 (*1.69*)[a]	206.80 (*189.50*)[a]

Table is taken from Meixner and Herbert (2018). Different superscripted letters a, b, and c indicate statistically significant differences between word categories regarding the respective dimensions ($p \leq 0.05$); mean values are depicted, values in brackets represent standard deviations. Word length is expressed in total characters; word frequency is expressed as appearance per one million words, for further information, please see the section "Materials".

Each stimulus pair (pronoun–noun or article–noun pair) was presented in one trial, resulting in a total of 180 trials. Each trial started with a fixation cross displayed for a random interval between 1000 and 1500 ms. Word stimuli were presented on a computer screen with a resolution of 1280 × 1024 pixels at a refresh rate of 60 Hz, in black 70 pt letters (Times New Roman) on a white background. Participants were seated at a comfortable viewing distance of 60 cm, resulting in a visual angle of 1° 54° 0.58° (stimulus height). Stimuli remained on the screen for 3000 ms or until participants pressed any of the answer keys. After each verbal stimulus, a visual stimulus consisting of six letters (XXXXXX) was presented for 2000 ms to diminish any carry over effects from one trial to the next. Presentation order of the stimuli was randomized for each participant to avoid sequence effects.

Procedure

Upon arrival, participants read and signed the consent form and answered basic demographic questions about their age, gender, mother language including specific anamnestic variables asking for visual/acoustic impairments, history of neurological/psychiatric disorders, alcohol/drug abuse, etc. Subsequently, participants received detailed written and oral instructions from the experimenter regarding the experimental paradigm. They were told that they will be presented a series of words that could describe emotions or objects belonging either to themselves, to a third person or that contained no personal reference (article–noun conditions). Participants were instructed to evaluate those stimuli using one of three keyboard buttons. Keyboard buttons were color-coded in green (positive) or red (negative) or uncolored (neutral). Key presses had to be given with the index finger of the dominant hand, resting on a fixed starting position, equidistant to the three target buttons. Furthermore, participants were instructed to respond spontaneously based on their feelings elicited during reading and – based on these – as fast and as accurate as possible. The experimental paradigm lasted about 20 min and was programmed using Presentation® software[5] (Version 0.60, Neurobehavioral Systems, Inc., Berkeley, CA, United States).

Afterward, participants answered all self-report measures. These included measurements of depressive symptomatology (Beck-Depression Inventory, BDI-II, German version by Hautzinger et al., 2009), anxiety (State-Trait-Anxiety Inventory, STAI, Laux et al., 1981), different facets of self-concept (Deusinger, 1986), and empathy (Paulus, 2009; based on the Interpersonal Reactivity Index, IRI by Davis and Oathout, 1992). Furthermore, we included a measure of alexithymia (Toronto Alexithymia Scale, TAS-20, Bagby et al., 1994; German translation by Bach et al., 1996), since the inability to describe or identify one's own emotions might be related to the evaluation of self-related stimuli. In total, the complete experiment including the His-Mine paradigm, self-report questionnaires and genetic sampling (buccal swaps) lasted about 60 min.

A detailed overview on the descriptive data including participants' self-report data (age, gender, depression, anxiety, empathy, and alexithymia scores) as a function of their genotype is provided in **Table 2**.

Analysis: OXTR Genotypes (rs53576 and rs2268498) and Response Accuracy (Valence-Congruent Responses) and Reaction Times

The influence of participants' OXTR genotypes on response accuracy (i.e., number of valence-congruent responses[6]) and reaction times were statistically analyzed with repeated measures analysis of variance (ANOVA) using IBM SPSS Statistics 24 software and a 3 × 3 × 2 full factorial design for each SNP separately. The full factorial design included the factors *stimulus valence* (positive, negative, neutral), *stimulus reference* (self, other, no personal reference) as within-subject factors and *genotype* (A+/GG or C+/TT) as between-subject factor. Reaction times were kept in their raw units (ms) and, unless otherwise specified (see interpretation bias), only valence-congruent trials were included in the calculation of mean reaction times.

If participants didn't respond to the word categories in a valence-congruent way (e.g., evaluating neutral stimuli such as "my furniture" with a neutral button press), mean reaction times for this category could not be computed. Consequently, these participants were excluded from ANOVAs using reaction times as the dependent variable, which also results in different degrees of freedom compared to ANOVAs analyzing response accuracy, where 0 is a valid score.

Degrees of freedom were corrected using the Greenhouse–Geisser correction, if sphericity was violated. Significant within-subject effects in the ANOVA designs were further analyzed in *post hoc* tests using paired samples *t*-tests, significant between-subject effects were analyzed using independent samples *t*-tests. To assess a possible self-positivity bias and potential interactions with OXTR *genotype*, *post hoc* tests of reaction times and response accuracy have been calculated, comparing positive words with self-reference to positive words with other-reference and to negative/neutral words with self-reference (e.g., Meixner and Herbert, 2018). *Post hoc* tests of OXTR genotype-related differences in affective evaluation of other-related words consisted of independent samples *t*-tests of reaction times and response accuracy comparing A+ to GG carriers (rs53576;

[5]http://www.neurobs.com

[6]For reasons of brevity, the term "(response) accuracy" will be used. The term "response accuracy" thus refers to the number of valence-congruent responses.

TABLE 2 | Demographic data and BDI-II, STAI, empathy, and alexithymia scores (all calculated as sum scores as suggested by the respective manuals) of the sample, M (SD), including OXTR rs53576 A+ carriers (first line) and GG carriers (second line), and OXTR rs2268498 C+ carriers (third line) and TT carriers (fourth line).

	Age (years)	Gender (number of female participants)	BDI-II	STAI (*state*)	STAI (*trait*)	Empathy	Alexithymia
A+ (n = 80)	21.99 (*2.21*)[a]	n = 56[a]	5.67 (*6.55*)[a]	35.19 (*7.03*)[a]	39.03 (*8.40*)[a]	53.16 (*7.62*)[a]	46.19 (*9.80*)[a]
GG (n = 69)	22.42 (*2.84*)[a]	n = 48[a]	5.25 (*5.06*)[a]	35.39 (*7.88*)[a]	38.16 (*9.59*)[a]	53.51 (*6.50*)[a]	45.47 (*10.69*)[a]
C+ (n = 98)	22.20 (*2.49*)[a]	n = 68[a]	5.66 (*4.64*)[a]	35.17 (*6.96*)[a]	38.94 (*8.66*)[a]	53.31 (*7.30*)[a]	45.92 (*9.24*)[a]
TT (n = 51)	22.16 (*2.60*)[a]	n = 36[a]	5.08 (*5.06*)[a]	35.50 (*8.27*)[a]	38.02 (*9.52*)[a]	53.35 (*6.76*)[a]	45.72 (*11.94*)[a]

Different superscripted letters a and b would indicate statistically significant differences between groups regarding the respective dimensions (independent samples t-tests; gender: chi-square test of independence; $p \leq 0.05$); sum scores are depicted, values in brackets represent standard deviations.

one-sided testing), and C+ to TT carriers (rs2268498; two-sided testing), respectively. If homogeneity of variances could not be assumed, Welch's *t*-test is reported instead. Measures of effect size (partial eta square, η_p^2) are reported for the ANOVAs regarding OXTR genotypes.

OXTR Genotypes (rs53576 and rs2268498) and Interpretation Bias

For assessment of the interpretation bias, valence-incongruent responses (*positive* and *negative*) in the neutral stimulus category, regardless of stimulus reference, were summed up to check whether the total amount of valence-incongruent responses to neutral words differs as a function of participants' genotype. Next, percentage scores were computed to determine the degree of the negative vs. positive *interpretation bias*, which was defined as the *number of times a "neutral" stimulus had been evaluated as "negative"* relative to the *total interpretation bias (neutral evaluated as negative + neutral evaluated as positive)*. A high score (>0.5) therefore indicates a negativity bias in the reaction towards neutral words, whereas a low score (<0.5) indicates a positivity bias.

Analysis of variance and independent samples *t*-tests (one-sided testing) were performed to further examine the relation between the rs53576 *genotype* (A+ vs. GG) or the rs2268498 genotype (C+ vs. TT), and the positive or negative tendency of the *interpretation bias* (as described above).

OXTR rs53576, rs2268498 and Self-Report Measures

To determine whether OXTR genotypes show relations with self-reported empathy, empathic concern, mood states including depressive symptoms and anxiety, independent samples *t*-tests (see also **Table 2**) and correlation analyses were performed (Pearson correlation, two-sided testing with $p \leq 0.05$ as significance criteria).

RESULTS

Overall Response Accuracy, Reaction Times, and OXTR Genotypes

Since every stimulus category consisted of 20 pronoun–noun pairs, a maximum number of 20 valence-congruent responses was possible in each of the 3 (*stimulus valence*) × 3 (*stimulus reference*) categories. Mean accuracy of the sample was M = 15.53 (SD = 2.61), which equals 77.65% response accuracy across all categories, indicating accuracy well above guessing levels (33.3%). Mean reaction time in milliseconds was M = 1248.91 ms (SD = 293.65) across all categories. Overall reaction time data and response accuracy for each stimulus category are listed in **Table 3**.

Neither overall response accuracy nor overall reaction times differed significantly between A+ and GG carriers, or between C+ and TT carriers [rs53576: response accuracy: A+ (M = 15.26, SD = 3.03) vs. GG (M = 15.85, SD = 1.99); $t(138) = 1.41$; $p = 0.160$; reaction times in milliseconds: A+ (M = 1255.91, SD = 331.74) vs. GG (M = 1241.30, SD = 248.25); $t(138) = 0.293$; $p = 0.770$; rs2268498: response accuracy: C+ (M = 15.32, SD = 3.00) vs. TT (M = 15.92, SD = 1.58); $t(147) = 1.59$; $p = 0.113$; reaction times in milliseconds: C+ (M = 1269.15, SD = 300.28) vs. TT (M = 1212.49, SD = 280.59); $t(138) = 1.09$; $p = 0.275$].

Self-Positivity Bias and OXTR Genotypes

Reaction Times and OXTR Genotype (rs53576)

The 3 (*stimulus valence*) × 3 (*stimulus reference*) × 2 (*genotype A+/GG*) repeated measures ANOVA (DV: *reaction times* in milliseconds) revealed significant main effects of the factors *stimulus valence* [$F(1.82,252) = 71.86$, $p \leq 0.001$, $\eta_p^2 = 0.342$], and *stimulus reference* [$F(2,276) = 71.42$, $p \leq 0.001$, $\eta_p^2 = 0.341$], as well as a significant interaction between *stimulus valence* and *stimulus reference* [$F(3.45,476) = 22.18$; $p \leq 0.001$, $\eta_p^2 = 0.138$]. However, there were neither interaction effects between *genotype* and *stimulus valence* [$F(1.82,251) = 1.38$; $p = 0.254$, $\eta_p^2 = 0.010$]

TABLE 3 | Reaction times in milliseconds (upper part) and response accuracy (lower part) of all participants for stimuli with self-reference, other-reference, no personal reference and of positive, negative, neutral valence, M (SD).

M (*SD*)	Self-reference	Other-reference	No personal reference
Reaction time in milliseconds			
Positive	1131.54 (*289.20*)	1230.91 (*337.6*)	1113.54 (*257.25*)
Negative	1252.59 (*345.21*)	1206.18 (*329.38*)	1185.90 (*370.22*)
Neutral	1415.96 (*405.63*)	1455.38 (*397.24*)	1254.89 (*337.24*)
Response accuracy (valence-congruent answers)			
Positive	17.72 (*3.34*)	15.79 (*4.96*)	16.77 (*3.64*)
Negative	17.84 (*3.76*)	17.52 (*3.91*)	17.62 (*3.84*)
Neutral	10.30 (*4.87*)	12.03 (*5.41*)	14.19 (*4.22*)

or *stimulus reference* [$F(1.99,274) = 1.62$; $p = 0.200$, $\eta_p^2 = 0.012$], nor a three-way interaction [$F(3.45,476) = 0.195$; $p = 0.921$, $\eta_p^2 = 0.001$], nor could a main effect of *genotype* be found [$F(1,138) = 0.086$; $p = 0.770$, $\eta_p^2 = 0.001$]. *Post hoc* tests revealed a self-positivity bias showing faster reaction times for self-related positive as compared to other-related positive words (self-positive (M = 1127.91, SD = 288.94) vs. other-positive (M = 1230.91, SD = 337.59); $t(143) = 6.28$; $p \leq 0.001$), which, however, did not differ significantly between A+ and GG carriers, as is evident in the lack of an interaction effect. Notably, in contrast to expectations, reaction times of valence-congruent responses to other-related words did also not differ between A+ and GG carriers [A+ (M = 1302.15, SD = 337.67) vs. GG (M = 1299.13, SD = 280.60); $t(138) = 0.057$; $p = 0.477$].

Response Accuracy and OXTR Genotype (rs53576)

The 3 (*stimulus valence*) × 3 (*stimulus reference*) × 2 (*genotype A+/GG*) repeated measures ANOVA (DV: *response accuracy*) revealed significant main effects of the factors *stimulus valence* [$F(1.51,223) = 115$, $p \leq 0.001$, $\eta_p^2 = 0.438$], and *stimulus reference* [$F(1.75,257) = 32.88$, $p \leq 0.001$, $\eta_p^2 = 0.183$], as well as a significant interaction between *stimulus valence* and *stimulus reference* [$F(2.74,403) = 41.11$; $p \leq 0.001$, $\eta_p^2 = 0.219$]. There were neither interaction effects between *stimulus valence* and *genotype* [$F(1.51,223) = 0.039$; $p = 0.926$, $\eta_p^2 = 0.000$], nor between *stimulus reference* and *genotype* [$F(1.75,257) = 1.04$; $p = 0.347$, $\eta_p^2 = 0.007$], nor could a significant three-way interaction [$F(2.74,403) = 0.054$; $p = 0.978$, $\eta_p^2 = 0.000$], nor could a main effect of *genotype* be found [$F(1,147) = 1.88$; $p = 0.172$, $\eta_p^2 = 0.013$]. *Post hoc* tests revealed a self-positivity bias, showing higher response accuracy for self-related positive as compared to other-related positive words [self-positive (M = 17.72, SD = 3.34) vs. other-positive (M = 15.79, SD = 4.96); $t(148) = 5.94$; $p \leq 0.001$]. However, as is evident in the lack of an interaction effect, this did not differ significantly between A+ and GG carriers. In addition, response accuracy in other-related words did not differ significantly between A+ and GG carriers [A+ (M = 14.73, SD = 3.51) vs. GG (M = 15.56, SD = 2.45); $t(147) = 1.63$; $p = 0.053$].

Reaction Times and OXTR Genotype (rs2268498)

The 3 (*stimulus valence*) × 3 (*stimulus reference*) × 2 (*genotype C+/TT*) repeated measures ANOVA (DV: *reaction times* in milliseconds) revealed significant main effects of the factors *stimulus valence* [$F(1.81,250) = 62.14$, $p \leq 0.001$, $\eta_p^2 = 0.310$], and *stimulus reference* [$F(2,276) = 71.29$, $p \leq 0.001$, $\eta_p^2 = 0.341$], as well as a significant interactions between *stimulus valence* and *stimulus reference* [$F(3.44,475) = 19.64$; $p \leq 0.001$, $\eta_p^2 = 0.125$]. There were no significant interaction effects between *stimulus valence* or *stimulus reference* and *genotype*, nor a three-way interaction, nor could a main effect of *genotype* be found [$F(1,138) = 1.20$; $p = 0.275$, $\eta_p^2 = 0.009$]. Comparable to the rs53576, *post hoc* tests revealed no significant differences in reaction times to self-related positive words or other-related words as a function of genotype [C+ (M = 1310.69, SD = 306.16) vs. TT (M = 1282.73, SD = 320.69); $t(138) = 0.509$; $p = 0.612$].

Response Accuracy and OXTR Genotype (rs2268498)

The 3 (*stimulus valence*) × 3 (*stimulus reference*) × 2 (*genotype C+/TT*) repeated measures ANOVA (DV: *response accuracy*) revealed significant main effects of the factors *stimulus valence* [$F(1.51,222) = 99.79$, $p \leq 0.001$, $\eta_p^2 = 0.404$], and *stimulus reference* [$F(1.75,257) = 31.64$, $p \leq 0.001$, $\eta_p^2 = 0.177$], as well as a significant interaction between *stimulus valence* and *stimulus reference* [$F(2.75,404) = 38.84$; $p \leq 0.001$, $\eta_p^2 = 0.209$]. There were no interaction effects between *stimulus valence* and *genotype*, nor between *stimulus reference* and *genotype,* nor a three-way interaction, and no main effect of *genotype* could be found [$F(1,147) = 1.77$; $p = 0.185$, $\eta_p^2 = 0.012$]. *Post hoc* test revealed no significant differences in response accuracy to self-related positive words or other-related words as a function of individual genotype variations [C+ (M = 14.95, SD = 3.43) vs. TT (M = 15.42, SD = 2.28); $t(138) = 0.887$; $p = 0.377$].

The results of the *post hoc* tests for the two SNPs are summarized in **Figure 2**.

OXTR Genotypes (rs53576 and rs2268498) and Interpretation Bias

On average, all participants answered $M = 12.17$ ($SD = 4.20$) times with a "neutral" button press in the neutral stimulus categories, which is significantly less than valence-congruent answers in positive [M = 16.76, SD = 3.51; $t(148) = 10.08$; $p \leq 0.001$] or negative [$M = 17.66$, $SD = 3.57$; $t(48) = 13.11$; $p \leq 0.001$] stimulus categories. Moreover, neutral words were evaluated on average more often as positive than as negative [positive: M = 6.56, SD = 3.72; negative: M = 0.95, SD = 1.37; $t(148) = 18.02$; $p \leq 0.001$], suggesting an overall tendency or bias to interpret neutral words in a positive manner (positive interpretation bias).

An independent samples t-test indicated that the *total interpretation bias* (positive and negative evaluations of neutral words) did not differ between A+ and GG carriers [A+ ($M = 7.61$, $SD = 4.17$) vs. GG ($M = 7.83$, $SD = 4.09$); $t(147) = 0.007$; $p = 0.932$]. Also, *the total interpretation bias* did not differ between C+ and TT carriers [C+ (M = 7.84, SD = 4.21) vs. TT (M = 6.86, SD = 3.91); $t(147) = 1.38$; $p = 0.170$]. 3 (*stimulus reference*) × 2 (*genotype A+/GG or C+/TT*) repeated measures ANOVAs were carried out to test for interactional and main effects of genotype and stimulus reference on the *interpretation bias*, revealing for the rs53576 *genotype* significant main effects of *stimulus reference* [$F(1.65,243) = 24.95$, $p \leq 0.001$, $\eta_p^2 = 0.145$] and *genotype* [$F(1,147) = 4.89$, $p \leq 0.05$, $\eta_p^2 = 0.032$], but no interaction between the two factors [$F(1.65,243) = 0.586$, $p = 0.526$, $\eta_p^2 = 0.004$]. For the rs2268498 *genotype* (C+ vs. TT) the repeated measures ANOVA revealed significant main effects of *stimulus reference* [$F(1.66,244) = 19.74$, $p \leq 0.001$, $\eta_p^2 = 0.118$] and *genotype* [$F(1,147) = 5.66$, $p \leq 0.05$, $\eta_p^2 = 0.037$], and no interaction between the two factors [$F(1.66,244) = 1.47$, $p = 0.234$, $\eta_p^2 = 0.010$].

The main effects of *genotype* were examined further in each of the reference categories separately for the two SNPs. As hypothesized, the *interpretation bias* varied with self-other reference. Regarding the rs53576, A+ carriers displayed a weaker positive interpretation bias compared to GG carriers in the

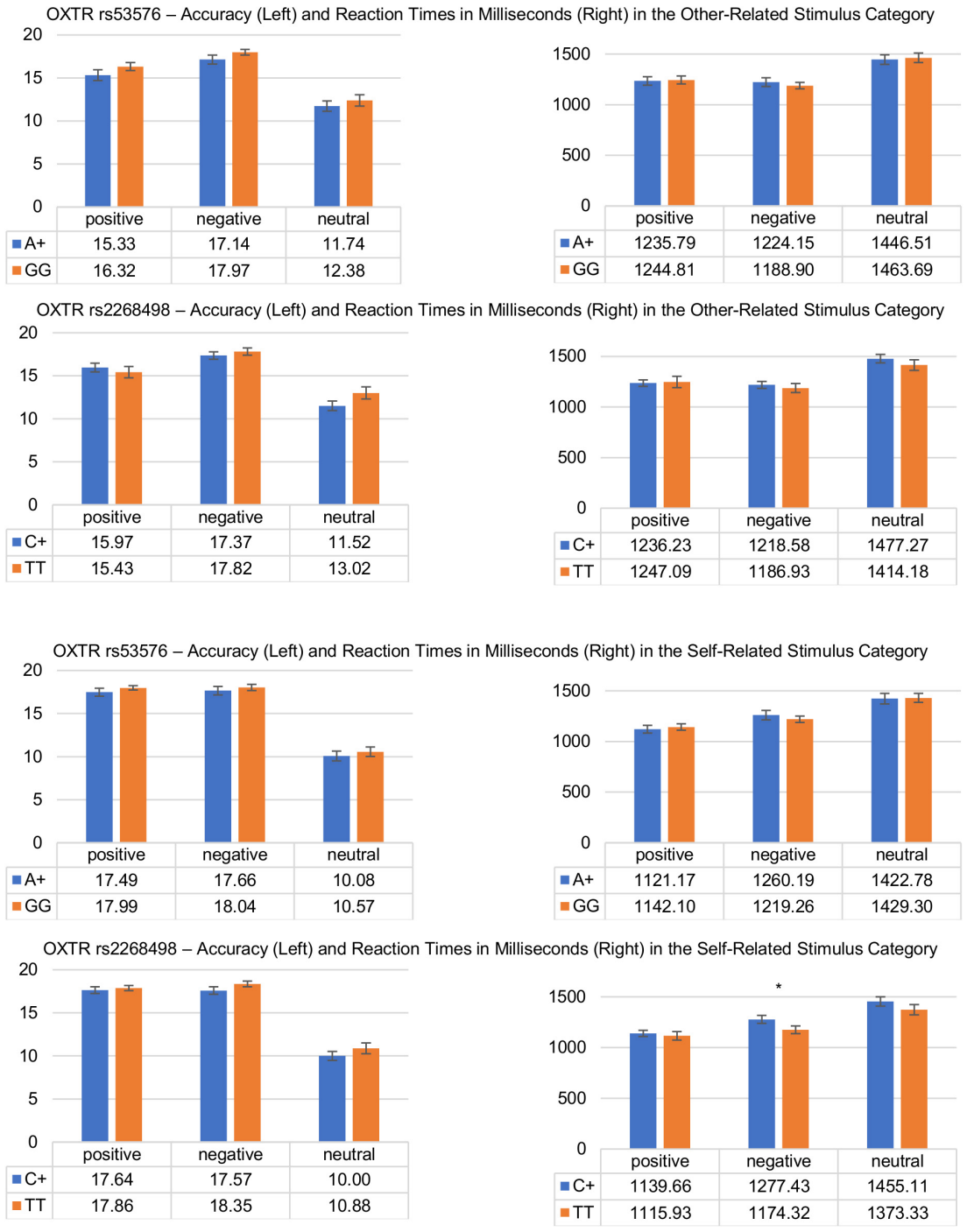


FIGURE 2 | Differences in response accuracy and reaction times during the affective evaluation of other-related (upper) and self-related (lower) stimuli as a function of OXTR genotype (rs53576 and rs2268498). Vertical bars denote ±SE (*$p \leq 0.05$).

other- and unreferenced stimulus categories, and also showed a tendentially weaker positive interpretation bias in the self-referenced stimulus category which did not reach significance [self-reference: A+ (M = 0.086, SD = 0.177) vs. GG (M = 0.053, SD = 0.100); $t(128)$ = 1.42; p = 0.079; other-reference: A+ (M = 0.238, SD = 0.292) vs. GG (M = 0.163, SD = 0.226); $t(145) = 1.77$; $p = 0.040$; no reference: A+ ($M = 0.126$, $SD = 0.231$) vs. GG (M = 0.069, SD = 0.109); $t(116)$ = 1.97; p = 0.026]. Regarding the rs2268498, participants with the C+ variants differed from TT carriers in the *interpretation bias* in the self- and in the other-referenced stimulus categories, showing a weaker positive interpretation bias in the self-reference condition and

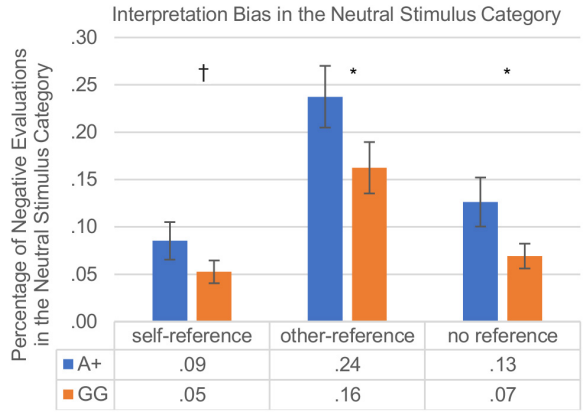


FIGURE 3 | Interpretation bias in neutral words with self-reference vs. other-reference vs. no reference in percent; group comparison: rs53576-A+ vs. rs53576-GG carriers. Vertical bars denote ±SE (†$p \leq 0.1$; *$p \leq 0.05$). As described in detail under the section "Procedure" a high score (>0.5) indicates a negativity bias in the reaction towards neutral words, whereas a low score (<0.5) indicates a positivity bias.

in the other-reference condition than TT carriers [self-reference: C+ (M = 0.084, SD = 0.170) vs. TT (M = 0.043, SD = 0.081); $t(146)$ = 2.00; p = 0.047; other-reference: C+ (M = 0.238, SD = 0.290) vs. TT (M = 0.135, SD = 0.194); $t(138)$ = 2.57; p = 0.011; no reference: C+ (M = 0.114, SD = 0.199) vs. TT (M = 0.072, SD = 0.159); $t(147)$ = 1.41; p = 0.160]. The results of the interpretation bias are depicted in **Figure 3**.

OXTR Genotype and Self-Report Measures

A+ carriers differed significantly in their scores on the personal distress subscale of the empathy scale from GG carriers [A+ (M = 11.04, SD = 3.26) vs. GG (M = 10.00, SD = 2.53); $t(145)$ = 2.18; p = 0.031]. Besides that, all other group comparisons between A+ and GG carriers, regarding overall empathy (SPF), its corresponding subscales except "personal distress," overall alexithymia (TAS) and its subscales, self-concept and its facets, as well as anxiety (STAI state/trait) and depression scores, were not significant (all $p > 0.1$). Regarding the SNP rs2268498, C+ and TT carriers did not differ in any of the self-report measures (all $p > 0.1$). For a detailed overview of scores and corresponding t-tests reported in this section, please see also **Table 2**.

DISCUSSION

This study investigated the relationship between individual differences in OXTR (rs53576 and rs2268498) genotypes and affective evaluation of emotional and neutral words with self-, other- or no personal reference. According to previous genetic studies, it is largely unknown whether genetic variations of the OXTR gene and its previously reported differences in socio-emotional information processing also hold for biologically less determined stimuli such as words, and if so, for which contents and stimulus categories affective evaluation may differ by interindividual differences in OXTR genotypes (A+ vs. GG carriers and C+ vs. TT carriers). Using a novel, yet established experimental task (the so called His-Mine paradigm), we determined whether response accuracy and reaction times as well as valence-incongruent responses to neutral words (interpretation bias) differ as a function of participants' OXTR genotypes.

Regarding affective evaluations of positive and negative words varying in self-other reference, there was no evidence that would support an influence of participants' OXTR genotype status on affective stimulus evaluation. Participants' affective evaluations seemed to be unaffected by the oxytocin genotype status as was evident in the lack of any interaction between the factors *genotype* (rs53576 – A+ vs. GG or rs2268498 – C+ vs. TT) and *stimulus valence* or *stimulus reference*, regarding response accuracy as well as reaction times. Also, response accuracy and reaction times to other-related words (positive, negative or neutral) did not differ between A+ and GG or between C+ and TT carriers. This is contrary to our first hypothesis which - built on results from previous studies on non-verbal socio-emotional information processing - would predict differences in A+ and GG carriers and in C+ and TT carriers in the processing of signals relevant for interpersonal communication such as emotional information belonging to oneself or to others. One reason for the discrepancy between previous and the current findings could be that for words, the content of positive and negative self- and other-referenced stimuli is semantically obvious, easy to categorize and thus not vulnerable to misinterpretation and not dependent on individual differences in participants' trust, emotional recognition or empathy skills that all have been shown to vary with OXTR genotype. In the present study, A+ and GG or C+ and TT carriers did not differ significantly in self-reported emotion recognition (alexithymia), self-reported trait and state anxiety or depression. Regarding empathy, significant differences could be found regarding personal emotional distress suggesting A+ carriers to be more susceptible to emotional distress than GG carriers.

According to the Component Process Model of Emotions (CPM; Ellsworth and Scherer, 2003; Sander et al., 2005) a sequential process is applied after confrontation with a stimulus. With the first step being sensory perception, appraisal afterward comprises a novelty check, a self-relevance check containing an intrinsic pleasantness check, a goal/need significance check, a coping potential check and a norm-self-compatibility check (Ellsworth and Scherer, 2003; Sander et al., 2005). Misjudgments of personally relevant information may happen at any of these stages, possibly leading to negative reactions in oneself and in others. It is reasonable to assume that the less information is provided, the more interpretative liberty is given to the individual, making neutral stimuli an empty canvas for a person's affective evaluation, especially if presented without any obvious valence or personal reference. This is also evident in the present study: neutral words have been less often correctly evaluated as "neutral," but instead have been interpreted as positive or negative, suggesting a genotype-independent and overall tendency to evaluate neutral stimuli in an affective fashion.

Additionally, our data indicates slower reaction times for the "neutral" stimulus category, which is probably due to the (mis-) interpretation of the stimulus taking more time compared to responding in a valence-congruent fashion.

There were no differences in A+ and GG carriers or in C+ and TT carriers in overall response accuracy of the evaluation of neutral words. However, there was a general tendency to evaluate neutral stimuli more often as positive as negative (interpretation bias), which was modulated by participants' OXTR genotype. More specifically, rs53576 A+ carriers showed a weaker positive interpretation bias compared to GG carriers during affective evaluation of other- and unreferenced neutral words. Rs2268498 C+ carriers showed a weaker positive interpretation bias during affective evaluation of self- and other-referenced neutral words compared to TT carriers. One limitation of the present finding regarding the interpretation bias could be the overall small trial number included for its calculation. Future studies might therefore include overall larger trial numbers per word category or selectively incorporate more neutral trials per word category to replicate and validate the present observation of an interpretation bias and its modulation by the OXTR genotypes.

One possible explanation of these findings could be that neutral words constitute the category with the least information, making their affective evaluation more susceptible to misinterpretation and therefore more ambiguous than affective evaluation of emotional words. Given that both SNPs did affect valence judgments of neutral words in a slightly different way, this supports previous observations (see the section "Introduction" for details) that variance in social behavior captured by the two different SNPs – OXTR rs53576 and rs2268498 – is not mutually interchangeable. In addition, the results support a role of the two SNPs in the appraisal of neutral content, with A+ carriers being less prone to positive interpretation biases for other- and unreferenced neutral words than GG carriers (rs53576) and C+ carriers being less prone or sensitive to positive interpretation biases for self- and other-related neutral words than TT carriers (rs2268498).

At the moment, we can only speculate about the adaptive value of these OXTR genotype-related differences in the interpretation bias: from an evolutionary perspective, both, a reduced as well as an increased positive interpretation bias for unreferenced as well as for self-related or other-related content might have adaptive value in terms of well-being, whereas a negative interpretation bias may be associated with negative effects on well-being and affective disorders as has been shown for depression and anxiety (e.g., Huppert et al., 2003; Amir et al., 2005; Wisco and Nolen-Hoeksema, 2010; Berna et al., 2011). Given that especially A+ genotypes have been reported to be more prone to depressive symptoms (Saphire-Bernstein et al., 2011) and since in the present study only healthy participants were included, it would be interesting to investigate the interpretation bias in depression- or anxiety-prone subjects with varying OXTR genotype status in future studies. On a related note, additionally including participants with an ASD diagnosis in the present experimental design may shed additional light onto the relationship of the OXTR gene and social behavior, as differences in OXTR genotypes and ASD have been reported for the SNP rs2268498 (Montag et al., 2017), and for rs53576 (in a Chinese population; Wu et al., 2005), which, however, seem to be dependent on factors such as ethnicity (Jacob et al., 2007), or OXTR DNA methylation (Rijlaarsdam et al., 2017). It could also be interesting to extend the present paradigm to (semi-)realistic interactional scenarios to fully understand extent and meaning of the reported interpretation bias.

Regarding the selection of the SNPs (rs53576 and rs2268498) of the OXTR gene, the two SNPs of the present study were chosen according to the previous literature. So far, relatively little is known about the impact of both OXTR SNPs on the biochemical pathways underlying the oxytocinergic neurotransmission. Regarding rs2268498 (C+ vs. TT), its direct relation with oxytocin expression has been recently demonstrated in a functional neuroimaging study in humans (Reuter et al., 2017). Possibly, such molecular mechanisms may play a role in the context of our observed association between OXTR rs2268498 and the interpretation bias, whereas direct links between behavior, oxytocin release or oxytocin expression and OXTR rs53576 genotype have still not be proven in humans. Nevertheless, recent studies suggest that the OXTR rs53576 genotype – although being located in an intronic region of the OXTR gene – might still have an impact on gene expression: in prairie voles it has been demonstrated that genetic variation near *cis*/regulatory elements of the OXTR gene could contribute to individual differences in gene expression in brain areas of relevance for social attachment such as the *nucleus accumbens* (NAcc) (King et al., 2016). Furthermore, individual differences in hypothalamic-limbic areas of the brain depending on genetic information of rs53576 has been shown by Tost et al. (2010) providing further evidence, that this SNP somehow is linked to brain processes, perhaps indirectly via linkage to other genetic variants.

CONCLUSION

As we outlined in the "Introduction" and in the "Discussion" sections above, the literature points towards functional connections between neuronal areas associated with oxytocin production and the limbic system, including the amygdala and the hippocampus (Landgraf and Neumann, 2004; MacDonald and MacDonald, 2010). Previous studies have also shown an involvement of the amygdala, an area rich in OXTRs, in the processing of affective language (e.g., Kuchinke et al., 2005; Herbert et al., 2009), in the processing of emotional words related to self and others (Herbert et al., 2011b). Moreover, previous studies suggested a relationship between OXTR genotypes and the aforementioned brain structures (e.g., Tost et al., 2010). Therefore, to further evaluate the mechanisms of social and affective information processing, it would be interesting to replicate the findings of this study utilizing neuroimaging methods such as fMRI to gain further insight into possibly genotype-dependent neural activity in the processing of self- and other-related or personally unrelated emotional words particularly also regarding the choices of valence-incongruent responses (interpretation bias). In general, effects of OXTR genotypes on behavior are small and therefore larger sample sizes

than the one available in the present study are needed to robustly track and replicate the present observations regarding genetic effects.

While delivering first insight into the association between different OXTR genotypes (rs53576 and rs2268498) and affective processing of verbal stimuli, the presented study also has its limitations: First, real-world interactions and interpersonal communication are often much more complex than the evaluation of basal, verbal stimuli, as employed in this study. Therefore, although the present paradigm and study investigated important parts of the appraisal processes in people with different OXTR genetic status, future studies will need to take the full process and sequences of stimulus appraisal as for instance described in the Component Process Model of Emotions (CPM; Ellsworth and Scherer, 2003; Sander et al., 2005) into consideration. Additionally, although the previous literature describes A+ (rs53576) or C+ (rs2268498) carriers as "deficient" in the processing of socio-emotional information, one should consider that this might simply be conventional nomenclature and that this polymorphism probably has adaptive value to it as well (i.e., what might be called deficits in some areas might be an advantage in other aspects of life). The present findings revealing individual differences in the interpretation bias between A+ and GG carriers and between C+ and TT carriers in a healthy participant sample might speak in favor of this assumption.

DATA AVAILABILITY STATEMENT

The data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher. Due to the informed consent form in which the possibility of raw data being published online was not explicitly stated, only group-level data, as it is provided in this manuscript, will be made accessible.

AUTHOR CONTRIBUTIONS

FM prepared the manuscript and CH revised it for content. FM recorded the data and preprocessed and analyzed the results under the supervision of CH. FM prepared the tables and figures. CH programmed and designed the paradigm. CM and his team were responsible for the genetic analysis (preprocessing). All authors approved the final version of the manuscript.

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Study II

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Friedrich Meixner prepared the original draft and Cornelia Herbert revised it for content. Friedrich Meixner recorded the data and preprocessed and analyzed the results under the supervision of Cornelia Herbert. Friedrich Meixner prepared the tables and figures. Cornelia Herbert programmed and designed the paradigm and supplied resources and software for the investigation. Both authors validated the presented data, edited the manuscript during the review process and approved the final version of the manuscript.

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[1] The authors contributed equally to this article.

PLOS ONE

RESEARCH ARTICLE

Whose emotion is it? Measuring self-other discrimination in romantic relationships during an emotional evaluation paradigm

Friedrich Meixner[☯], **Cornelia Herbert**[*☯]

Applied Emotion and Motivation Psychology, Institute of Psychology and Education, Ulm University, Ulm, Germany

☯ These authors contributed equally to this work.
* cornelia.herbert@uni-ulm.de

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Abstract

In healthy subjects, emotional stimuli, positive stimuli in particular, are processed in a facilitated manner as are stimuli related to the self. These preferential processing biases also seem to hold true for self-related positive stimuli when compared to self-related negative or other-related positive stimuli suggesting a self-positivity bias in affective processing. The present study investigates the stability of this self-positivity bias and its possible extension to the emotional other in a sample of $N = 147$ participants including single participants ($n = 61$) and individuals currently in a romantic relationship ($n = 86$) reporting moderate to high levels of passionate love. Participants were presented a series of emotional and neutral words that could be related to the reader's self (e.g., "my pleasure", "my fear"), or to an insignificant third person, unknown to the reader (e.g., "his pleasure", "his fear") or devoid of any person reference (e.g., "the pleasure", "the fear"). The task was to read the words silently and to evaluate the word pairs in reference to one's own feelings elicited during reading. Results showed a self-positivity bias in emotional judgments in all participants, particularly in men. Moreover, participants in a romantic relationship (women and men) evaluated positive, other-related stimuli more often as valence-congruent with one's own feelings than single participants. Taken together, these findings support the idea of a self-positivity bias in healthy subjects and an expansion of this bias while being in a romantic relationship.

Introduction

Emotional stimuli are processed in a facilitated manner compared to neutral stimuli. This is a robust finding that could be confirmed in many behavioral and neuroscientific studies for different types of stimuli (e.g., faces, pictures, words; for an overview/review see: [1–3]. Regarding stimulus valence, however, findings often diverge suggesting either preferential (e.g., faster, more accurate or more elaborate) processing of negative stimuli over positive stimuli or vice versa. Regarding the processing of verbal stimuli, many studies support a positivity bias in affective processing in healthy subjects. This bias could be confirmed in neurophysiological

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studies during passive viewing of positive, negative and neutral words (e.g., [4–6]) and during tasks in which participants were asked to appraise emotional stimuli such as trait adjectives in reference to the self (e.g., [7,8]). Recent research suggests no restriction of this bias to explicit self-evaluation of trait adjectives. Instead, several studies have already demonstrated a self-positivity bias in tasks in which emotional stimuli vary in self-reference: for example, words of emotional and neutral content are presented that are either directly related to the self of the participant or to the self of another person, unknown to the participant (e.g., [9–12]).

Theoretically, self-serving biases [13], mood-congruent processing [14] and a positivity offset (i.e., dominance of approach over avoidance motivation when no imminent threat is present) [15] may facilitate this self-positivity bias. Also, positive mood and absence of imminent threat are being considered the normal experience in most healthy subjects [13,16–20]. In contrast, psychopathological disorders characterized by profound instabilities in mood, affect and self-image such as borderline personality (e.g., [21]), or schizophrenia [22] may diminish the self-positivity bias. Depressive symptoms may even turn the bias into a self-negativity bias [23,24].

Hence, changes in affective state and in self-reference should be strong predictors of whether self-related stimuli are preferentially processed and whether participants prefer positive over negative information. However, little is known about how non-pathological changes in affective experience may influence processing biases of emotional stimuli varying in self-reference. Love, as a biologically grounded, approach- and reward motivated affective state [25–27] may be an ideal testing case to this end.

Love as a self- and other-oriented affective state

Falling in love can be accompanied by changes in affect and in self-reference. Affective changes may range from intense feelings of passion and euphoria on the one hand, to mania, insecurity and anxiety on the other hand, especially in the initial phase of entering a romantic relationship [25,28]. Therefore, whatever the affective quality experienced in the early-stage of romantic love might be, it may be strongly associated with the 'emotional other'. For example, according to scientific surveys at least 78–79% of people in love report to think intrusively about the desired person [29]. In fact, when asked to make "me/not me" decisions people in a romantic relationship tend to confuse stimuli related to the self with those related to their loved ones [30]. Consequently, one could assume that falling and feeling in love might also change appraisal of self- and other-related emotional stimuli.

Empirical support for this hypothesis comes from a series of recent experimental studies which found that individuals in love appraise other-related emotional stimuli differently than individuals not in love. For instance, in a series of EEG and behavioral studies by Langeslag and colleagues, individuals in love processed stimuli, e.g., beloved-related vs. friend-related words and phrases in a more elaborate way [31–33]. This intensified processing was observed irrespective of the task. Moreover, with regard to cortical processing (EEG), modulation of late brain potentials such as the LPP, an index of sustained and motivated attention was facilitated in a similar way as would have been expected for preferential processing of self-related and emotional stimuli [30,31]; see also [5]. In line with these findings are results from neuroimaging studies revealing considerable overlap in brain activity during appraisal of information related to the participant's self or a close other [34]; for related discussion see also [35,36]. The findings suggest diminished self-other discrimination on a neurofunctional level and a decrease of perceived self-other boundaries when thinking of a beloved one. Also, the self-reference effect [37], in general associated with better memory for self-related than other-related stimuli [38], has been found to be significantly reduced when stimuli are appraised in relation

to an intimate other (for meta-analysis, see [38]). Moreover, some studies seem to suggest that when in a romantic relationship, personality traits representing the self are confused with personality traits representing the partner [30]. These effects may even extend to other-related stimuli unrelated to the romantic partner [30]. In romantic relationships, this latter effect (extension to other-related stimuli that are unrelated to the partner) might be due to over-representation of the partner when appraising stimuli in the other-related stimulus category. Therefore, it is still unclear whether 'self-expanding' effects are partner-specific or whether individuals in love and currently in a romantic relationship are generally more susceptible to incorporating information about other people into one's own self.

Theoretically, the assumption of self-expansion in individuals in a romantic relationship is well in line with the psychological model of self-expansion by Aron and colleagues (for an overview see [27]). According to this model, love emanates from a basic need of the self to grow and expand by incorporating the other into one's own mental representation and concept of the self [39]. The expansion of one's own self when in love is assumed to be an affectively positive experience for many if not all lovers [40,41] facilitating a positivity bias for positive aspects of the partner [25]. This positive bias towards the other is considered to be functional, self-serving and may predict relationship satisfaction [42].

Viewed from an experimental perspective, reading about "his/her fun/joy/success" should therefore elicit similar strong feelings of pleasure in lovers as should reading of self-related positive emotional words. However, as outlined above, it is still unclear if romantic relationships bolster a self-positivity bias while at the same time expanding this bias not only to close and significant others but to others in general. In other words, in individuals in a romantic relationship one would expect a) facilitated processing of other-related emotional words, particularly positive ones–due to the generally increased relevance of other-related information for the lover's self—plus b) a persisting self-positivity bias in the processing of self-related emotional stimuli. This extension of the self-positivity bias to the emotional other may arise in lovers either due to over-representation of the partner in the other-related stimulus category or because of generally reduced self-other boundaries in lovers, love being a self- and other-oriented positive affective state.

The aim of the present study was to test these assumptions experimentally by investigating changes in response accuracy and reaction times during appraisal of self- and other-related emotional words in $N = 168$ single participants and participants in a romantic relationship and currently in love. We aimed to take a) the relationship status (i.e., being single vs. in a romantic relationship) and, for participants in a relationship, b) feelings of passionate love as well as c) the relationship quality as independent variables into account. This will show, whether a) being in romantic relationship vs. being single will be sufficient to produce an extension of the self-positivity bias and b) whether this effect is dependent on the intensity of love or the quality of the relationship. Experimental stimuli and design were adapted from variants of the His-Mine Paradigm, an experimental paradigm, developed by the corresponding author and shown to robustly measure biases in the processing of self-related and other-related stimuli across tasks and methods including behavioral measures such as response accuracy and reaction times [9,10,21,23,43–45].

In line with the considerations outlined above, the following hypothesis and research questions were tested: (1) Participants in a romantic relationship as well as singles show a self-positivity bias in the appraisal of self-related emotional words, i.e., response accuracy and reaction times to self-related positive words do not differ between the two groups. (2) Compared to singles, participants in a romantic relationship evaluate other-related positive words in a similar way as self-related positive words. This should be reflected in significant group differences in the appraisal of other-related positive words, even in the absence of partner-specific instructions.

Materials and methods

Participants

$N = 168$ healthy adults participated in the present study. Participants were recruited via mailing lists and advertisements at the campus of the University of Ulm, Germany. Advertisements contained messages explicitly encouraging individuals currently in a romantic relationship or being single to take part in the study. Participants could take part in the study only if they were heterosexual, 18–30 years of age, neither married nor engaged ever in their lifetime and if they had no children. Participants gave written informed consent and received course credit or 10 euros for participation. The experiment was conducted according to the Declaration of Helsinki and the experimental design was approved by the local ethics committee (https://www.uni-ulm.de/einrichtungen/ethikkommission-der-universitaet-ulm/).

Data from six participants had to be excluded from further analyses because these participants reported acute psychiatric disorders (four participants reported suffering from depression, one from anorexia and one stated suffering from post-traumatic stress disorder). Nine participants had to be excluded because of non-responsive task behavior or technical difficulties and six participants had to be excluded from further analyses because they didn't indicate their relationship status. Thus, the remaining sample consisted of $N = 147$ healthy adults (94 females, 51 males, 2 unspecified), mean age $M = 22.33$ years, $SD = 2.70$, all native speakers of German.

15 participants indicated they were left-handed, 131 indicated they were right-handed and 1 participant reported being ambidextrous. Right- or left-handedness of participants did not influence reaction times, $t(144) = .658$, $p = .512$, nor average number of valence-congruent responses, $t(144) = -.048$, $p = .962$. Also, right-handedness vs. left-handedness/ambidextrous was not significantly associated with participants' gender, $X^2\,(1) = 3.50$, $p = .061$, no expected cell frequencies were below 5. Given that participants were asked to answer with their dominant hand, left-handed and ambidextrous participants remained in the participant sample.

86 participants (24 males) were in a relationship at the time of testing (mean duration $M = 26.51$ months, $SD = 19.72$, range 1–71 months) whereas 61 participants (27 males) indicated they were currently single. Participants in a relationship felt significantly more intense feelings of passionate love for their actual partner on the PLS than singles who had no current partner ($t(145) = 5.66$, $p \leq .001$). Given that the present study is interested in self-expansion effects elicited during states of being in love with an actual partner as compared to states in which feelings of passionate love are mainly unidirectional (single participants) and at the time of testing unrelated to an actual partner or a relationship, PLS scores were only considered further in participants who were currently in a relationship and felt passionate love for their current partner.

Materials

The stimulus material consisted of 60 nouns, 20 nouns per emotional valence category (positive, negative and neutral). Nouns were taken from own previous research and matched according to normative ratings of valence and arousal in line with standardized datasets of affective words [46]. In line with previous emotion word processing studies [9,10,23,47] nouns were matched for several linguistic dimensions including word length and word frequency and differed only in valence and arousal, i.e., positive and negative words eliciting higher arousal than neutral nouns. Descriptive statistics of the word material can be found in Table 1. The full list of stimuli is available from the authors upon request.

Each noun of each of the three different valence categories was paired with a possessive pronoun of the first person ("mein/meine", German word for "my"), a possessive pronoun of the

Table 1. Descriptive statistics of the different word categories used in this study.

	Valence	Arousal	Concreteness	Length	Frequency
Positive	7.31 (*0.72*) [a]	4.68 (*0.74*) [a]	4.68 (*0.70*) [a]	5.75 (*1.71*) [a]	263.15 (*283.53*) [a]
Neutral	5.34 (*0.67*) [b]	2.43 (*0.97*) [b]	4.05 (*1.83*) [a]	6.35 (*1.35*) [a]	227.00 (*253.77*) [a]
Negative	2.56 (*0.53*) [c]	4.77 (*0.69*) [a]	4.33 (*0.89*) [a]	6.30 (*1.69*) [a]	206.80 (*189.50*) [a]

[abc] Different superscripted letters a, b and c indicate statistically significant differences between stimulus categories regarding the respective dimensions ($p \leq .05$); mean values are depicted, values in brackets represent standard deviations. Valence, arousal and concreteness range from 1–9 (1: unpleasant/low arousing, abstract/unconcrete; 9: pleasant/high arousing/very concrete). Length represents average number of letters, frequency corresponds to CELEX [48] frequency/per million words).

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third person ("sein/seine", German word for "his") or an article ("der/die/das", German word for "the") devoid of any person reference. Although the present sample consisted of male and female participants, who are either single or in a heterosexual relationship, we refrained from using verbal stimuli employing the female pronoun "her" (ihr/ihre) as in German language, "her" (ihr/ihre) is almost indiscernible from "their" (Ihr/Ihre) and may lead to ambiguity. To control if using only male pronouns is influencing how male and female participants, whether single or in love, evaluate emotional stimuli, a manipulation check was included, and gender was taken into consideration in additional analyses (see manipulation check).

Each stimulus pair (pronoun-noun or article-noun pair) was presented in one trial, resulting in a total of 180 trials (see Fig 1 for an overview). Hence, each noun could be related to the reader (e.g., "my fear", "my joy", "my furniture" . . .), to another person, unknown to the reader (e.g., "his fear", "his joy", "his furniture" . . .), or had no personal reference at all (e.g., "the fear", "the joy", "the furniture" . . .), the latter stimulus combinations serving as control stimuli. Each trial started with a fixation cross displayed for a random interval between 1000 and 1500 milliseconds. Word stimuli were presented on a computer screen with a resolution of 1280x1024 pixels at a refresh rate of 60 Hz, in black 70pt letters (Times New Roman) on a white background, with an average viewing distance of 600 mm, resulting in a visual angle of 1˚ 54' 0.58" (stimulus height), for 3000 milliseconds or until terminated through the participants pressing one of any answer key. After each word stimulus, a visual stimulus consisting of letter strings (XXXXXX) was presented for 2000 milliseconds to reduce carry over effects from

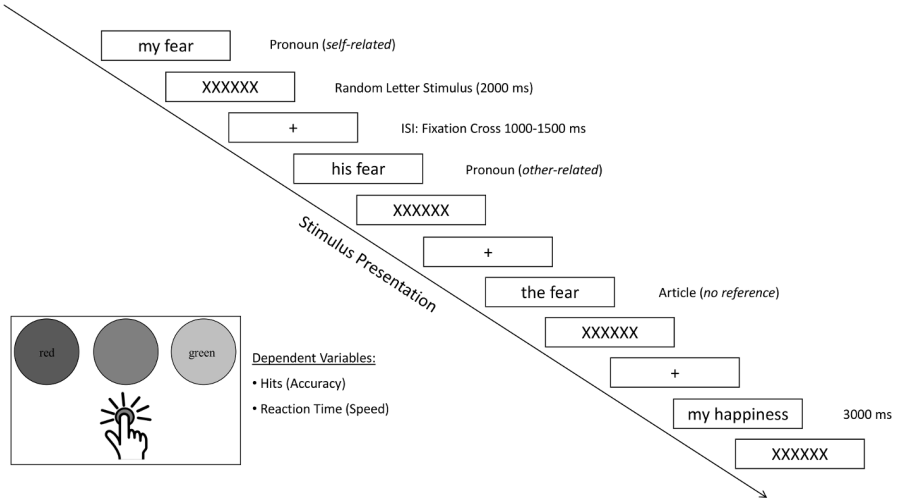


Fig 1. Time course of the experimental paradigm.

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one trial to the other. In addition, given that each noun was presented three times in one run, i.e., either with self-reference, other-reference or devoid of person reference, presentation order of the stimuli was randomized for each participant to avoid sequence effects. Participants had to indicate the valence of the presented stimuli using one of three keyboard buttons. Key presses had to be given with the index finger of the dominant hand, rested on a fixed starting position, equidistant to the three target buttons (Fig 1).

Participants received detailed written and oral instructions. They were told that they would be presented a series of words that could describe emotions or objects belonging to themselves (such as "my fun" or "my furniture") or to an insignificant third person, unknown to the reader (". . .another person, unknown to you"; such as "his fun" or "his furniture"), whereas other words could be personally unrelated (such as in "the fun" or "the furniture"). Regarding other-related stimuli there was deliberately no mention of a romantic partner in the instructions to ensure the measurement of non-partner-specific evaluation of other-related stimuli. Furthermore, participants were instructed to respond spontaneously based on their feelings elicited during reading and—based on these—as accurately and as fast as possible. Before the start of the experiment, participants completed practice trials to ensure they understood the instructions. The whole experimental paradigm lasted about 15–25 minutes. The paradigm was programmed using Presentation® software (Version 0.60, Neurobehavioral Systems, Inc., Berkeley, CA, www.neurobs.com).

Procedure

Upon arrival at the laboratory, participants provided written informed consent and were questioned about their mental and physical health, they filled in a demographic questionnaire about age, gender, native language, relationship status, and relationship duration. In addition, they answered an anamnestic questionnaire on visual and acoustic impairments, history of neurological/psychiatric disorders. Hereafter, participants completed the experimental paradigm and filled in self-report questionnaires to assess the intensity of feelings of passionate love and the relationship quality in participants in a relationship. These measures included the Passionate Love Scale (PLS; [48–50]), as well as the Relationship Assessment Scale (RAS; [51–53]). The PLS was included to ensure that all participants in the relationship sample were indeed in a *romantic* relationship at the time of testing. The PLS was also filled out by single participants. The PLS is designed such that is it able to measure an individual's general level of passionate love toward another person (i.e., how passionate you are about someone whom you may be actually in love with (real partner) or whom you were in love with (ex-partner), regardless of whether you've actually been in a relationship with that person, or whom someone came closest to caring for in that way).

According to the classifications made by Hatfield & Sprecher [50], $n = 56$ of the participants in a relationship reported to be extremely passionately in love, while $n = 22$ of the participants reported to experience passionate love, whereas only $n = 8$ reported to experience passionate love occasionally and none of the participants scored low or very low on the PLS. The mean score of the PLS (see Table 2) in the romantic relationship sample is comparable to the mean scores reported for exclusively dating couples in Hatfield & Sprecher ([48]; $M_{men} = 215.45$, $M_{women} = 220.89$). Since all participants reported to experience passionate love at least occasionally, and with the majority of participants in a relationship being passionately in love, it can therefore be safely assumed that all participants in a relationship are experiencing feelings of passionate love for their partner. As shown in Table 1, single participants who were currently not in a romantic relationship scored significantly lower on the PLS than participants in a relationship. Nevertheless, single participants reported moderate scores on the PLS.

Table 2. Demographic data and PLS-, RAS-, BDI-II, STAI and empathy scores (all calculated as sum scores as suggested by the respective manuals, except RAS (mean score); reliability coefficients are listed) of the study sample, M (SD) including individuals in a romantic relationship (first line) and those being single (second line).

	Age (*Years*)	Relationship Duration (*Months*)	Passionate Love Scale	Relationship Assessment Scale	BDI-II	STAI (*State*)	STAI (*Trait*)	Empathy
Relationship (n = 86)	22.67 *(2.78)*[a]	26.80 *(19.64)*	216.92 *(28.24)* [a]	6.08 *(.683)*	6.40 *(6.55)*[a]	33.90 *(7.52)*[a]	37.21 *(8.73)*[a]	52.85 *(8.06)*[a]
Single (n = 61)	21.84 *(2.50)*[a]	-	186.98 *(35.74)* [b]	-	6.05 *(5.06)*[a]	36.77 *(7.09)*[b]	41.23 *(9.59)*[b]	52.79 *(7.43)*[a]
Cronbach's α	-	-	.938	.907	.842	.851	.890	.789

[ab] Different superscripted letters a and b indicate statistically significant differences between groups regarding the respective dimensions ($p \leq .05$); sum scores are depicted, values in brackets represent standard deviations.

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According to Hatfield & Sprecher's [50] classification, they are/were also passionate about someone, albeit with less intensity.

In addition, participants filled in the Beck-Depression-Inventory (BDI-II; [54]) as well as the State-Trait-Anxiety Inventory (STAI; [55]) to check for possible subclinical changes in mood and anxiety (see Manipulation Check and Exploratory Analysis). Regarding BDI-scores, data from n = 32 participants were lost due to incomplete data collection. Further control variables included, among others, self-report scales measuring facets of the self-concept [56], and empathy [57,58], including empathic concern to ensure that individuals in a romantic relationship did not differ significantly in these measures from singles. A detailed overview of the demographic and individual characteristics of the study sample, including reliability coefficients (Cronbach's α) for the scales of interest is provided in Table 2.

Analysis: Response accuracy and reaction times

Participants' evaluative judgments including response accuracy (i.e., number of valence-congruent responses) and reaction times were statistically analyzed with repeated measures analysis of variance (ANOVA) using IBM SPSS Statistics 24 software and a 3 x 3 x 2 full factorial design. The full factorial design included the factors *stimulus valence* (positive, negative, neutral) and *stimulus reference* (self, other, no personal reference) as within-subject factors and *relationship status* (single, relationship) as between-subject factor, differentiating individuals currently in a romantic relationship and in passionate love with their partner from individuals being single. For reaction times, latencies were kept in their raw units (milliseconds) and only valence-congruent trials were included in the calculation of mean reaction times. Different sample sizes (and consequently different degrees of freedom) in analyses of reaction times compared to analyses of accuracy are due to some participants having never evaluated a certain stimulus category in a valence-congruent way (e.g., having never evaluated neutral stimuli such as "my shoes" with a "neutral" button press), therefore having no reaction times for these stimuli, which excludes them from the ANOVAs using reaction times as the dependent value. However, since valence-incongruent answers are still valid answers even if zero valence-congruent responses were obtained in a certain stimulus category, this was no exclusion criterion.

Degrees of freedom were corrected using the Greenhouse-Geisser correction, if sphericity was violated. Significant within-subject effects in the ANOVA designs were further analyzed using paired samples t-tests, significant between-subject effects were analyzed using independent samples t-tests. If homogeneity of variances was not given, Welch's t-test was calculated and reported instead. All reported p-values are uncorrected. If multiple comparisons were performed apart from analyses testing the main hypotheses, Bonferroni correction was applied.

Measures of effect size (Partial Eta Square, ηp^2) and 95% confidence intervals are reported for the ANOVAs and post-hoc t-tests and for the manipulation check, but not in the exploratory analyses.

Manipulation check

Given our heterosexual sample and that only the male category was used in the other-related stimulus category, additional ANOVAs (including *gender* as a between-subject factor, together with the factor *relationship status*) were performed with response accuracy (number of valence-congruent responses) and reaction times as dependent variables. Moreover, participants were asked open questions about whom they were thinking when judging self- and other-related stimuli to assess the extent of intrusive thinking of the partner, particularly when appraising stimuli in the other-related stimulus category.

Exploratory analysis

To determine whether effects may be mediated by interindividual differences in control variables (e.g., relationship satisfaction, empathic concern, mood states including depressive symptoms and anxiety), mediation analyses and Pearson correlation coefficient analyses were performed (two-sided testing with $p \leq 0.05$ as significance criteria) and Bonferroni correction was applied.

Results and discussion

Since every stimulus category consisted of 20 pronoun-noun pairs, a maximum number of 20 valence-congruent responses was possible. Mean accuracy of the sample was $M = 15.37$ ($SD = 2.48$), which equals 76.85% valence-congruent responses across all categories. Mean reaction time was $M = 1284.44$ ms ($SD = 317.35$) across all categories.

Positivity bias–self–other: Effects of relationship status

Response accuracy (number of valence-congruent responses). The 3 (stimulus valence) x 3 (stimulus reference) x 2 (relationship status) repeated measures ANOVA (dependent value, DV: response accuracy) revealed significant main effects of the factors *stimulus valence* ($F(1.66, 241) = 111.37$, $p \leq .001$, $\eta p^2 = .434$), and *stimulus reference* ($F(1.74, 252) = 28.05$, $p \leq .001$, $\eta p^2 = .162$), as well as significant interactions between *stimulus valence* and *relationship status* ($F(1.66, 241) = 3.37$, $p = .045$, $\eta p^2 = .023$), and between *stimulus valence* and *stimulus reference* ($F(2.73, 395) = 36.76$; $p \leq .001$, $\eta p^2 = .202$), as well as between *stimulus valence* and *stimulus reference* and *relationship status* ($F(2.73, 395) = 4.67$, $p \leq .001$, $\eta p^2 = .048$).

Post-hoc tests of the interaction between *stimulus valence* and *stimulus reference* revealed a self-positivity bias in line with our hypothesis (1): Within-subject comparisons revealed that positive stimuli were associated with significantly more valence-congruent responses when they were self-related as compared to when they were other-related or presented without any person reference (all participants: self-positive ($M = 17.63$, $SD = 3.20$) vs. other-positive ($M = 15.62$, $SD = 4.72$); $t(146) = 6.11$; $p \leq .001$; self-positive vs. unreferenced-positive ($M = 16.80$, $SD = 3.44$); $t(146) = 4.90$; $p \leq .001$). Also, positive, self-related stimuli were responded to more accurately compared to neutral, self-related stimuli but accuracy (number of valence-congruent responses) did not differ between positive, self-related and negative, self-related words (all participants: self-positive vs. self-negative ($M = 17.80$, $SD = 4.07$); $t(146) = .49$, *n.s.*; self-positive vs. self-neutral ($M = 9.97$, $SD = 4.87$); $t(146) = 14.16$, $p \leq .001$). As can be seen in Table 3, this

Table 3. Valence-congruent answers: Paired samples t-test results for differences between selected stimulus categories for singles and participants in a romantic relationship.

					95% CI	
Pair	***M***	***SD***	***t***		**Lower Bound**	**Upper Bound**
Single Participants[a]						
self-positive—other-positive	3.39	4.20	6.30	***	2.32	4.47
self-positive—self-negative	-0.08	3.90	-0.16		-1.08	0.92
self-positive—self-neutral	6.84	7.58	7.04	***	4.89	8.78
self-positive—unreferenced-positive	0.80	1.70	3.69	***	0.37	1.24
Participants in a Romantic Relationship[b]						
self-positive—other-positive	1.02	3.53	2.69	**	0.27	1.78
self-positive—self-negative	-0.23	4.39	-0.49		-1.17	0.71
self-positive—self-neutral	8.24	5.70	13.41	***	7.02	9.47
self-positive—unreferenced-positive	0.84	2.25	3.45	***	0.35	1.32

[a]df = 60

[b]df = 85

**$p \leq .01$

***$p \leq .001$

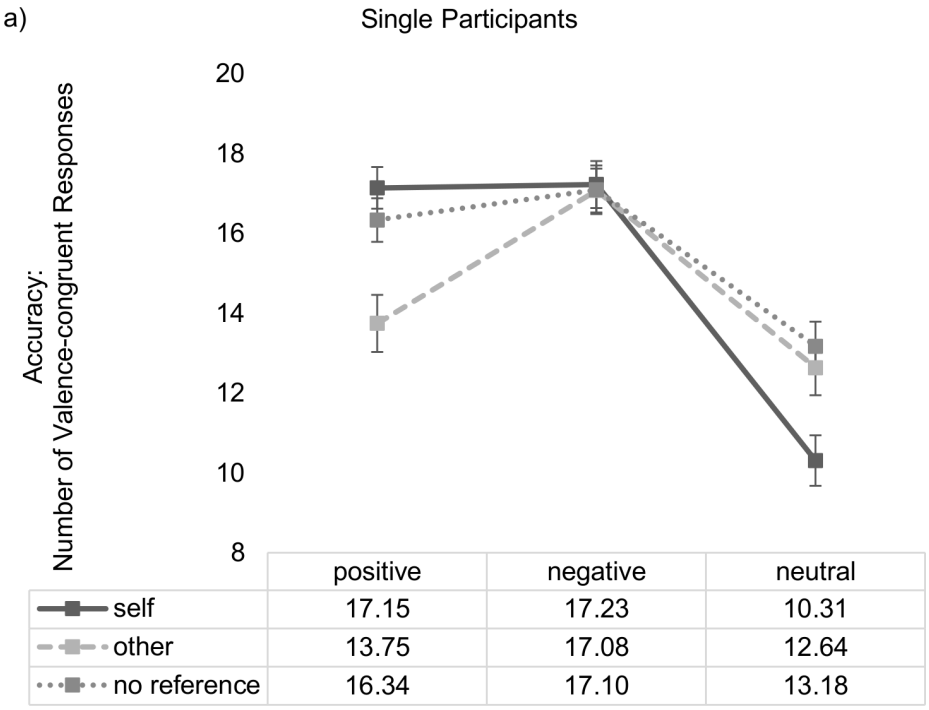
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pattern does not differ significantly for single participants and participants in a romantic relationship, indicating that both groups demonstrate a strong self-positivity bias.

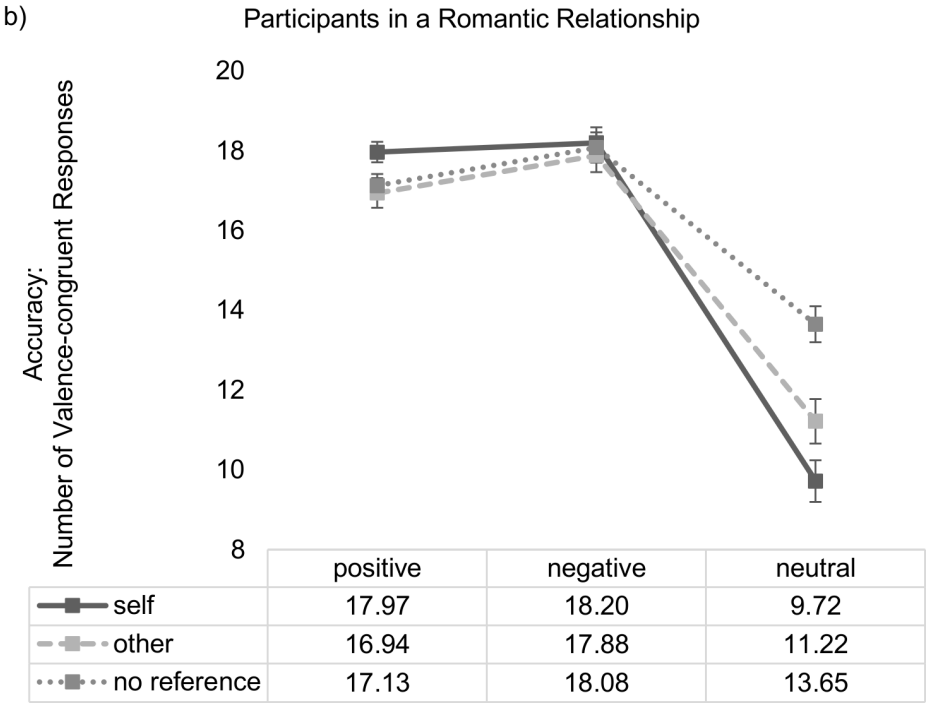
However, between-subject comparisons revealed that participants in a romantic relationship were significantly more accurate in the categorization of positive, other-related stimuli than were single participants (participants in a romantic relationship: $M = 16.94$, $SD = 3.44$; single participants: $M = 13.75$, $SD = 5.59$; $t(91.93) = 3.96$, $p \leq .001$) whereas both groups showed no significant differences in the evaluation of positive, self-related stimuli (participants in a romantic relationship: $M = 17.97$, $SD = 2.39$; single participants: $M = 17.15$, $SD = 4.06$; $t(89.31) = 1.41$, $p = .16$). Effects are summarized in Table 3, Fig 2 and Fig 3. Consequently, regarding accuracy data, the difference score between "positive, other-related stimuli" and "positive, self-related stimuli" also displayed a significant group difference between single participants and participants in a romantic relationship (participants in a romantic relationship: $M = -1.02$, $SD = 3.53$; single participants: $M = -3.39$, $SD = 4.20$; $t(114) = 3.60$, $p \leq .001$).

Reaction times. Analysis of reaction times revealed significant main effects of *stimulus valence* ($F(1.81, 245) = 77.32$, $p \leq .001$, $\eta p^2 = .364$), *stimulus reference* ($F(1.98, 267) = 71.51$, $p \leq .001$, $\eta p^2 = .346$), and *relationship status* ($F(1,135) = 5.02$, $p = .027$, $\eta p^2 = .036$), as well as significant interaction effects between *stimulus valence* and *stimulus reference* ($F(3.18, 430) = 17.34$; $p \leq .001$, $\eta p^2 = .114$) but, as shown in Fig 4, no significant three-way interaction between *stimulus valence*, *stimulus reference* and *relationship status* ($F(3.18, 430) = 1.53$; $p = .191$, $\eta p^2 = .011$). Using log-transformed data instead of raw data did not influence the direction, magnitude or significance of these findings.

Post-hoc-tests of the interaction between *stimulus valence* and *stimulus reference* revealed that reaction times for self-related positive stimuli were significantly faster than were reaction times for self-related negative or self-related neutral words or reaction times for other-related positive words (all participants: self-positive ($M = 1146.59$, $SD = 295.45$) vs. self-negative ($M = 1276.30$, $SD = 355.17$); $t(143) = 6.61$, $p \leq .001$; self-positive ($M = 1152.17$, $SD = 298.01$) vs. self-neutral ($M = 1501.14$, $SD = 540.40$); $t(142) = 9.46$, $p \leq .001$; self-positive ($M = 1146.94$, $SD = 295.37$) vs. other-positive ($M = 1252.11$, $SD = 353.73$); $t(142) = 5.62$, $p \leq .001$). As shown in



	positive	negative	neutral
self	17.15	17.23	10.31
other	13.75	17.08	12.64
no reference	16.34	17.10	13.18



	positive	negative	neutral
self	17.97	18.20	9.72
other	16.94	17.88	11.22
no reference	17.13	18.08	13.65

Fig 2. Stimulus valence x stimulus reference x relationship status interaction (DV: accuracy) for singles (a) and participants in a romantic relationship (b). Vertical bars denote +/- standard errors.

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Fig 4 these effects did not differ significantly between groups (single participants vs. participants in a romantic relationship).

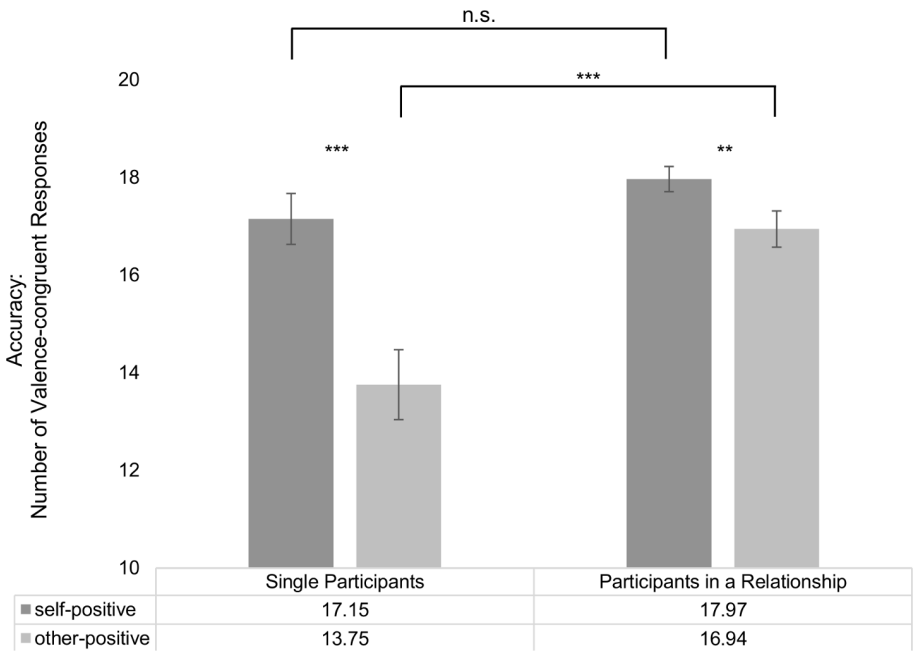


Fig 3. Accuracy for positive words with self-reference vs. other-reference; group comparison: Control group of singles compared to participants in a romantic relationship. Vertical bars denote +/- standard errors.

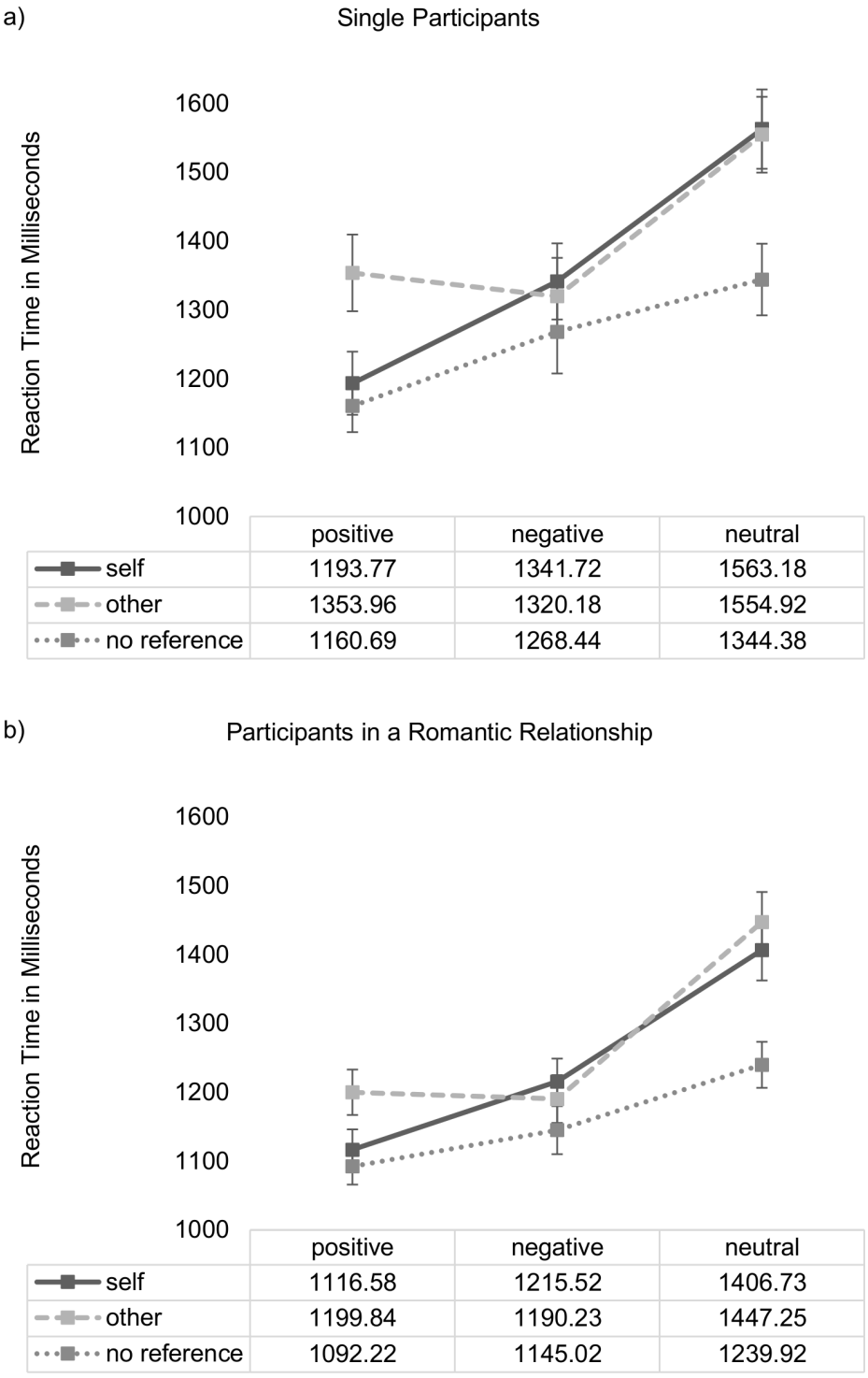
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Manipulation check and exploratory analysis

Gender effects. To check for possible gender effects, an additional 3 (*stimulus valence*) x 3 (*stimulus reference*) x 2 (*gender*) ANOVA (DV: response accuracy) was performed. The ANOVA revealed significant main effects of the factors *stimulus valence* ($F(1.62, 231) = 97.61$, $p \leq .001$, $\eta p^2 = .406$), and *stimulus reference* ($F(1.74, 250) = 24.09$, $p \leq .001$, $\eta p^2 = .144$), as well as significant interactions between *stimulus valence* and *gender* ($F(1.61, 231) = 10.69$, $p = .045$, $\eta p^2 = .070$), and between *stimulus valence* and *stimulus reference* ($F(2.83, 405) = 39.40$; $p \leq .001$, $\eta p^2 = .216$), as well as between *stimulus valence*, *stimulus reference* and *gender* ($F(2.83, 405) = 13.94$, $p \leq .001$, $\eta p^2 = .089$). Between-group comparisons between women and men demonstrated a significant difference in the number of valence-congruent answers to positive, other-related words (male participants: $M = 14.25$, $SD = 5.63$; female participants: $M = 16.37$, $SD = 4.03$; $t(143) = -2.62$, $p = .010$). Women showed higher accuracy (number of valence-congruent responses) for positive, other-related words than men. Within-subject comparisons (positive self-related vs. positive other-related words; positive self-related vs. neutral self-related words) showed a self-positivity bias in both male and female participants (see S1 Table and S1 Fig).

Regarding reaction times, the 3 (*stimulus valence*) x 3 (*stimulus reference*) x 2 (*gender*) ANOVA revealed significant main effects of *stimulus valence* ($F(1.80, 239) = 71.42$, $p \leq .001$, $\eta p^2 = .349$), *stimulus reference* ($F(1.98, 263) = 72.88$, $p \leq .001$, $\eta p^2 = .354$), *gender* ($F(1,133) = 11.42$, $p \leq .001$, $\eta p^2 = .079$), and significant interaction effects between *stimulus valence* and *stimulus reference* ($F(3.20, 425) = 14.15$; $p \leq .001$, $\eta p^2 = .096$). Post-hoc tests suggest that women responded faster than men overall, regardless of the stimulus category (male participants: $M = 1374.07$, $SD = 341.24$; female participants: $M = 1230.06$, $SD = 293.85$; $t(143) = 1.83$, $p = .009$). Effects are depicted in S2 Fig.

Interactions between relationship status and gender were tested in a 3 (*stimulus valence*) x 3 (*stimulus reference*) x 2 (*relationship status*) x 2 (*gender*)-ANOVA (DV: response accuracy),



	positive	negative	neutral
self	1193.77	1341.72	1563.18
other	1353.96	1320.18	1554.92
no reference	1160.69	1268.44	1344.38

	positive	negative	neutral
self	1116.58	1215.52	1406.73
other	1199.84	1190.23	1447.25
no reference	1092.22	1145.02	1239.92

Fig 4. Stimulus valence x stimulus reference x relationship status interaction (DV: mean reaction time in milliseconds) for singles (a) and participants in a romantic relationship (b). Vertical bars denote +/- standard errors.

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which showed main effects of *stimulus valence* ($F(2, 282) = 95.13$, $p \leq .001$, $\eta p^2 = .403$) and *stimulus reference* ($F(2, 282) = 24.80$, $p \leq .001$, $\eta p^2 = .150$) as well as interaction effects of *stimulus valence* and *stimulus reference* ($F(4, 564) = 40.70$, $p \leq .001$, $\eta p^2 = .224$), *stimulus valence* and *gender* ($F(2, 282) = 9.92$, $p \leq .001$, $\eta p^2 = .066$), *stimulus valence* x *stimulus reference* x *gender* ($F(4, 564) = 11.29$, $p \leq .001$, $\eta p^2 = .074$), *stimulus valence* x *stimulus reference* x *relationship status* ($F(4, 564) = 4.43$, $p \leq .01$, $\eta p^2 = .030$), but no significant interaction of the factors *gender* and *relationship status* ($F(1, 141) = 2.02$, $p = .158$, $\eta p^2 = .014$) and no significant four-way interaction ($F(4, 564) = 1.05$, $p = .382$, $\eta p^2 = .007$).

Analyzing reaction times in a 3 (*stimulus valence*) x 3 (*stimulus reference*) x 2 (*relationship status*) x 2 (*gender*)-ANOVA, revealed significant main effects of *stimulus valence* ($F(2, 262) = 68.59$, $p \leq .001$, $\eta p^2 = .344$), *stimulus reference* ($F(2, 262) = 70.19$, $p \leq .001$, $\eta p^2 = .349$), *relationship status* ($F(1, 131) = 4.27$, $p \leq .05$, $\eta p^2 = .032$) and *gender* ($F(1, 131) = 9.78$, $p \leq .01$, $\eta p^2 = .069$). Furthermore, there were interaction effects between *stimulus valence* and *stimulus reference* ($F(4, 524) = 13.80$, $p \leq .001$, $\eta p^2 = .095$), but neither a significant interaction between *stimulus valence*, *stimulus reference* and *relationship status* ($F(4, 524) = 1.93$, $p = .105$, $\eta p^2 = .014$), *stimulus valence*, *stimulus reference* and *gender* ($F(4, 524) = 1.42$, $p = .227$, $\eta p^2 = .011$), nor between factors *gender* and *relationship status* ($F(1, 141) = 2.02$, $p = .510$, $\eta p^2 = .003$), nor between *stimulus valence*, *stimulus reference*, *relationship status* and *gender* ($F(4, 524) = 1.75$, $p = .138$, $\eta p^2 = .013$).

Manipulation check. Post-experimental questions asking whom participants had imagined while judging other-related stimuli showed that $n = 62$ (55 female, 7 male participants) reported having thought at least occasionally about their partner, ex-partner or friends and family members while evaluating other-related stimuli. Notably, this occurred in participants in love as well as in single participants.

Exploratory analysis. Positivity Bias–Self–Other: Effects of Passionate Love: To assess whether feelings of passionate love influence the positivity bias to other-related positive stimuli and how this might interact with participants' relationship status (singles vs. being in a romantic relationship) correlation analyses were performed for the whole sample as well as separately for each group (singles vs. participants in a romantic relationship). Regarding participants in a romantic relationship, correlation analyses also included relationship quality (RAS scores). Correlation analyses were performed for accuracy in positive, other-related stimuli. Group-specific analyses revealed that neither PLS scores (single participants: $r = .165$, $p = .202$; participants in a romantic relationship: $r = -.040$, $p = .718$) nor RAS scores ($r = -.017$, $p = .895$) were correlated with the accuracy in other-related positive stimuli. Across all participants, however, PLS was positively correlated with the accuracy in positive, other-related stimuli ($r = .212$, $p = .010$).

A mediation analysis was conducted to investigate whether passionate love mediates the effect of relationship status on the accuracy in positive, other-related stimuli. Results indicated that relationship status (single participants vs. participants in a romantic relationship) was a significant predictor of PLS score, $b = 29.94$, $SE = 5.28$, $p < .001$, and that the PLS score was a significant predictor of the accuracy in positive, other-related stimuli, $b = .029$, $SE = .011$ $p = .010$. However, relationship status was still a significant predictor after controlling for participants' PLS score, $b = 2.28$, $SE = .825$, $p < .001$. About 12% of the variance in accuracy in positive, other-related stimuli could be explained by the predictors ($R^2 = .118$). The indirect effect was tested using a bootstrap estimation (5000 samples), which indicated that the indirect effect was not significant ($b = .342$, $SE = .375$; 95% $CI = -.388, 1.12$).

Moreover, in this non-clinical sample, there were no significant correlations between relationship duration, relationship satisfaction, empathic concern, depressive symptoms or state/trait anxiety and overall reaction times (all $p > .05$). Also, correlation analyses of reaction

times taking *stimulus valence* and *stimulus reference* into account showed no significant correlations with the aforementioned variables as well (all $p > .05$).

Regarding accuracy (valence-congruent responses), significant negative correlations were found between overall number of valence-congruent responses and measures of trait anxiety ($r = -.217$, $p = .008$) and depressive symptoms ($r = -.300$, $p = .003$), but there were no significant correlations with relationship duration, relationship satisfaction, empathic concern, nor state anxiety. Regarding depression, results could be obtained only for a subset of the participants for why results have to be taken with caution.

Analyzing the relations between control variables revealed that intensity of love (PLS) was positively correlated with relationship satisfaction ($r = .425$, $p \leq .001$), and relationship duration (log-transformed; $r = .317$, $p \leq .01$), but not with empathic concern ($r = .11$, $p = .175$), state anxiety ($r = -.10$, $p = .288$), nor with trait anxiety ($r = -.03$, $p = .715$) or depressive symptoms ($r = .085$, $p = .369$). Differences between single participants and participants in romantic relationship are reported in Table 2. All p-values reported in this section are reported uncorrected and significant effects also held true after Bonferroni correction.

Discussion

The present study investigated how a romantic relationship and being passionately in love with a partner influences the appraisal of self- and other-related emotional stimuli. Following previous research and taking Aron et al.'s theoretical model of self-expansion [30] into account it was investigated whether participants in a romantic relationship will show an extended self-positivity bias towards other-related, positive stimuli even if these stimuli are related to third persons in general. In addition, it was investigated whether appraisal of self-related, positive stimuli and hence, the self-positivity bias would be unaffected by this and it was explored how feelings of passionate love as well as gender and relationship duration affect the appraisal of self- and other-related emotional stimuli.

The presented results suggest that participants in a relationship showed intense feelings of passionate love towards their partner. Their PLS scores were comparable to scores of exclusively dating couples reported in Hatfield & Sprecher [48]. PLS scores of singles were moderate in height indicating that singles may experience feelings of passionate love to some degree but in an unreciprocated fashion and not with the same intensity as participants in a romantic relationship. Regarding appraisal of self-related words, results revealed a self-positivity bias. This bias occurred in both participant samples (singles vs. individuals in a romantic relationship), which was evident in response accuracy (number of valence-congruent responses) and reaction times. Comparisons within each group (see Figs 2 and 3 and Table 3) revealed that singles as well as individuals in a romantic relationship showed significantly more valence-congruent judgments for positive words when these were self-related as compared to when these were other-related or presented without any person reference. Moreover, singles as well as individuals in a romantic relationship responded significantly faster to self-related positive words than to self-related negative or neutral words. This suggests that a processing bias towards positive, self-related content exists independently from being in a romantic relationship. Moreover, this positivity bias for self-related positive words cannot be explained by confounding linguistic dimensions as the same set of nouns was presented in each reference condition; additionally, words were carefully matched on several linguistic dimensions previously shown to affect emotional word processing.

However, between-subject comparisons (i.e., when individuals in a romantic relationship were compared to singles) revealed an extended self-positivity bias, specifically for other-related positive words in individuals in a romantic relationship compared to singles. This bias

was evident in response accuracy: as shown in Fig 3 individuals in a romantic relationship showed more valence-congruent judgments for positive, other-related words than singles. This was observed in the absence of instructions hinting specifically at a close other (i.e., romantic partner). Thus, the extended positivity bias from self-related to other-related words in individuals in a romantic relationship may point towards an increased relevance of other-related, positive stimuli in general, irrespective of the personal significance of the 'other'. This would be in accord with the hypothesis of overall reduced self-other boundaries regarding positive emotions when in a romantic relationship. Interestingly, individuals in a romantic relationship were generally faster in their emotional evaluations than singles. This did, however, not interact with better accuracy for other-related, positive words in individuals in a romantic relationship compared to singles: the main effect did not interact with *stimulus valence* or *stimulus reference*, and neither could a three-way interaction between *stimulus valence*, *stimulus reference* and *relationship status* be found.

Intrusive thinking about the partner in individuals in a romantic relationship could explain the observed group differences in the processing of other-related positive words. When questioned post-experimentally, 55 participants in total, reported having thought occasionally about their partner, ex-partner, friends or close others when appraising stimuli in the insignificant-other-related stimulus categories. Intrusive thinking about the partner or about any other close relative cannot fully explain why specifically individuals in a romantic relationship appraised other-related positive words more often in a valence-congruent fashion, compared to singles. However, future studies are needed to validate this finding. To this end, an additional experimental condition should be included which explicitly instructs participants to think about their partners or ex-partners. This might help to further examine reduced self-other boundaries in individuals in a romantic relationship regarding their specificity towards the romantic partner compared to generalized effects towards an unspecified other.

Also, gender might play a role: exploratory analysis taking participants' gender as an additional factor into account revealed overall faster reaction times for significant interactions between the factors *stimulus valence* and *gender*, as well as an interaction between *stimulus valence*, *stimulus reference* and *gender*. Notably, there was no significant interaction between *stimulus reference* and *gender*, neither for response accuracy nor for reaction times. This might be interpreted as evidence that women and men did not respond differently to the masculine form of the pronouns used in this paradigm. Women compared to male participants, however, show an increased accuracy in the evaluation of specifically positive, other-related words compared to male participants while not differing in their evaluation of positive, self-related words. Therefore, male participants showed greater differences in the evaluation of positive, self-related words compared to other-related positive words. This suggests a stronger self-positivity bias in men compared to women. Regarding the specificity of the reported self-expansion effects in romantic relationships, it can be assumed that gender might have a similar facilitating effect on the general accuracy in the evaluation of other-related positive stimuli. Yet, no significant interactions containing both *gender* and *relationship status* were found. Therefore, although gender may bias the interaction between the emotionality of a word and its reference during emotional evaluation, the expansion of the self-positivity bias in participants in a romantic relationship was unrelated to any possible effects caused by the participants' gender.

As hypothesized, it appears that in the present study, the self-positivity bias is expanded towards other-related words when individuals in a romantic relationship are compared to single participants. This seems to occur, even in the absence of instructions directing thoughts towards close others (i.e., romantic partner) and is unrelated to the participants' gender, although the latter might have a similar effect. Being in love may expand the processing bias for self-related stimuli towards other-related stimuli. This self-other overlap would be in line

with the *self-expansion theory* by Aron et al. [27,30,59]. Moreover, the present results suggest that this effect might not be limited towards the close other. Instead, this effect may rather lead to a broadening of the processing bias towards positive, other-related stimuli in general.

Limitations and future directions

Since the present study was quasi-experimental in nature, the results should be interpreted accordingly. While we did find significant group differences in the responses towards other-related positive stimuli comparing single participants and participants in a romantic relationship, this obviously does not imply causation. Participants in a relationship might differ from singles in traits other than those measured and that we had controlled for in the present study. For instance, it is likely that singles and participants in a relationship differ in traits that influence why some people seek for and stay in a romantic relationship. It could be, that such traits may also influence the evaluation of self- and other-related information processing. A longitudinal study investigating participants in love over the course of forming, maintaining and maybe also terminating a romantic relationship while measuring changes in self-reported romantic love, relationship satisfaction and experimental reactions towards self- and other-related stimuli could provide insight into the mechanisms underlying love-related changes in the appraisal of self- and other-related stimuli. Moreover, extending participant samples to non-Western cultural samples might be especially fruitful to determine cultural differences in love-related changes in self-other evaluation.

On a related note, the presented results are a first step in understanding the exact mechanics underlying the extension of the self-positivity bias in romantic relationships. While it could be demonstrated that relationship status alone does influence the emotional evaluation of positive, other-related stimuli, and that neither relationship duration nor relationship quality mediate this effect, the exact mechanism and exact role of passionate love in this process still need to be uncovered. Although no correlation of intensity of passionate love and valence-congruent appraisal of other-related, positive words occurred, this might simply be because the present participants included in the relationship sample were homogenously passionately in love. It might be interesting to replicate the present experimental study with a broader sample of participants, covering all of Hatfield & Sprecher's [50] proposed categories of intensity of passionate love as well as participants in long-term romantic relationships over decades of their lives. Interestingly, the present sample of young, unmarried participants with academic backgrounds in relatively short-term relationships displayed a positive correlation between relationship duration and PLS scores. The intensity of their passionate feelings might be the reason for these couples to stay together in the first place. In long-term relationships, however, there might be a decline in certain aspects of passionate love [60] over time, reflecting a change in the nature of the relationship, which points towards the possibility that appraisal of self- and other-related stimuli might also change after years or decades of living in a romantic relationship.

In future studies, one may also include singles and participants in a relationship who are matched in their intensity of passionate love, which is reciprocated in one case and not in the other. This would allow for a proper evaluation of any effects of passionate love on the degree of enhancement in the processing of positive, other-related stimuli. However, participants in a relationship who aren't at least somehow passionately in love might terminate their romantic relationship sooner or later, making them rare to find. Furthermore, experimentally manipulating or assessing experienced closeness would allow for an elaborate distinction between effects of passionate love and effects of mere closeness with another person such as a friend, a relative, or, oppositely, a stranger. Additionally, real-world scenarios are often much more

complex than solely appraising certain stimuli such as words in the laboratory. Moreover, besides passionate love, other variables such as context, attitude towards the "other" and recent interpersonal interactions might influence emotional evaluation in real life.

Conclusion

As outlined in detail above, being in a romantic relationship extends the self-positivity bias to positive other-related stimuli. This expanded self-positivity bias, now a self-other-positivity bias, supports the self-expansion model proposed by Aron and colleagues [27,30,61]. The observed behavioral differences cannot be alternatively explained by differences in relationship duration or relationship satisfaction, or by interindividual differences in empathic concern, depressive symptoms or anxiety. In summary, our results suggest that positive emotions regarding another person might increase in relevance if a person is in love with another person and shares a relationship with him/her. Hence, the theoretically described effects of self-expansion and broadening of self-reference to another person when in love [38] seem to be emotion-specific, particularly to positive emotions and not limited to memory effects [38]. Taken together, the present results add to the notion that also non-pathological changes in affective experience can influence processing biases of emotional stimuli varying in self-reference.

Supporting information

S1 Fig. Stimulus valence x stimulus reference x relationship status interaction (DV: accuracy) for male (a) and female participants (b). Vertical bars denote +/- standard errors.
(PDF)

S2 Fig. Stimulus valence x stimulus reference x relationship status interaction (DV: mean reaction time in milliseconds) for male (a) and female participants (b). Vertical bars denote +/- standard errors.
(PDF)

S1 Table. Valence-congruent answers: Paired samples t-test results for differences between selected stimulus categories for male and female participants.
(PDF)

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Author Contributions

Conceptualization: Cornelia Herbert.

Formal analysis: Friedrich Meixner, Cornelia Herbert.

Investigation: Friedrich Meixner.

Methodology: Cornelia Herbert.

Project administration: Cornelia Herbert.

Resources: Cornelia Herbert.

Software: Cornelia Herbert.

Supervision: Cornelia Herbert.

Validation: Friedrich Meixner, Cornelia Herbert.

Visualization: Friedrich Meixner.

Writing – original draft: Friedrich Meixner, Cornelia Herbert.

Writing – review & editing: Friedrich Meixner, Cornelia Herbert.

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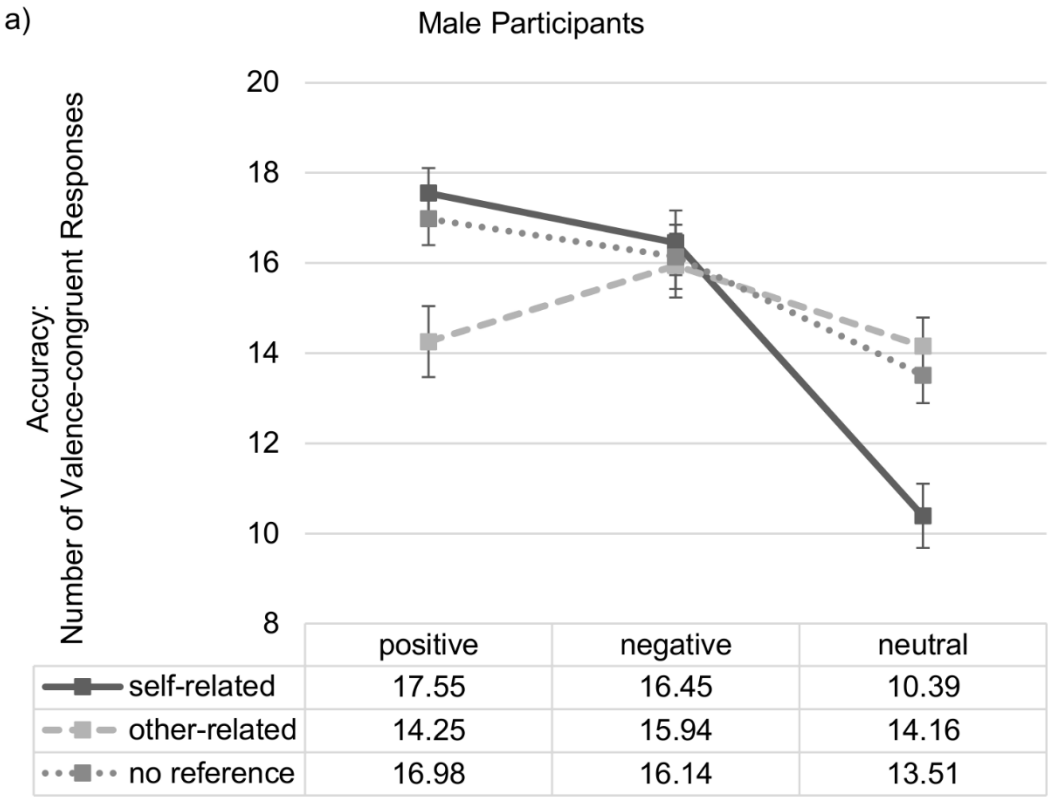
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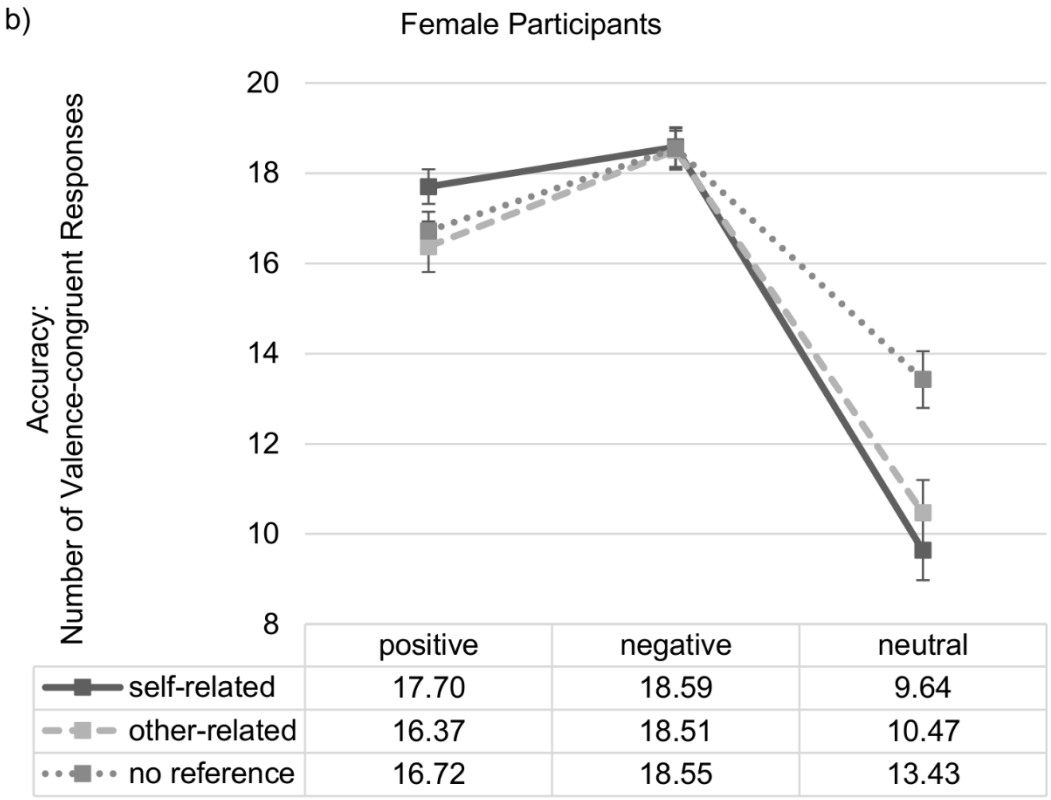
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Supporting Information

S1 Fig. Stimulus valence x stimulus reference x relationship status interaction (DV: accuracy) for male (a) and female participants (b). Vertical bars denote +/- standard errors.



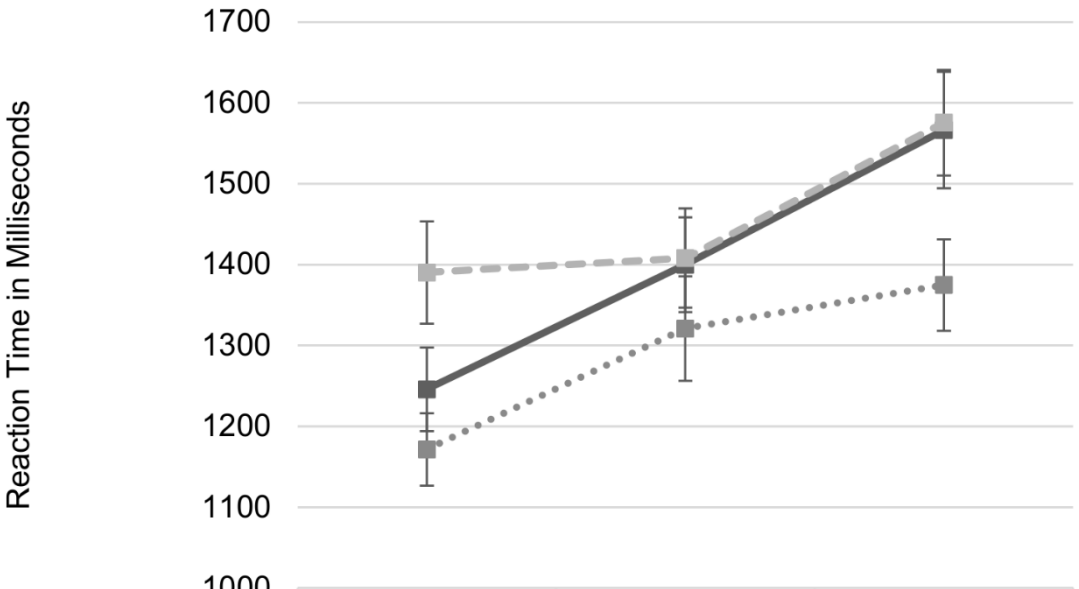
	positive	negative	neutral
self-related	17.55	16.45	10.39
other-related	14.25	15.94	14.16
no reference	16.98	16.14	13.51



	positive	negative	neutral
self-related	17.70	18.59	9.64
other-related	16.37	18.51	10.47
no reference	16.72	18.55	13.43

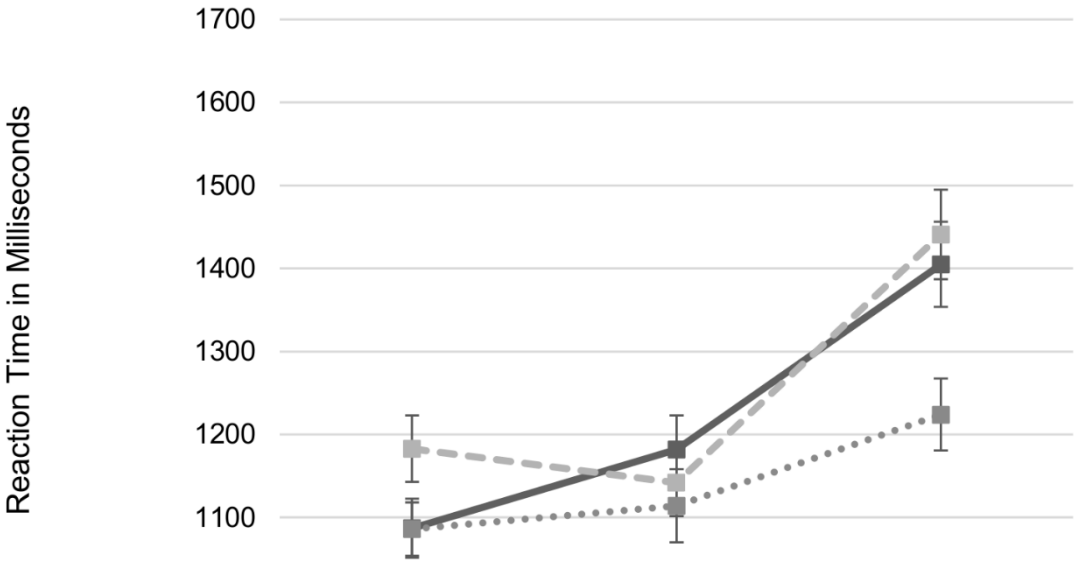
S2 Fig. Stimulus valence x stimulus reference x relationship status interaction (DV: mean reaction time in milliseconds) for male (a) and female participants (b). Vertical bars denote +/- standard errors.

a)



	positive	negative	neutral
self-related	1245.80	1399.96	1566.40
other-related	1390.32	1408.01	1575.49
no reference	1171.51	1320.93	1374.77

b)



	positive	negative	neutral
self-related	1087.10	1181.89	1404.99
other-related	1182.91	1141.64	1441.02
no reference	1086.17	1114.12	1223.95

S1 Table. Valence-Congruent Answers: Paired Samples t-Test Results for Differences between Selected Stimulus Categories for Male and Female Participants.

					95% CI	
Pair	*M*	*SD*	*t*		Lower Bound	Upper Bound
Male Participants[a]						
self-positive - other-positive	3.29	4.72	4.98	***	1.97	4.62
self-positive - self-negative	1.10	3.78	2.07	*	0.03	2.16
self-positive - self-neutral	7.16	7.25	7.05	***	5.12	9.19
self-positive - unreferenced-positive	0.57	1.90	2.14	*	0.03	1.10
Female Participants[b]						
self-positive - other-positive	1.33	3.40	3.80	***	0.63	2.03
self-positive - self-negative	-0.88	4.24	-2.02	*	-1.75	-0.01
self-positive - self-neutral	8.06	6.17	12.67	***	6.80	9.33
self-positive - unreferenced-positive	0.98	2.11	4.49	***	0.55	1.41

[a]df = 50
[b]df = 93
*$p \leq .05$
**$p \leq .01$
***$p \leq .001$

Study III

Reference:

Meixner, F., & Herbert, C. (2022). Acute aerobic exercise and attentional focus influence the self-positivity bias in emotional evaluation. Evidence from an experimental study. *Open Psychology*, *4*(1), 187–204. https://doi.org/10.1515/PSYCH-2022-0010

Friedrich Meixner prepared the manuscript, tables, and figures. Cornelia Herbert revised it for scientific and intellectual content. Friedrich Meixner planned the experiment, collected the data, preprocessed, and analyzed the results under the supervision of Cornelia Herbert. Both authors contributed to the article and approved the final version of the manuscript.

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Research Article

Friedrich Meixner, Cornelia Herbert*

Acute aerobic exercise and attentional focus influence the self-positivity bias in emotional evaluation. Evidence from an experimental study

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Abstract: The influence of aerobic exercise, as a possibly mood-enhancing experience, was investigated for its effect on emotional evaluation of self- vs. other-related emotional (e.g., my/his joy) or neutral (e.g., my/his notes) stimuli. *N*=30 participants (healthy, female novices, i.e., with no regular, dedicated training schedule) performed four separate sessions of moderate aerobic exercise (22 min of cycling at 60-70% HRmax). Attentional focus was manipulated across exercise bouts (internal focus vs. external focus vs. no instructed attention focus vs. control condition consisting of no exercise and no instructed attention focus). Emotional evaluation of verbal stimuli was assessed 10 minutes after each exercise bout. Exercise increased self-reported positive affect compared to the inactive control condition regardless of attentional focus. Exercising without instructed attentional focus led to faster reaction times in the emotional evaluation task compared to the inactive control condition. Instructed internal or external attentional focus did not affect evaluations (number of valence-congruent responses) or reaction times compared to the no-exercise control condition. Self-reported internal attentional focus during cycling was associated with a subsequently stronger, and in the case of an external focus with a subsequently rather reduced self-positivity bias in the evaluation of self-related, positive vs. other-related positive words.

Keywords: aerobic exercise; emotional evaluation; physical activity; attentional focus; self-positivity bias.

1 Introduction

Acute physical activity – particularly low-to-moderate aerobic exercise - is widely regarded to have positive effects on mood (Basso & Suzuki, 2017; Broman-Fulks et al., 2015; Chase & Hutchinson, 2015; Crush et al., 2018; McDowell et al., 2016; Müller et al., 2021; Nouchi et al., 2020; Petruzzello et al., 1991; Reed & Ones, 2006; Steptoe & Cox, 1988; Szabo, 2003; Yeung, 1996). Depending on exercise intensity (Alvarez-Alvarado et al., 2019; Ekkekakis et al., 2004, 2008, 2011; Paolucci et al., 2018), expectations about potential benefits (Helfer et al., 2015; Mothes et al., 2016), modality (Cavarretta et al., 2018; Chase & Hutchinson, 2015), training experience (Cavarretta et al., 2018; Hoffman & Hoffman, 2008), appraisal of previous exercise experiences (see also Dual Mode Theory DMT and Affective-Reflective Theory ART; Ekkekakis, 2003, 2009; Ekkekakis & Brand, 2019) or attentional focus (Brick et al., 2014; Lind et al., 2009; Neumann & Moffitt, 2018), participants usually report a reduction in aversive mood-related symptoms. This holds true for a healthy population, but also in participants suffering from depressive disorders (Brand et al., 2018; Frühauf et al., 2016; Niedermeier et al., 2021), or anxiety (Bibeau et al., 2010). It has also been reported to reduce a cognitive interpretation bias (Clarke et al., 2018), i.e., the tendency to cognitively interpret neutral or even positive information in a negative

***Corresponding author: Cornelia Herbert,** Applied Emotion and Motivation Psychology, Institute of Psychology and Education, Ulm University, 89081 Ulm, Baden-Württemberg, Germany, E-mail: cornelia.herbert@uni-ulm.de
Friedrich Meixner, Applied Emotion and Motivation Psychology, Institute of Psychology and Education, Ulm University, 89081 Ulm, Baden-Württemberg, Germany

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fashion, which is strongly suspected to be one of the vulnerability factors for clinical depression (Beck, 1967), especially if stimuli are self-related (e.g. Herbert et al., 2014).

Therefore, aerobic exercise has found its way into therapeutic guidelines for many psychiatric disorders (e.g., Schneider et al., 2017). Besides clinical populations, aerobic exercise is also a common recommendation for a healthy population to alleviate stress and benefit from its mood-enhancing effects. However, it has not yet been evaluated how the positive affect people usually gain from exercising translates into later behavioural choices or stimulus evaluations, such as a diminished cognitive interpretation bias (Clarke et al., 2018). Some previous research also suggested that acute aerobic exercise enhances self-image and feelings of self-worth even after a single bout of exercise (Salci & Martin Ginis, 2017; Vocks et al., 2009; contrary results e.g. Fallon & Hausenblas, 2005), suggesting a degree of self-specificity of the effects of aerobic exercise.

To sum it up, it has yet to be determined if the mood-beneficial effects from exercising translate into a general positivity bias via mood-congruency, i.e., if the positive mood after exercising generally leads to the processing of stimuli in a more positive fashion. Alternatively, exercise might also translate exclusively into a self-positivity bias due to self-specificity of the mood enhancement: Positive mood effects might be strictly self-specific (e.g., feeling good about oneself), translating into a positivity bias only regarding self-related stimuli. Testing the effects of aerobic exercise on evaluation choices of positive, negative, or neutral, self-, and other-related stimuli might be a first step in understanding the interplay of aerobic activity, its effects on mood, the role of the self, and their influence on latter behavioural expression, i.e., evaluation of self- and other-related emotional stimuli.

1.1 Emotional evaluation of self- and other-related stimuli

In general, healthy subjects usually display a substantial bias for processing information with self-reference (Blume & Herbert, 2014; Esslen et al., 2008; Symons & Johnson, 1997; Zhou et al., 2010). In addition, a positivity bias is usually reported in healthy participants (Augustine et al., 2011; Herbert et al., 2008, 2009), suggesting a more elaborate processing of positive compared to negative stimuli (verbal stimuli such as “joy” vs. “fear”), i.e., faster reaction times and increased memory of positive stimuli in recall tasks. This positivity bias has been found to interact with the self-reference of the stimulus (Fields & Kuperberg, 2016; Fossati et al., 2003; Herbert, Herbert, Ethofer, & Pauli, 2011; Meixner & Herbert, 2018; Meixner, Montag, & Herbert, 2019; Weis & Herbert, 2017). In particular, it has been shown that information processing for positive words is enhanced when these are paired with self-referential information, compared to self-related neutral, or other-related, positive information (e.g., verbal stimuli such as “my pleasure” versus “his pleasure”), which is known as the self-positivity bias (Herbert, Herbert, Ethofer, & Pauli, 2011; Meixner & Herbert, 2018; Meixner, Montag, & Herbert, 2019; Weis & Herbert, 2017). Experimentally, emotional evaluation and the self-positivity bias can be assessed in tasks such as the His-Mine paradigm (Herbert, Herbert, et al., 2011; Herbert, Pauli, & Herbert, 2011; Meixner & Herbert, 2018; Meixner et al., 2019; Weis & Herbert, 2017; Winter et al., 2015, 2018): In this task, participants are presented with pronoun-noun combinations of positive, negative, or neutral words and reference information (self-, or other-specific pronouns), e.g. “my joy”, “his appointment”, and asked to evaluate the emotional content of the presented stimulus as either positive, negative, or neutral.

A series of experiments suggested that the His-Mine paradigm and the self-positivity bias can serve as indicators of altered self-other-discrimination as well as participants’ emotional evaluation choices. For example, it could be shown that participants suffering from depression display a self-negativity bias instead of a self-positivity bias (Herbert et al., 2014). Secondly, interpersonal relationships seem to be associated with a reduced self-positivity bias, probably due to altered self-other boundaries (Meixner & Herbert, 2018). In patients suffering from disorders related to the self, e.g., schizophrenia, the self-positivity bias is also diminished (Herbert et al., 2018). These results suggest variability of the self-positivity bias, depending on the participants’ focus on his/her self.

In accordance with appraisal theories of emotion, such as the *component process model of emotion* by Scherer et al. (CPM; Grandjean & Scherer, 2008; Sander et al., 2008; Scherer, 2001), the previously reported results might be based on changes in individual appraisal mechanisms, which are influenced by a) mood congruency, as well as b) the salience of oneself or another person in the experimental setting. In this experiment, we wanted to test these hypotheses by manipulating attentional focus during exercise, i.e., making the participants’ Self more, or less salient during exercise.

1.2 Focusing attention on self- vs. non-self-related stimuli during exercise

During aerobic exercise, it is a common strategy to use attentional focus to reach a specific exercise goal: Novices, i.e., participants not regularly engaged in performance-oriented sports usually, prefer distraction from themselves, i.e., their physical symptoms, since an internal focus of attention is often reported to be aversive and exerting (Blanchard et al., 2004; LaCaille et al., 2004; Welch et al., 2007). Professional athletes, however, might employ an internal focus of attention voluntarily in particularly difficult phases of a competition: It has been hypothesized that an internal focus of attention, while possibly being more exerting, might aid in injury prevention (Brick et al., 2014; Lind et al., 2009). In exercise psychology, Stevinson & Biddle (1998, 1999) or Brick et al. (2014) proposed a model of attentional focus during exercise in which the authors distinguish between two dimensions: *task-relevance* (i.e., how relevant is the stimulus to the success of the performed activity, e.g., road conditions being highly relevant, and music being rather irrelevant to successful running) and *internal/external direction* of attention (i.e., is the stimulus located within the exercising person, e.g., own thoughts or burning sensations in the muscles could be classified internal, and competitors could be classified external). In their review, Brick et al. (2014) concluded that during exercise with internal sensory monitoring, exertion is usually perceived as greater. However, employing an external-irrelevant attentional focus, i.e., distraction, was associated with increased positive feelings such as revitalization and tranquillity, and reductions in physical exhaustion (Blanchard et al., 2004; LaCaille et al., 2004).

Controversy in the taxonomy of attentional focus categories has shown that attentional focus needs to be precisely defined. In the present study, we focused on an internal-relevant and external-irrelevant focus of attention. An internal-relevant focus of attention could theoretically allow for an increased salience of self, due to a persisting focus on self-related and self-relevant stimuli. Additionally, it is conceptually narrower than an internal-irrelevant focus of attention, ensuring better comparability between participants' exercise experience. We also refrained from including an internal-irrelevant focus of attention due to its conceptual vagueness (mind-wandering, arithmetic calculations, imagery, imagining music). An external-irrelevant focus of attention could be considered the most conceptually distant focus to an internal-relevant focus, representing as much distraction as possible from the task and from self-related information, possibly decreasing salience of the self and related concepts. An external-relevant focus of attention (track conditions, competitors) would be hard to emulate and highly artificial in a standardized laboratory environment and has therefore also been excluded.

Taking together the previously reported results, it seems crucial to control for exercise experience, exercise intensity, and attentional focus during exercise. Without controlling for attentional focus, moderate physical activity would primarily elicit the employment of distracting strategies in novices. Besides experimentally manipulating attentional focus, it is also sensible to assess the self-reported, or self-chosen focus of attention by asking participants after the activity what they thought about during the activity (Wininger & Gieske, 2010). As outlined above, the attentional focus during acute exercise can be directed towards or away from one's self. A prolonged focus in either of those categories could influence mood and perceived exertion of the exercising person, as has previously been reported. However, it has not previously been investigated if and how a prolonged attentional focus during exercising might also influence subsequent processing and evaluation of self- or non-self-related, positive, negative, and neutral information, which we investigated in this study.

1.3 Aim and hypotheses

The present study was conducted to study the effects of aerobic exercise with varying attentional focus in healthy novices. The term "novice" is henceforth used to describe participants who are not regularly engaged in professional or competitive sports and have no dedicated training schedule. 'Novices' is not meant to describe a completely sedentary sample. We also define a cutoff of exceeding five hours of dedicated, performance-oriented training per week.

It is assumed that novices are not familiar with specific attentional focus techniques to influence their performance. Since gender might be a confounding factor due to gender-specific reactions to attentional focus (Frazier & Fatis, 1980; Lind et al., 2009; Wrisberg et al., 1988), reasons for exercise (e.g. Furnham, Badmin, & Sneade, 2002), physiological responses to exercise (Acevedo, 2012; Hill, Housh, Smith, Schmidt, & Johnson, 2018; Roepstorff et al., 2002), mood responses to acute aerobic exercise (McDowell et al., 2016), as well as a possible influence to emotional evaluation

of self- and other-related emotional information (Meixner & Herbert, 2018), the present sample has been restricted to female participants.

Three outcomes were assessed, 1) affective experience of exercising with varying/no attentional focus instructions (confirmatory to previous research), 2) a general (self-)positivity bias after aerobic exercise in congruency with participants' mood, and 3) dependence of the latter effect on focusing attention on themselves (internally) compared to distractions (externally) during exercising.

Since previous studies did not consistently manipulate attentional focus experimentally, but instead relied on self-report data[1], the following hypothesized effects were tested twice: Firstly, as comparisons between experimental conditions, and secondly as functions of self-reported attentional focus.

1) Acute aerobic exercise is expected to influence affective experience: An increase in positive affect and more perceived exertion is expected immediately and 10 minutes after the exercise, compared to an inactive control condition, regardless of attentional focus.
2) Aerobic exercise leads to an increase in positive mood, further leading to a mood-congruent processing bias (higher speed and more valence-congruent evaluations) for positive verbal stimuli, compared to negative or neutral stimuli.
3) An increased focus on self-related stimuli (*internal* focus of attention) enhances the processing of subsequently presented self-related information. An *internal* focus of attention should therefore facilitate (i.e., higher speed and more valence-congruent evaluations), whereas an external focus of attention should impede (i.e., reduced speed and valence-congruent evaluations) subsequent emotional evaluation of self-related stimuli, compared to baseline values. It is also expected that these effects interact with the valence of the presented stimuli, i.e., attentional focus and positive mood interacting to influence the self-positivity bias in emotional evaluation.

Lastly and exploratively, it has been hypothesized that interpersonal differences in interoceptive awareness might explain adherence to instructions of an internal attentional focus. Therefore, interoceptive awareness has been analysed as a potential mediator for possible effects of internal attentional focus on the self-positivity bias.

2 Materials and Methods

2.1 Participants

The required number of participants has been calculated using G*Power 3.1 (Faul et al., 2009) with the following input parameters: f=.25, α=.05, 1-β=.95, 1 group, 36 measurements (3 (*stimulus valence*)*3 (*stimulus reference*)*4 (*experimental condition*) ANOVA), ε =.8, resulting in a required sample of N=22 participants to detect medium effects. N=32 female participants fulfilled all inclusion criteria and were invited to participate in the experiment. Two participants dropped out after two experimental sessions. Thus, the remaining sample consisted of N=30 (age M=21.00, SD=2.17, exclusively female, right-handed, and native speakers of the German language) participants.

Since this study set out to examine attentional focus effects in novices, an exclusion criteria has been set up following the World Health Organization's (WHO) recommendations for physical activity: participants have been excluded if they reported regular training or vigorous exercise for more than 5 hours per week (i.e. being notably more active than the World Health Organization's WHO recommendations; Armstrong and Bull, 2006), or if they reported to be preparing for a sports competition. No participant reported to be completely physically inactive. All participants reported some physical activity in their leisure time, during their jobs or on their way to university, albeit less than the described five hours per week. Therefore, participants could neither be classified as sedentary, nor as athletes, but instead as healthy novices. Further exclusion criteria were self-reported psychiatric or neurological disorders, not being 18-30 years of age, a smoking habit, as well as physical ailments (Physical Activity Readiness Questionnaire; PAR-Q;

1 Most articles included in the seminal review by Brick et al. (2014) assessed self-reported attentional focus after the exercise. More recently, articles by e.g., Schücker et al. (2016) reported employing experimental manipulations of attentional focus, primarily investigating the effects on movement economy.

Thomas et al., 1992) or visual impairments preventing safe/successful completion of the aerobic exercise (cycling) or the emotional evaluation paradigm.

Participants were recruited using poster advertisements on campus (containing only necessary information, i.e., physical exercise would be performed, duration of the experiment, inclusion criteria, and a contact e-mail address) or via dedicated mailing lists. An online questionnaire prior to the laboratory sessions ensured that participants met the inclusion criteria. Therefore, no participants had to be excluded after data collection. All participants gave written, informed consent, and received course credit in return for their participation. The study protocol was approved by the local ethics committee. All subjects gave written informed consent prior to testing.

2.2 Materials

In the present study, we employed a variant of the established affective His-Mine paradigm (Herbert et al., 2018; Herbert, Herbert, et al., 2011; Herbert, Pauli, et al., 2011; Meixner et al., 2019; Meixner & Herbert, 2018; Weis & Herbert, 2017; Winter et al., 2015, 2018). The affective His-Mine Paradigm investigates emotional evaluation of stimuli varying in stimulus valence (positive, negative, or neutral) and in self- vs. other-reference using emotional and neutral pronoun-noun pairs as self-referential (self and other) and article-noun pairs as non-referential emotional and neutral control stimuli. It is therefore well-suited to address the research questions of mood-congruent and self-related information processing after aerobic exercise with different attentional focus: Information processing of self- versus other-related information, an interpretation bias, as well as a self-positivity bias (Fields & Kuperberg, 2016; Fossati et al., 2003; Herbert, Pauli, et al., 2011a,b; Meixner & Herbert, 2018; Weis & Herbert, 2017), are indicated by two behavioural measured including *reaction time* and number of *valence-congruent answers*. In the present study, 30 nouns were included for each valence category (positive, negative, neutral). Each noun has been paired with one of three pronouns (my, his, her), totalling 270 pronoun-noun combinations, i.e., each noun is presented thrice, albeit with a different pronoun each time. The nouns used in this study were previously matched for several linguistic dimensions, i.e., word length and word frequency (all $p>.1$), and for arousal, with the aid of standardized word sets. Positive, negative, and neutral nouns differed significantly in their valence ratings ($p\leq.05$), and arousal ratings: positive and negative nouns were comparable in their elicited arousal ($p>.1$), yet both differed from the neutral nouns ($p\leq.05$). More detailed information on stimulus material is available in Meixner and Herbert (2018).

At the beginning of each trial, a fixation cross was displayed for a random time interval of 1000 to 1500 milliseconds. The computer screen was set to a resolution of 1280x1024 pixels and a refresh rate of 60 Hz. Words were presented in white 70pt letters (Times New Roman) on a black background. Viewing distance of participants was ~60cm, which resulted in a visual angle of 1° 54' 0.58'' for stimulus height. Each stimulus was presented for 3000ms or until participants gave any evaluation. Following each word pair, a six-letter string (XXXXXX) was presented for 2000ms to reduce carry-over effects. Order of the stimuli has been randomized for each participant, but it was ensured that stimuli of the same category (e.g., self-positive stimuli) never occurred immediately after one another.

During the initial online questionnaire, participants answered self-report measures to check for a) inclusion/exclusion criteria, b) scores exceeding recommended cut-offs for likely diagnoses, i.e., depressive symptomatology or anxiety and c) to assess potential mediating influences of interoceptive awareness (exploratory hypothesis) on the effects of attentional focus. Measures included: depressive symptomatology (BDI-II; Hautzinger, Keller, Kühner, & Beck, 2009), trait positive/negative affect (PANAS; Krohne et al., 1996; Watson et al., 1988), state/trait anxiety (STAI; Laux, Glanzmann, Schaffner, & Spielberger, 1981), interoceptive awareness (MAIA; Bornemann, Herbert, Mehling, & Singer, 2015; Mehling et al., 2012), general physical activity (GPAQ, World Health Organization WHO; Armstrong and Bull, 2006), and a self-report measure of their preferential attentional focus during physical activity, and how much time participants usually spend with it from 0-100% (based on Stevinson & Biddle, 1998; Wininger & Gieske, 2010). Table 1 illustrates the self-report measure used to assess habitual (online questionnaire) and situational (i.e., during experimental sessions) attentional focus.

Table 1: Assessment of habitual and situational attentional focus (based on Wininger & Gieske, 2010, albeit with categories based on Stevinson & Biddle, 1998). Participants were asked to give their responses on a visual analogue scale (0-100% of the time; table taken from Meixner, F., & Herbert, C. 2021).

Attentional Focus *(not visible to participants)*	**Instruction: Please indicate if / how much of the time you [spend during a typical physical activity]** *or* **[spent during the 15 minutes of physical activity] with the following categories.**
Internal-relevant	Your attention is directed inwards, i.e. how your body feels during the exercise – Examples are breathing, muscle soreness, thirst, fatigue, sweating, blisters, nausea.
External-relevant	Your attention is directed outwards on things that are relevant for the execution of the task – Examples are strategy, track markers, water stations, lap times, the track and its conditions.
Internal-irrelevant	Your attention is directed inwards on things that are irrelevant for the execution of the task – Examples are daydreaming, imagining music, arithmetic problems, philosophy, religion.
External-irrelevant	Your attention is directed outwards on things that are irrelevant for the execution of the task – Examples are scenery, spectators, other exercising people, environment.

2.3 Procedure

After completion of the online questionnaire (see Materials) participants were invited to four experimental sessions in the laboratory at self-chosen time slots, always one week apart and always at the same time of day.

Each participant completed three aerobic exercise conditions and one inactive control condition. All conditions started with ICG (impedance cardiography) electrode placement and a 5-minute baseline measurement. The impedance cardiography was included in the study protocol to assess psychophysiological changes associated with different attentional focus during aerobic exercise, as part of a larger study and to be presented in a different manuscript. Study samples are identical, even after exclusion of participants. However, analyses regarding psychophysiological data differed in objective, research question, analytic methods, and conclusions, and can therefore be discussed independently in a separate manuscript by the authors.

In the exercise conditions, participants were asked to cycle on a stationary bicycle ergometer (Daum, ergo_bike premium8i). An adaptive bicycle track simulation using the ErgoPlanet software (http://www.ergoplanet.de/) was projected on the wall in front of the participants. During a 5-minute warmup period, cycling intensity (Watt) has been adjusted to moderate intensity, directed by participants' heart rate (i.e., moderate intensity was defined as 60-70% of age-based HRmax; calculated via the formula proposed by Tanaka et al., 2001). Afterwards, participants were told to cycle for 15 minutes, and were instructed to either focus on the force production of the quad muscles (condition A; *internal-relevant* attentional focus; Schücker et al., 2016a; auditory reinforcements every 30 seconds), or to focus on the brightness changes in the bicycle track simulation (condition B; *external-irrelevant* attentional focus; auditory reinforcements every 30 seconds), or to simply cycle for 15 minutes without any specific attentional focus instruction (condition C; no auditory reinforcements). In the control condition D, participants were asked to sit for five minutes on the bicycle without cycling and no auditory instructions. Although the time spent on the bicycle ergometer in control condition D has been shorter compared to conditions A, B and C, consecutive physical inactivity during condition D was 15 minutes, and is thus comparable to the 15 minutes of exercise in conditions A, B, and C.

During the conditions with the internal-relevant attentional focus (A) or the external-irrelevant attentional focus (B), the attentional focus instructions were reinforced every 30 seconds by auditory instructions and participants had to state how force production/brightness has changed (A: stronger/unchanged/lighter; B: brighter/unchanged/darker). In condition C and D, participants only received initial instructions, but heard no auditory reinforcements, and were not asked for any verbal statements during the exercise. Order of the experimental conditions has been randomized for each participant.

After the aerobic exercise, a 2-minute cooldown followed. A self-report questionnaire asking for actual attentional focus during the activity (based on Stevinson & Biddle, 1998; Wininger & Gieske, 2010; see Table 2) followed. A 10-minute break followed to ensure comparable recovery status in all participants, e.g., heart rate returning to baseline levels, and to exclude heightened physical arousal as a confounding factor in the evaluation of emotional stimuli.

Next, participants completed the affective His-Mine paradigm (~20 minutes; Herbert, Herbert, et al., 2011; Herbert, Pauli, et al., 2011; Meixner & Herbert, 2018; Meixner, Montag & Herbert, 2019; Weis & Herbert, 2017). Instructions on the screen explained that they will be presented words, which could be either related to their own feelings or to those of a virtual, unknown third person. Participants were primarily instructed to evaluate the presented verbal stimuli based on their own gut feelings, using color-coded buttons on a response pad (green: positive, red: negative, grey: neutral), i.e., they were not asked to categorize the presented stimuli but to appraise the pronoun-noun pairs in terms of their emotional self-relevance. Based on their gut feelings, they were told to respond, with the index finger of their dominant hand (all participants were right-handed). Index finger had to rest on, and between trials return to a fixed starting position, equidistant to each of the response buttons. Before the trials, participants completed seven test trials to ensure they understood the instructions. The paradigm has been programmed and presented using Presentation® software (Version 19, Neurobehavioral Systems, Inc., Berkeley, CA, http://www.neurobs.com). Lastly, if it was the fourth and last experimental session, participants completed the BDI-II (Hautzinger et al., 2009) and the PANAS (trait; Krohne et al., 1996; Watson et al., 1988) for pre-post study comparison.

During the experimental sessions, positive and negative affect (PAAS; Lox et al., 2000) as well as perceived exertion (RPE; Borg, 1982, 1998) were measured four times: before (T1), immediately after (T2), +10 min after (T3; immediately before the His-Mine paradigm), and +30 min after the aerobic exercise (or the inactivity in the control condition D) (T4; immediately after the His-Mine paradigm).

2.4 Analysis

As a first step, self-reported attentional focus during the exercise was analysed separately for each condition as a manipulation check using paired samples *t*-tests.

Secondly, all exercise conditions were compared to the control condition in a repeated measures (rm) MANOVA with the dependent variables positive affect, negative affect (PAAS), and perceived exertion (RPE) and simple contrasts.

Subsequently, two 3 (*valence*) x 3 (*reference*) x 4 (*condition*) repeated measures (rm) ANOVAs were calculated to check for the usually found self-positivity bias in dependent variables (DV) *reaction times* and *number of valence-congruent answers*, and effects of experimental conditions. Only valence-congruent trials were included in the calculation of mean *reaction times*. Typically, in reaction time experiments, reaction times and number of valence-congruent answers (i.e., accuracy) are negatively associated due to a speed-accuracy trade-off. However, the instructions to the His-Mine paradigm are aimed at an evaluation based on participants' gut feelings towards the presented stimulus. The instructions do not encourage speed, nor accuracy, as goals in the evaluation paradigm. Therefore, reaction times and valence-congruent answers are not associated in terms of a classic speed-accuracy trade-off but can be interpreted relatively independent from each other: Reaction times can be used to estimate processing speed, i.e., integrating information on reference and valence, reaching an evaluative decision, and pressing the corresponding button. Number of valence-congruent answers indicates how stimulus reference influences the emotional evaluation of positive, negative, and neutral stimuli.

As outlined in the introduction, additional analyses have been performed using the *self-reported* attentional focus. This required scaling of the self-positivity bias. Hence, the self-positivity bias has been calculated as difference scores of other-related positive stimuli vs. self-related positive stimuli, and of self-related neutral stimuli vs. self-related positive stimuli. The difference scores can range from +30 to -30, with a negative score implicating more valence-congruent evaluations for self-related positive stimuli compared to other-related positive or self-related neutral stimuli. Subsequently, measures of affect, exertion, and of the self-positivity bias (i.e., both difference scores) were correlated with the self-reported attentional focus using Pearson correlation analyses (one-sided). To ensure that possible effects are due to the combination of aerobic exercise plus the attentional focus, these analyses have been repeated for the physically inactive control condition versus the exercise conditions separately.

Measures of *reaction times* and *number of valence-congruent answers* were subsequently correlated with measures of positive and negative affect to check for effects of mood-congruent processing on emotional evaluation, using Pearson correlation analyses (one-sided).

Exploratory analyses were performed to check for repetition effects in the His-Mine paradigm and for possible mediation by interoceptive awareness. To check for training effects, two 3 (*valence*) x 3 (*reference*) x 4 (*session*) rmANOVAs

were calculated to check for practice effects in the His-Mine paradigm across the four weeks of testing. To test the requirements for mediation analyses, the relationships of self-reported interoceptive awareness (MAIA subscales), and situational as well as habitual attentional focus, were analysed (two-sided) using Pearson correlational analyses.

Bonferroni-correction was applied. All *p*-values are reported uncorrected. If sphericity has been violated, Greenhouse-Geisser correction was applied. Partial Eta Square (η_p^2) is reported as measure of effect size.

3 Results

3.1 Manipulation Check: Self-reported Attentional Focus

In the internal-relevant focus condition (condition A), an internal-relevant focus was the attentional focus participants spent most of their exercise time with, compared to all other attentional focus types (all comparisons $p \leq .001$) and was applied $M=47.97$ % of the time spent exercising during the experiment (self-reported attentional focus of the participants in each condition can be taken from Figure 1). In the external-irrelevant focus condition, participants focused mostly on external-irrelevant stimuli ($M=28.63$ %) compared to other attentional focus categories, but the differences did not reach statistical significance (all $p>.1$). Therefore, the experimental manipulation led to participants more often focusing their attention in the instructed way compared to focusing their attention contrary to the instruction. Although no experimentally manipulated focus led to 100% adherence, the manipulations led to meaningful shifts in attention. Figure 1 depicts the self-reported attentional focus in each of the experimental conditions.

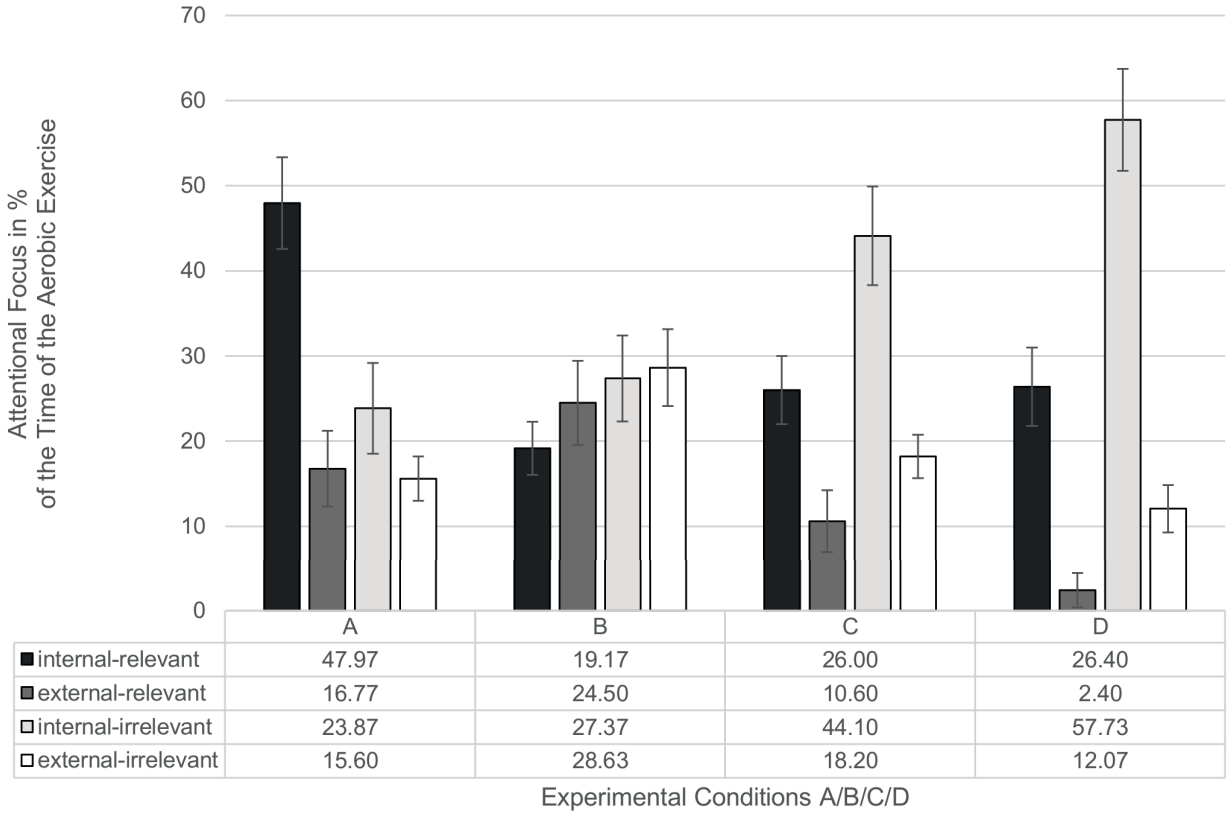


Figure 1. Percentage of the time spent focusing on internal/external, task-relevant/irrelevant stimuli during each experimental condition. Condition A included an instruction of an internal-relevant attentional focus, condition B an external-irrelevant attentional focus, condition C no specific focus instruction, and condition D was an inactive control condition, also without attentional focus instructions.

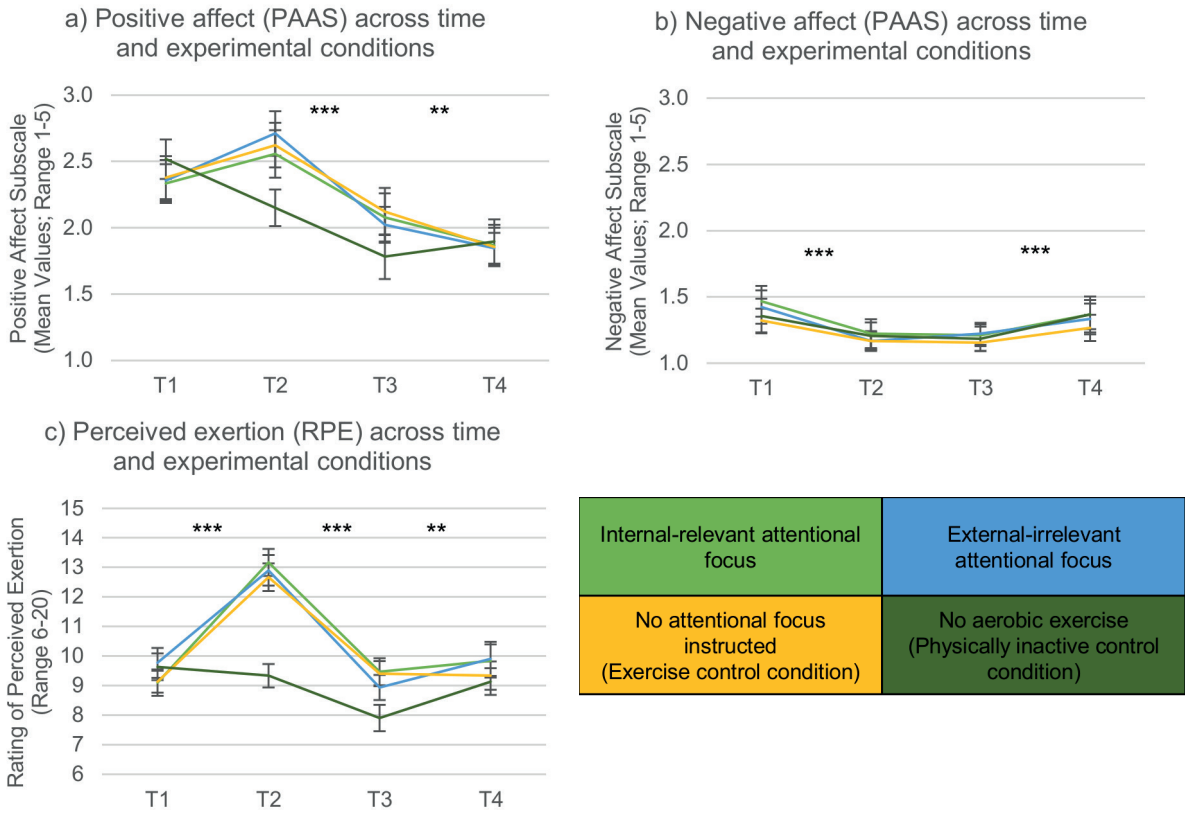


Figure 2a-c: Positive affect, negative affect (PAAS subscales) and Rating of Perceived Exertion (RPE) before (T1), after (T2), +10 min after (T3; immediately before the His-Mine paradigm), and +30 min after (T4; immediately after the His-Mine paradigm) the aerobic exercise (or the inactivity in the control condition), and for each experimental condition (varying attentional focus, exercise). Condition A: internal-relevant; Condition B: external-irrelevant; Condition C: exercise control condition without attentional focus instruction; Condition D: physically inactive control condition. Asterisks indicate significant differences between time points, regardless of exercise condition (** $p < .01$; *** $p < .001$). Condition D (physically inactive) is depicted for additional reference. (Figure 2 partly adopted from Meixner, F., & Herbert, C. 2021).

3.2 Analysis by experimental condition

Analysing the subscales of the physical activity affect scale (PAAS) *positive affect*, *negative affect*, as well as the *rating of perceived exertion (RPE)*, a 4 (*conditions*) x 4 (*time*: *before / after / 10min after / 30min after aerobic exercise*) repeated measures MANOVA was performed. Using Pillai's trace, there was a significant effect of *condition* (V=.39, F(9, 252)=4.23, p≤.001, η_p^2=.13), a significant effect of *time* (V=1.19, F(9, 252)=18.49, p≤.001, η_p^2=.40) and a significant interaction *time*condition* (V=.51, F(27, 756)=5.76, p≤.001, η_p^2=.17). Subsequent ANOVAs showed the following pattern for each of the dependent variables: *time*: all DV p≤.01; *condition:* only RPE p≤.001, all other p>.1; *time*condition*: only positive affect and RPE p≤.001, NA p>.1). Figures 2a-c depict the changes of positive affect, negative affect, and perceived exertion across the experimental sessions, and for each experimental condition.

3.3 Mood-congruent processing and emotional evaluation

As could be expected, positive (PA) and negative affect (NA) were significantly correlated with the evaluation of positive stimuli (irrespective of stimulus reference), visibly both in reaction times (e.g., PA: T1, r=-.04, p>.1; T2, r=-.22, p≤.05; T3, r=-.20, p≤.05; T4, r=-.25, p≤.01; NA: T1, r=.19, p≤.05; T2, T3, T4, p>.1) and number of valence-congruent answers (PA: T1, r=.21, p≤.05; T2, r=.24, p≤.01; T3, r=.18, p>.1; T4, r=.31, p≤.01; NA: T1, r=-.24, p≤.01; T2, r=-.17, p≤.05; T3, r=-.24, p≤.01; T4,

Table 2: Pearson correlation coefficients of positive/negative affect at different points throughout experimental sessions with reaction times and number of valence-congruent responses, irrespective of stimulus reference (bootstrap estimation, 1000 samples). 95% CIs are given below each correlation coefficient.

		Baseline		Post-Activity		+10 min		+30 min	
		Positive Affect	Negative Affect	Positive Affect	Negative Affect	Positive Affect	Negative Affect	Positive Affect	Negative Affect
Reaction Times in Milliseconds	**Positive Stimuli**	-.04	.19*	-.22*	.11	-.20*	.18	-.25**	.19*
		[-.25, .18]	[.03, .35]	[-.39, -.03]	[-.06, .30]	[-.39, .03]	[0, .35]	[-.42, -.07]	[.05, .35]
	Negative Stimuli	.09	.05	-.13	-.01	-.12	.00	-.14	.01
		[-.12, .28]	[-.08, .20]	[-.30, .06]	[-.13, .14]	[-.30, .08]	[-.12, .13]	[-.31, .06]	[-.12, .15]
	Neutral Stimuli	.10	.09	-.10	.03	-.11	.04	-.10	.02
		[-.09, .29]	[-.04, .24]	[-.26, .08]	[-.07, .17]	[-.27, .07]	[-.07, .18]	[-.26, .06]	[-.11, .16]
Valence-congruent Responses	**Positive Stimuli**	.21*	-.24**	.24**	-.17	.18	-.24**	.31**	-.31**
		[.02, .39]	[-.43, -.02]	[.03, .45]	[-.40, .05]	[0, .36]	[-.42, -.03]	[.18, .42]	[-.50, -.11]
	Negative Stimuli	.01	.06	-.03	.11	-.01	.11	.08	.10
		[-.18, .18]	[-.08, .17]	[-.20, .15]	[.01, .19]	[-.19, .16]	[.02, .19]	[-.13, .27]	[-.02, .19]
	Neutral Stimuli	.03	-.07	.00	-.05	.02	-.05	.03	-.05
		[-.15, .20]	[-.22, .07]	[-.18, .17]	[-.18, .07]	[-.17, .19]	[-.18, .07]	[-.19, .22]	[-.23, .09]

Note: * $p < .05$; ** $p < .01$

r=-.31, $p \leq .01$). Negative and neutral stimuli, however, seem to be completely unrelated to participants' affective state (all $p > .1$). See also Table 2 for a complete overview of the correlational analyses.

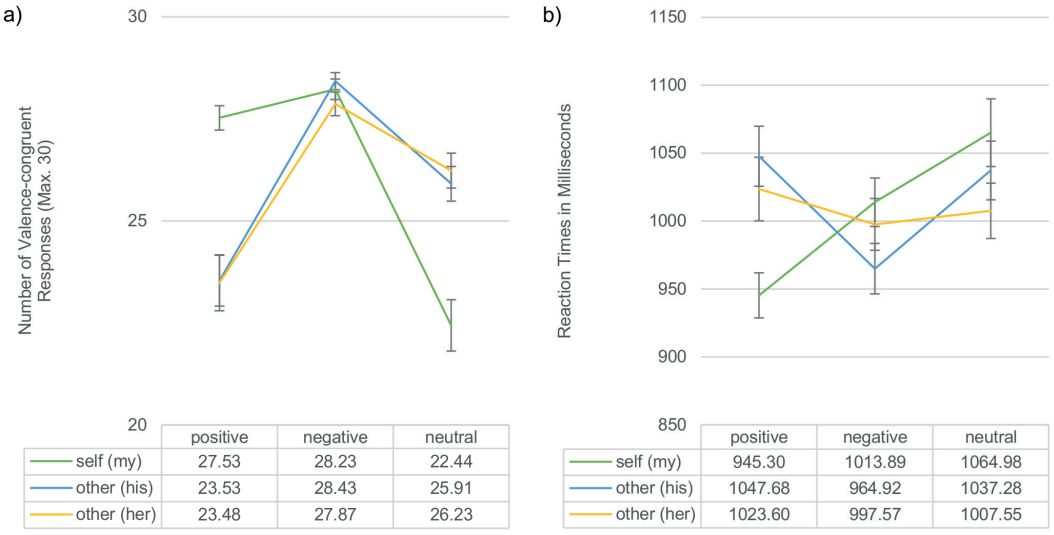
3.4 Emotional evaluation paradigm

3.4.1 Valence-congruent responses

A 3 (*valence*) x 3 (*reference*) x 4 (*condition*) rmANOVA revealed a significant main effect of *valence* ($F(1.51, 44)=8.52$, $p \leq .01$, $\eta_p^2=.23$, $\varepsilon=.75$) as well as a significant interaction for *valence*reference* ($F(1.62, 46.89)=17.16$, $p \leq .001$, $\eta_p^2=.37$, $\varepsilon=.40$). Neither main effects for experimental *condition* or *reference*, nor any other interactions could be found (all $p > .1$). Post-hoc tests revealed a self-positivity bias in valence-congruent responses: Positive stimuli with self-reference were answered more often in a valence-congruent fashion compared to neutral stimuli with self-reference (self-positive: M=27.53, SD=2.84 vs. self-neutral M=22.44, SD=6.31; $t(29)=4.14$, $p \leq .001$) and compared to positive stimuli with other-reference (self-positive: M=27.53, SD=2.84 vs. other-positive (male pronoun 'his') M=23.53, SD=6.42; $t(29)=3.79$, $p \leq .001$; self-positive: M=27.53, SD=2.84 vs. other-positive (female pronoun 'her) M=23.48, SD=7.13; $t(29)=3.27$, $p \leq .01$). Figure 3a depicts number of valence-congruent answers as a function of stimulus valence and reference.

3.4.2 Reaction times

A 3 (*valence*) x 3 (*reference*) x 4 (*condition*) rmANOVA revealed a significant main effect of *condition* ($F(2.45, 71)=2.92$, $p \leq .05$, $\eta_p^2=.09$, $\varepsilon=.82$), as well as a significant interaction for *valence*reference* ($F(2.12, 61.33)=18.45$, $p \leq .001$, $\eta_p^2=.39$, $\varepsilon=.53$). Neither main effects for stimulus *reference*, stimulus *valence* nor any other interactions could be found (all $p > .1$).



	positive	negative	neutral
self (my)	27.53	28.23	22.44
other (his)	23.53	28.43	25.91
other (her)	23.48	27.87	26.23

	positive	negative	neutral
self (my)	945.30	1013.89	1064.98
other (his)	1047.68	964.92	1037.28
other (her)	1023.60	997.57	1007.55

Figure 3a-b: Number of valence-congruent responses (a) and reaction times in milliseconds (b) in the emotional evaluation paradigm as a function of stimulus valence (positive, negative, neutral) and of stimulus reference (self- or other-reference (male/female pronouns)).

Post-hoc tests of the interaction *valence*reference* show a self-positivity bias in reaction times in milliseconds: Positive stimuli with self-reference were evaluated faster compared to neutral stimuli with self-reference (self-positive: M=945.30, SD=159.74 vs. self-neutral M=1064.98, SD=239.61; $t(29)$=-4.22, $p \leq .001$) and compared to positive stimuli with other-reference (self-positive: M=945.30, SD=159.74 vs. other-positive (male pronoun 'his') M=1047.68, SD=206.57; $t(29)$=-4.61, $p \leq .001$; self-positive M=945.30, SD=159.74 vs. other-positive (female pronoun 'her) M=1023.60, SD=223.87; $t(29)$=-3.64, $p \leq .001$). Figure 3b depicts reaction time in milliseconds as a function of stimulus valence and reference.

Additionally, an effect of experimental condition was observed: after aerobic exercise without attentional focus instruction, participants responded faster (M=954.97, SD=169.38) compared to an internal-relevant (M=1032.69, SD=224.01; $t(29)$=2.41, $p \leq .05$) or an external-irrelevant attentional focus (M=1030.79, SD=205.74; $t(29)$=3.53, $p \leq .001$), or compared to the inactive control condition (M=1027.21, SD=214.57; $t(29)$=2.60, $p \leq .05$).

3.4.3 Analysis by self-reported attentional focus

Across all experimental conditions, *self-reported* internal-irrelevant attentional focus was significantly negatively correlated with positive affect (PAAS) immediately after the exercise (T2; internal-irrelevant; r=-.16, p<.05), and *self-reported* internal-relevant attentional focus was significantly negatively correlated with negative affect (PAAS) after the emotional evaluation paradigm (T4; internal-relevant; r=-.16, p<.05; all other p>.1). Also, the more participants reported to have focused on *internal-irrelevant* stimuli (e.g., daydreaming), the less exertion they reported immediately after the (in-)activity (r=-.35, $p \leq .001$). This correlation, however, was mainly due to the physical inactivity condition (only exercise conditions: all p>.1, *n.s.*).

Pearson correlation analyses revealed a negative relationship of a self-reported *external-irrelevant* focus of attention with the self-positivity bias in *reaction times* (difference in reaction times to positive, other-related minus positive, self-related stimuli; r=-.22, p<.01), and a positive relationship with the self-positivity bias in *valence-congruent responses* (difference in valence-congruent responses in positive, other-related minus positive, self-related stimulus categories; r=.19, p<.05). A self-reported *internal-irrelevant* focus of attention was negatively associated with the self-positivity bias in *valence-congruent responses* (r=-.21, p<.05), but not in *reaction times* (p >.1).

3.4.4 Exploratory analyses

To check for repetition/training effects from the first to the last of the four experimental sessions in the emotional evaluation paradigm, a 3 (*valence*) x 3 (*reference*) x 4 (*session*) rmANOVA with reaction times as a dependent variable was performed. A main effect of the experimental *session* emerged (F(1.86, 54.01)=42.91, p≤.001, η_p^2=.60, ε=.62), as well as the already reported significant main effects of *valence* and a significant interaction of *valence*reference* (all p<.001; all other main effects or interactions p>.1, *n.s.*). Post-hoc tests revealed a steady decrease in reaction times across the four weeks of measurement (weeks 1-4, reaction time in milliseconds: 1) M=1144.64, SD=183.49; 2) M=1015.37, SD=186.07; 3) M=960.51, SD=189.64; 4) M=925.15, SD=196.58), suggesting a substantial practice effect regarding reaction times. However, a 3 (*valence*) x 3 (*reference*) x 4 (*session*) rmANOVA with valence-congruent responses as a dependent variable did not show this pattern (no main effect of *session*; p>.1). To rule out errors in randomization, a Chi-Square test of independence has been performed for *condition* and *session*. Independence was evident (χ^2 (9)=4.53, p=.87), ruling out a practice effect across *sessions* as an alternative explanation for the effects of *condition* on reaction times.

Additionally, facets of interoceptive awareness (MAIA; Bornemann, Herbert, Mehling, & Singer, 2015; Mehling et al., 2012) have been correlated with self-reported attentional focus after the aerobic exercise. None of the subscales (noticing body sensations, not-distracting oneself from discomfort, not-worrying about discomfort, attention regulation, emotional awareness, self-regulation, body listening, trusting one's body) were significantly associated with self-reported attentional focus in any of the experimental conditions after Bonferroni correction. Since no significant correlations between self-reported attentional focus and interoceptive awareness were found, the requirements for mediation analyses were not given.

4 Discussion

The aim of this study was to test the effects of aerobic exercise and exercise-related attentional focus on emotional evaluation of verbal stimuli varying in self-reference and emotional content to investigate whether in healthy subjects (women) exercise in general, as well as the combination with attentional focus strategies takes effect on the self-positivity bias. Previous research has delivered insight into the effects of different attentional strategies in professional athletes, or highly ambitious leisure time exercisers, such as marathon runners (e.g., Stevinson & Biddle, 1998). Also, as has been outlined in the introduction, it has previously been reported that novices not only prefer, but also react differently to certain attentional styles (e.g., distraction being associated with mood improvements; for overviews see Brick et al., 2014; Brick et al., 2020; Lind et al., 2009) compared to experienced athletes. Participants in the presented study did not frequently engage in vigorous exercise, nor prepared for a sports competition and were expected to be inexperienced in focusing their attention during exercising. Although they adhered to the instructed attentional focus mostly throughout the exercise (see Figure 1), they also reported to have focused on *internal-irrelevant*, as well as *external-relevant* stimuli, although not explicitly instructed to do so in any experimental condition. In general, the presented data suggest a considerable influence of the *self-reported* compared to the *instructed* attentional focus on emotional evaluations of self-referential verbal stimuli after the exercise. Moreover, positive affect seems to be increased by aerobic exercise (as compared to physical inactivity), regardless of the attentional focus it is performed with.

In the reported participant sample, neither *instructed* nor *self-reported* attentional focus influenced affect, which contradicts previous observations of increased negative affect and feelings of exertion when focusing attention internally during physical activity (Blanchard et al., 2004; LaCaille et al., 2004; Welch et al., 2007). While surprising, this might be explained by participants failing to follow the attentional instructions 100% of the time, or due to the operationalizations of an internal focus of attention. In many studies, an internal focus of attention has been assessed after high-intensity aerobic exercise, in which attention can hardly be directed away from physical symptoms. Thus, our results support the notion that an internal-relevant focus itself is not enough to create an aversive exercise experience during moderate intensity exercise. Physical stimuli, such as force production of the quad muscles, might need to be more intense and present to the individual. Therefore, future studies might investigate this relationship further by varying the workload of the exercise above 60-70% of HRmax but keeping it below the participants' ventilatory

threshold. Exercise in this intensity range would maintain the experimental manipulability of attentional focus, which would not be possible if the workload of the exercise exceeds the ventilatory threshold.

Regarding emotional evaluation, there has been some support for the initial hypothesis of a general positivity bias after exercising, i.e., an increase in positive affect after exercise and subsequent mood-congruent processing. Nevertheless, this effect has been limited to the evaluation of positive stimuli. Evaluation of positive stimuli was associated with positive and negative state affect, regardless of stimulus reference. This result could not be found for negative or neutral stimuli. To fully confirm mood-congruent processing, one would expect associations also between negative affect and the processing of negative stimuli, which the data does not seem to support. It can therefore be said that the His-Mine paradigm measures emotional evaluation, an appraisal process, which is known to be influenced by long-term affective states, i.e., mood, as can be taken from studies involving participants who self-report depressive systems (e.g., Herbert et al., 2014), psychotic disorders (Herbert et al., 2018) or who report to be in love (e.g., romantic relationships, Meixner and Herbert, 2018), but seems to be mostly unaffected by short-term affective influences, such as a negative state affect induced for example by acute bouts of moderate physical exercise.

However, there has been no support for the hypothesis that the positivity bias might be limited to self-specific stimuli. Nevertheless, there has been some support of the follow-up hypothesis of an internal focus enhancing self-related processing, specifically for positive stimuli. If participants reported to have spent more time focusing on *internal-irrelevant* stimuli (e.g., being focused on (stimuli within) themselves), regardless of the instruction, their self-positivity bias was increased 10 to 30 minutes after the aerobic exercise in the His-Mine paradigm. This might be interpreted as an interaction of a) the higher positive affect after aerobic exercise, compared to inactivity (Figure 2a), leading to more valence-congruent responding towards positive stimuli (see Table 2), and b) an increased self-focus if an internal, self-related attentional focus has been employed during the previous exercise. However, this effect was only evident in more valence-congruent responses, but not in faster reaction times. Since reaction speed did not decrease at the same time, a change in strategy (e.g., gaining accuracy at the cost of speed, i.e., a speed-accuracy trade-off) is unlikely. As described in the materials and methods section, it seems likely that participants' evaluation was based on gut feelings as per instruction, since reaction times and valence-congruent responses are not associated, as would be expected in a speed-accuracy trade-off. Instead, it is reasonable to assume that by focusing on internal stimuli during the previous exercise, the subsequent evaluation of positive self-related words is more often accurate, a) because their valence is congruent to participants' positive mood and b) because the processing of the verbal stimuli is semantically prepared by previously engaging in self-related thoughts. Conversely, if participants spent more time focusing on *external-irrelevant* stimuli, the self-positivity bias was significantly reduced afterwards, both in reaction times as well as in valence-congruent responses. These findings cannot be alternatively explained by attentional focus alone since this association could not be shown when analysing only the physically inactive control condition.

Also, the proprioceptive task of focusing on the quad muscles might have been too distal to activate self-related concepts. Therefore, it might be enlightening for future studies to use more proximal stimuli as an internal-relevant focus of attention, i.e., heartbeat, during exercise (e.g. Hill, Schücker, Hagemann, & Strauß, 2017), a task which has also been widely used to measure interoceptive awareness (Schandry, 1981). In this experiment, it has also been tested if any effects of self-reported attentional focus would be mediated by self-reported interoceptive awareness: Self-reported interoceptive did not show any significant associations with any self-reported attentional focus during the exercise after Bonferroni correction. However, to rule out interoceptive awareness as a mediating factor for attentional focus effects, a more objective measure, e.g., the heartbeat perception task, might be beneficial to future studies.

Given the results of the presented study, it is also crucial to experimentally instruct an *internal-irrelevant* focus of attention in the future. Since a self-reported internal-irrelevant focus has been associated with emotional evaluation, it might be insightful to explicitly instruct attentional focus towards stimuli from this category. Conceptually, this category is broad and incomparable, ranging from mind-wandering to arithmetic tasks to imagining music. Therefore, effects could be further discerned if the manipulation is done in smaller, more homogenous categories, e.g., focusing on self-related events, as compared to solving arithmetic tasks.

Maintaining an attentional focus proved to be an additional task for the novice participants in this sample: This manifested in longer response latencies in both attentional focus conditions (internal-relevant and external-irrelevant) compared to the exercise condition without any attentional focus instructions. Since both attentional focus conditions (A and B) led to reaction times comparable to the inactive control condition D, it can be assumed aerobic exercise

without instructions or interruptions led to decreased reaction times. This is in line with literature reporting increased choice reaction speed after physical activity (Chang et al., 2012; McMorris & Hale, 2015).

After the presented results we strongly advise to generally assess the self-reported attentional focus during physical activity, since attentional focus types are not only varying in their difficulty, but also in their appeal and are therefore differently adhered to.

5 Limitations and Conclusion

The presented effects could be shown in a young, female sample of novices, who do not prepare and train for, nor engage in performance-oriented sports. Therefore, the effects found in the present study might not be representative for the whole population, with possible differences originating from age, gender, exercise experience or physical fitness.

Furthermore, the presented results might be limited by the differences between experimental conditions. Physical activity without attentional focus instructions (condition C) has not been auditorily interrupted every 30 seconds, compared to attentional focus conditions (A and B). This contrast has been important to identify effects of auditory guidance of attention, as it is common in fitness courses, or when exercising while maintaining a conversation, e.g., cycling with a friend, compared to physical activity without any strong attentional guidance. Still, it is not possible to rule out an effect of the auditory interruption itself with the presented study. Also, participants had a shorter time of inactivity while sitting on the bicycle ergometer in control condition D (5 minutes), compared to their time spent exercising on the bicycle ergometer in conditions A, B and C (15 minutes). However, from the start of the experiment to the ten-minute break, condition D had 15 minutes of physical inactivity, and has thus been considered comparable the exercise conditions. Yet, during condition D, participants were only physically, but not totally inactive, e.g., received instructions and answered questionnaires in between, possibly limiting comparability of the conditions. Future research might therefore implement more experimental conditions, e.g., employing non-sensical auditory signals, or a control condition with 15 minutes of absolute inactivity with/without attention instructions, to grant additional insight into the specific effects of attentional focus instructions compared to general auditory interruptions.

Taken together, our study uses an experimental approach, and our results suggest an effect of aerobic exercise on emotional evaluation in an experimental paradigm. Participants were fastest in the emotional evaluation task when they were previously physically active without having to focus, which is in line with existing literature. The instruction to maintain an internal-relevant or an external-irrelevant focus of attention resulted in reaction times which were comparable to the reaction times after physical inactivity (control condition D), suggesting that the added demands of the attentional focusing possibly counteracted the reaction speed enhancement of physical activity. Aerobic exercise did lead to more positive affect compared to inactivity. But neither this nor mood at baseline can sufficiently explain emotional evaluation, as could be expected via mood-congruent processing. Rather than the instructed attentional focus, which was hard to maintain for participants, the self-reported attentional focus was associated with emotional evaluation: if participants focused on internal stimuli, the self-positivity bias in valence-congruent answers was more pronounced. However, if participants focused on external stimuli, the self-positivity bias in valence-congruent answers and reaction times was less pronounced. These results might be explained by internal/external focusing of attention during aerobic exercise leading to altered response behaviour in subsequent emotional evaluation. However, more research using experimental manipulations of the identified influential focus categories, i.e., internal-irrelevant stimuli, is needed to further evaluate the presented associations.

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Ethics approval: The protocol was approved by the local ethics committee (Ethics Committee of Ulm University; https://www.uni-ulm.de/einrichtungen/ethikkommission-der-universitaet-ulm/; ID 426/17). All subjects gave written informed consent in accordance with the Declaration of Helsinki.

Data availability statement: Raw data is available from the corresponding author upon request.

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Study IV

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Does Attentional Focus Influence Psychophysiological Responses to an Acute Bout of Exercise? Evidence From an Experimental Study Using a Repeated-Measures Design

*Friedrich Meixner and Cornelia Herbert**

Applied Emotion and Motivation Psychology, Institute of Psychology and Education, Ulm University, Ulm, Germany

Attentional focus during aerobic exercise has been studied in the context of sports performance, injury prevention and affective experience. Previous research suggests that an additional mental task parallel to the physical activity might influence exercise experience and performance. It has been tested if attentional focus influences cardiovascular activity, positive/negative affect, and subjective exertion during a cycling exercise. Data from *N* = 30 female participants has been collected using a repeated measures design, with the following experimental manipulations: (A) an internal attention focus (i.e., paying attention to force production of the quadriceps muscles), (B) an external attention focus (i.e., paying attention to changes in brightness in the cycling track simulation), and as control conditions, (C) exercise without attention focus (i.e., no specific instruction was given) and (D) no exercise, no attention focus. Subjective affect and subjective exertion were assessed, and changes in cardiovascular activity were recorded via mobile impedance cardiography (ICG) at rest, during and after the exercise, including HR, HRV (RMSSD, HF), PEP, CO, SV, LVET, and RSA. Exercise was associated with adaptations in cardiovascular activity, positive/negative affect, and subjective exertion. However, this did not interact with attentional focus. The original hypothesis could not be supported: instructed attentional focus does not influence affect, exertion, or cardiovascular activity during a cycling exercise. Therefore, attentional focusing during exercise does not appear to put notable additional mental demands on the physically active participant. Nonetheless, impedance cardiography delivered reliable measurements even during the cycling exercise.

Keywords: aerobic exercise, cycling exercise, attentional focus, psychophysiology, impedance cardiography

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Tibor Hortobagyi,
University Medical Center Groningen, Netherlands

***Correspondence:**
Cornelia Herbert
cornelia.herbert@uni-ulm.de

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INTRODUCTION

Acute exercise can lead to an increase in positive affect and relief of negative symptoms, e.g., depressive symptomatology (Frühauf et al., 2016), fear or anxiety (Bibeau et al., 2010). However, acute exercise can also lead to negative subjective experiences, i.e., fatigue, or feelings of excessive exertion. Being crucial to the future adherence to exercise regimens

(Hall et al., 2002; Ekkekakis et al., 2008, 2011; Zenko et al., 2016; Decker and Ekkekakis, 2017), it is important to identify factors that are reducing or unnecessarily increasing negative feelings during exercise.

Attentional focus has been suggested as a potential influence on affect and subjective exertion during aerobic exercise (Lind et al., 2009; Brick et al., 2014). Current theoretical frameworks classify two dimensions of attention during exercise: internal/external and task-relevant/-irrelevant (Stevinson and Biddle, 1998, 1999; Brick et al., 2014). Exercising at high intensities, i.e., beyond the ventilatory threshold has been shown to be aversive (Ekkekakis and Petruzzello, 1999; Ekkekakis et al., 2004), usually enforcing an internal focus of attention (e.g., Hutchinson and Tenenbaum, 2007). At moderate intensities, attentional focus seems to be controllable and possibly modulating affective experience (Lind et al., 2009; Brick et al., 2014). Although the relationship between attention, intensity and affect is described by numerous studies, their association with physiological changes during exercise remains largely undiscovered.

Cardiovascular changes elicited during aerobic exercise can be summarized as (A) an increase in heart rate (HR), (B) a decrease in heart rate variability (HRV; especially HF/RMSSD/RSA as signs of vagal/parasympathetic withdrawal; see Billman, 2013; Heathers, 2014), (C) an increase in cardiac output (CO) and stroke volume (SV), and D) a shortening of the systolic time intervals (STI) pre-ejection period (PEP) and left-ventricular ejection time (LVET), compared to baseline values at rest. Cardiovascular recovery can be broadly described as the reverse effects of A-D), i.e., each parameter returning to baseline levels after the exercise (for a review on cardiovascular regulation during exercise, see Michael et al., 2017). All of these parameters can be non-invasively measured via impedance cardiography (ICG; Willemsen et al., 1996).

Besides adaptation to meet physical demands, cardiovascular activity is also influenced by psychological factors such as cognitive demand (Montoya et al., 1997), emotions (Kreibig, 2010), stress (Steptoe et al., 1993; Al'Absi et al., 1997), effortful coping (Kelsey, 2012), or affect (Papousek et al., 2010; Radstaak et al., 2011). Psychological influences on cardiovascular activity can run counter or in the same direction as the effects of exercise, e.g., during a demanding task such as mental arithmetic, sympathetic activity as indicated by STIs such as PEP, rises to meet increased demands (Montoya et al., 1997), but during psychologically stressful tasks, such as the cold-pressor test, CO is decreased and vascular resistance is increased (Montoya et al., 1997). However, psychophysiological reactions as an effect of attentional focus while exercising have previously not been examined comprehensively.

Combining physical activity with a specific attentional focus might place additional cognitive demands on the active person, possibly eliciting a greater sympathetic reaction to supply necessary resources, compared to exercise without an instructed attentional focus (e.g., Roth et al., 1990; Taelman et al., 2011). However, this has not been consistently reported: It has been suggested that there are no additive effects of combined mental and physical challenges on psychophysiological reactions (Wasmund et al., 2002), but also that physiological responses to physical activity might be blunted or masked by a parallel mental task due to attention being directed away from the physical task (Greig et al., 2007).

Attentional focus is a widely used experimental manipulation (or analyzed correlate) in sports psychology. However, previous literature seldom acknowledged the possibility that attentional focus itself could be considered an additional task, adding mental demands on top of the physical demands of an exercise. This might be even more true for non-professional athletes, which are less experienced with the employment of an attentional focus. Our study was conducted to investigate a possible additive mental demand to an exercise by instructing a specific attentional focus.

We examined the impact of attentional focus on subjective exertion, affect and on physiological changes due to acute aerobic exercise in female non-professional exercisers, i.e., healthy, active adults not engaged in regular performance training or athletic competitions. Sample selection is critical due to possible gender-dependent responses to attentional focus (Frazier and Fatis, 1980; Wrisberg et al., 1988; Lind et al., 2009), differing reasons for exercise (e.g., see Furnham et al., 2002), physiological reactions to exercise (Roepstorff et al., 2002; Acevedo, 2012; Hill et al., 2018), as well as interactions with the experimenter's gender possibly influencing exertion reports for psychosocial reasons (e.g., for interactions on experimenter's gender and reported pain, see Levine and De Simone, 1991; Aslaksen et al., 2007).

Previous literature has not been uniformly manipulating attention experimentally, but also assessing self-reported attentional focus. Since theoretical categories of internal and external focus of attention are conceptually broad, it is crucial to experimentally manipulate an internal and an external focus of attention during exercise precisely, to maintain comparability between participants. Furthermore, the effects of an instructed attentional focus might differ from the effects of a voluntarily chosen attentional focus, possibly even if it focuses on the same stimulus category, since the former requires adhering to a specific additional task. It is therefore sensible to assess self-reported focus of attention in a separate condition without any attentional focus instructions.

We were particularly interested in replicating previous findings regarding the effects of an internal vs. an external focus of attention on subjective affect and subjective exertion using an experimental design, while also investigating whether an instructed, consistent focus of attention can be considered beneficial in terms of affect and subjective exertion compared to exercising with a voluntarily chosen, flexible focus of attention. Secondly, psychophysiological effects of the additional task of attentional focusing should be assessed, leading to the following open questions:

1a. In non-professional exercisers, instructing an internal focus of attention should lead to increased subjective exertion and reduced positive affect during and after exercise,

compared to exercise with an instructed external attentional focus.

1b. Exercise without any attentional focus instruction should lead to less subjective exertion and higher positive affect compared to both exercise conditions with an instructed focus of attention, due to the latter's combined mental and physical demands.

2. Since previous research has mainly employed mental arithmetic as an additional mental task, and results were discordant, the following hypothesis is explorative: Instructing an attentional focus should lead to additional mental demands, compared to aerobic exercise without attentional focus instructions. This should be visible in an increased sympathetic activity during exercise, and slower parasympathetic reactivation during recovery due to combined demands, compared to the exercise control condition. To assume a systemic point of view, all physiological parameters assessable via ICG are considered: An increased sympathetic reaction should be visible in a decreased PEP, and an increased CO and SV. However, CO and SV are expected to be counter-regulated by an increased vascular resistance as a reaction to the additional mental demands placed on the participant by instructing an attentional focus. Therefore, a decreased PEP and a blunted SV/CO response would be indicative of additional mental stress during the exercise.

MATERIALS AND METHODS

Participants

A required sample of $N = 26$ has been calculated to identify medium effects using G*Power 3.1 (Faul et al., 2009): $f = 0.25$, $\alpha = 0.05$, $1\text{-}\beta = 0.95$, 1 group, 4 measurements ANOVA, $\varepsilon = 0.8$.

$N = 32$ female participants were recruited via advertisements around university campus or mailing lists. Inclusion criteria were being 18–30 years of age, right-handed, physically able to exercise, non-smokers, native German speakers and not regularly exercising for more than 5 h per week (i.e., greatly exceeding the WHO recommendations for a healthy lifestyle), nor preparing for any sports-related competition. Menstrual cycle and use of contraceptives have been assessed, but did not lead to participants' exclusion (recent meta-analyses suggest that influence of menstrual cycle (McNulty et al., 2020), as well as oral contraceptives (Elliott-Sale et al., 2020) on exercise performance in women is trivial and not sufficient to form general guidelines). Two participants dropped out of the experiment after two sessions due to skin irritation caused by the cycling exercise. Participants received course credit for their participation.

Experimental Design and Procedure

The experiment was devised as a repeated-measures design. Each participant gave written informed consent and filled in an online questionnaire. On four different days, across 4 weeks, participants then took part in four different experimental sessions in the laboratory, in randomized order. In three conditions, they completed a 22 min cycling exercise (5 min warm-up, 15 min exercise, 2 min cool-down) on a stationary bicycle ergometer (Daum, ergo_bike premium8i) in front of a simulated, plain track alongside the Rhine river, projected with a diameter of ∼2.5 m. The simulation was displayed using the ErgoPlanet software[1]. Simulation speed was adaptive to participants' cycling speed. The track simulation contained the Rhine river, trees, other cyclists, and different lightings to provide a natural exercise setting and external stimuli for participants to focus on.

In each of the experimental conditions, participants received different instructions (Schücker et al., 2009, 2016a,b). During the internal focus condition A, participants were instructed to focus on the force production of their quad muscles. During the external focus condition B, participants were instructed to focus on brightness changes in the track simulation (Schücker et al., 2016a). Participants received pre-recorded auditory instructions every 30 s on where to direct their attentional focus and had to state out loud if they felt that force production (A) or brightness (B) has changed in the last 30 s. Participants' answers were controlled by the experimenter (see **Figure 1**). During the exercise control condition C, participants were simply instructed to cycle for 15 min and received no auditory instructions/prompts afterward. In condition D (non-exercise control condition), participants were instructed to sit passively on the ergometer, and to refrain from any cycling movements.

Experimental sessions lasted ∼90 min. All sessions were done over the course of 4 weeks, at the same time of day for every participant. All sessions were performed under the supervision of female experimenters. An overview over the design is given in **Table 1**.

Online Questionnaire

In the online questionnaire (presented using the platform EFS Survey, Unipark) preceding participation, participants answered anamnestic and demographic questions. In addition they filled in the Physical Activity Readiness Questionnaire (PAR-Q; Thomas et al., 1992). If participants met the inclusion criteria, they were invited to fill out self-report questionnaires (see Materials). Afterward, laboratory appointments were scheduled, and reminders were sent every week.

Laboratory Sessions

Each of the four laboratory sessions had the same structure. Upon arrival, participants were asked if they felt fit to be physically active. Afterward, electrodes were attached to measure impedance cardiography (ICG) and a 5-min baseline measurement (seated on a chair) took place. In the exercise conditions ABC, a 5-min warm-up phase on the ergometer followed, during which participants cycled at ∼60 RPM, while the investigator raised the resistance (Watt) until moderate intensity, i.e., the individually targeted heart rate has been reached[2] (60–70% of max heart rate according to Tanaka et al., 2001). The individual settings have been kept constant during the

[1] http://www.ergoplanet.de/

[2] According to the American Heart Association 50–70% of HRMax corresponds to moderate intensity (American Heart Organization: Target Heart Rates Chart, 2015). However, to account for other recommendations with a higher range, e.g., by the U.S. Department of Health and Human Services (Physical Activity Guidelines Advisory Committee Report, 2008); 64–76% of HRMax), but to avoid the ventilatory threshold, a range from 60 to 70% of HRMax has been chosen.

15 min of aerobic exercise. Mean heart rate for all participants in all activity conditions were in the target range (MeanHR: M = 121.52 bpm; SD = 8.16). More recent recommendations increasingly advocate the use of subjective exertion as an indicator for relative exercise intensity, suggesting a middle effort of 5–6 on a hypothetical, personal scale from 0 to 10 (Physical Activity Guidelines Advisory Committee Report, 2018) for moderate exercise intensity. **Figure 2E** indicates moderate intensity by using the latter indicator of a middle effort of subjective exertion (Please note that we used the classic RPE (Borg, 1998) ranging from 6 to 20, i.e., middle effort corresponds to ∼13). Afterward, participants cycled for two more minutes, gradually slowing down, as a cool-down.

Before (T1), immediately after (T2), 10 min after (T3) and 30 min after (T4) the exercise, participants filled out self-report measures on state positive/negative affect (PAAS; Lox et al., 2000), subjective exertion (Rating of Perceived Exertion, RPE; Borg, 1998). During the last minute of the exercise, participants answered the Feeling Scale (FS; Hardy and Rejeski, 1989). This way, the attentional focusing task has not been interrupted by the assessment of state affect, while still being conducted within the timeframe of the exercise. Also, the feeling scale has been performed before the cool-down, ensuring it does capture the affect caused by the exercise and not reflect the reaction to the end of it. At T2, participants additionally indicated their attentional focus during the exercise (see **Supplementary Material**). Between T2 and T3, participants had a 10-min break, where they were asked to remain seated on a chair. Between T3 and T4, participants completed the experimental His-Mine paradigm measuring emotional evaluation of self-related emotional stimuli (Herbert et al., 2011a,b, 2018; Winter et al., 2015, 2018; Weis and Herbert, 2017; Meixner and Herbert, 2018; Meixner et al., 2019). This paradigm was included in the protocol as an experimental measure to investigate effects of acute aerobic exercise on subsequent affective evaluation of self- and other-related verbal stimuli, as part of a larger study. Analyses regarding data from the His-Mine paradigm differed in objective, research question, analytic methods, and conclusions, focusing on information processing of verbal emotional information. They will therefore be presented and discussed independently from the psychophysiological data in a separate manuscript of the authors. A full overview over the experimental sessions is given in **Table 1**.

Materials

Prior to the laboratory sessions, participants completed an online questionnaire assessing, among others, clinically relevant symptoms of depression or anxiety due to their association with negative mood and their interaction with the His-Mine paradigm (Herbert et al., 2011a,b, 2018; Winter et al., 2015, 2018; Weis and Herbert, 2017; Meixner and Herbert, 2018; Meixner et al., 2019). Measures assessed depressive symptomatology (BDI; Hautzinger et al., 2009), dysfunctional attitudes toward oneself (DAS; Hautzinger et al., 2005), state and trait anxiety (STAI; Laux et al., 1981), general physical activity[3] (GPAQ; Armstrong and Bull, 2006), state and trait affect (PANAS; Watson et al., 1988; Krohne et al., 1996) and habitual attentional focus (Stevinson and Biddle, 1998; Wininger and Gieske, 2010; see **Supplementary Material**

[3]Participants did not regularly exercise on a bicycle ergometer but did use a bicycle multiple times per week.

TABLE 1 | Experimental design; order of laboratory sessions has been randomized for every participant.

One week prior	Repeated measures design over the course of 4 weeks (1 session every week)				Duration
	Laboratory sessions (randomized order for each participant)				
	Session 1: Aerobic exercise; internal attentional focus condition (A)	**Session 2: aerobic exercise; external attentional focus condition (B)**	**Session 3: aerobic exercise; no specific attentional focus condition (C)**	**Session 4: no aerobic exercise; control condition (D)**	
Online-Questionnaire (Unipark, EFS Survey)	Preparation and sensor application (ICG)				10 min
	T1 state measurements				
	Baseline measurement (eyes open)				5 min
	Warm-up			Waiting (eyes open; on bicycle ergometer)	5 min
				State measurement (feeling scale; last minute of inactivity)	
	Physical activity w/wo attentional focus instruction			T2 state measurements (same as T1)	15 min
				Pause (break/recovery)	
	State measurement (feeling scale; last minute of activity)			T3 state measurements (same as T1)	
	Cool-down			Emotional evaluation task	2 min
	T2 state measurements (same as T1)				10 min
	Recovery				
	T3 state measurements (same as T1)			T4 state measurements (same as T1)	
	Emotional evaluation task			Last session additionally: follow-up measurements of BDI, PANAS	20 min
	T4 state measurements (same as T1)				3 min
	∼70 min				

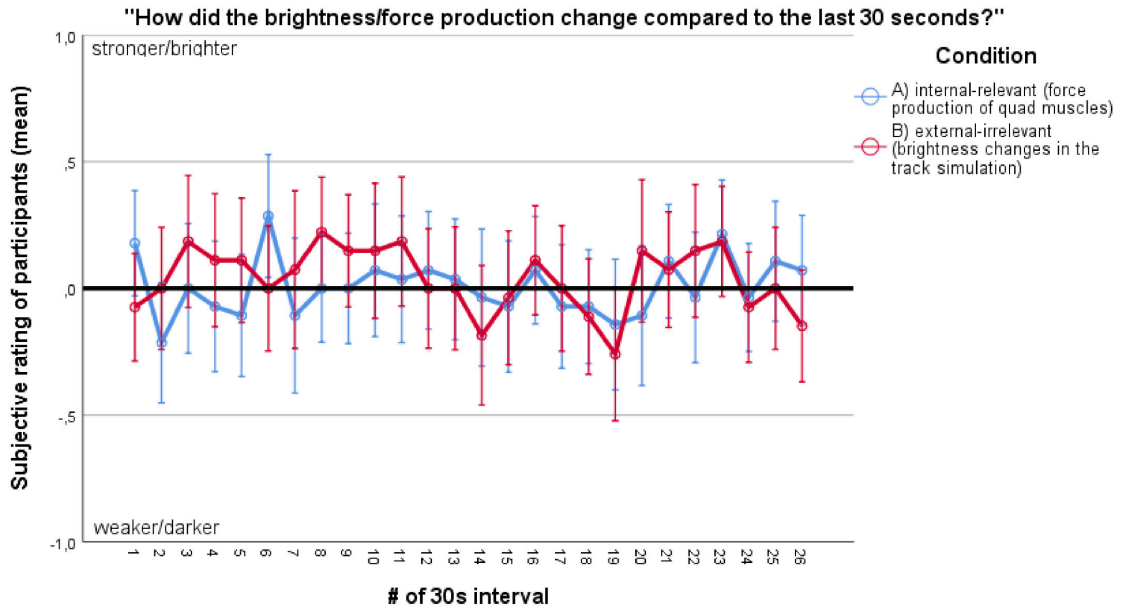


FIGURE 1 | Participants' mean subjective rating on change in the intensity of internal-relevant or external-irrelevant stimuli during the course of the cycling task. Vertical bars denote +/− standard errors.

TABLE 2 | Descriptive statistics, PANAS, STAI (Trait) and regular physical activity scores (sum scores as suggested by the respective manuals) of the study sample.

Variable	*n*	Mean	Std. Deviation	Reliability (Cronbach's α)
Age	30	21.00 (2.17)	2.17	–
BMI	30	21.13 (2.27)	2.27	–
Positive affect, trait (PANAS)	30	34.27 (6.13)	6.13	0.88
Negative affect, trait (PANAS)	30	17.33 (4.64)	4.64	0.81
Anxiety, trait (STAI)	30	38.30 (8.82)	8.82	0.90
Vigorous activity/week in minutes (GPAQ)	30	172.00 (225.28)	225.28	–

for exact wording). Clinically relevant scores on BDI or STAI as well as high values on the DAS scale, or abnormally high physical activity indicated in the GPAQ would have led to participants not being invited to the laboratory sessions. Habitual attentional focus has been assessed to gain additional insight if participants' self-reported habitual attentional focus predicts their actual employed attentional focus in the laboratory setting. An overview on participants' self-report data (age, affect (trait), anxiety, as well as regular, vigorous physical activity) is provided in **Table 2**.

Assessment of Impedance Cardiography (ICG) and Data Reduction

Impedance cardiography (ICG) was recorded during the whole experiment using the 7-electrode version of the VU-AMS 5fs device (ambulatory monitoring system; Vrije Universiteit)[4]. Data was cut into multiple intervals, and fixed non-overlapping windows were selected for analysis: Window size for baseline, activity/inactivity and late recovery (i.e., second half of recovery period after activity) was set at 4 min (see Willemsen et al., 1996; Houtveen et al., 2002) from the middle of the interval, i.e., cutting out the first 30s of every interval. For more details on software and filter settings, as well as methods of parameter extraction, please see **Supplementary Material**.

Data Analysis

Analyses were performed using IBM SPSS Statistics 24. A manipulation check (3.1) was performed via paired-samples *t*-tests: For each condition, the self-reported amount of time spent with the *instructed* attentional focus was compared to the amount of time participants focused on anything else. Furthermore, to ensure participants' personality did not notably interact with attentional focus and confound results, Pearson correlation analyses have been performed.

Due to a sample size of $n = 30$ with 4 points of measurement, i.e., 120 measurements in total, warranting assumption of normality and to prevent random results via multiple testing, the general analysis strategy will be as follows: firstly, multiple dependent variables will be grouped together and analyzed using MANOVA, reducing alpha inflation. Subsequently, *post hoc* ANOVAs will be used to further examine significant differences found in the MANOVA results, or dependent variables running counter to each other.

[4]www.vu-ams.nl

To test the effects of attentional focus on subjective exertion (RPE) and affect (subscales of the PAAS; 3.2), a 4 (*conditions*) × 4 (*time*: *before/after/10 min after/30 min after*) repeated measures MANOVA has been calculated. Feeling scale (FS) has been calculated in a separate 4 (*conditions*) × 4 (*time*: *before/during/after/10 min after/30 min after*) repeated measures ANOVA, since it has been measured at 5 points (additionally during the exercise), and could therefore not be included in the first MANOVA.

Physiological responses (including PEP, CO, SV, RSA, HF, RMSSD, HR, LVET; 3.3) as a function of the different attentional focus conditions were analyzed using a 4 (conditions) × 3 (time: before/during/after activity) repeated measures MANOVA, followed by respective ANOVAs if significant differences were confirmed. To evaluate recovery and parasympathetic reactivation in detail, heart rate recovery (HRR) has been additionally evaluated at 7 points of measurement (Baseline/Warmup/Activity/Cool-down/HRR180/HRR330/HRR480), and RSA and HF at 10 points of measurement (30 s periods from 180 to 480 s after the end of the activity, log-transformed data) using ANOVAs.

Lastly, self-reported focus of attention in conditions C (exercise without attentional focus instruction) and D (inactive control condition, without attentional focus instruction) and self-reported affect, subjective exertion, and psychophysiological responses have been correlated using Person correlation analysis (3.4). This has been done to gain additional insight for future research into possible effects of self-reported attentional focus.

If assumptions of sphericity have been violated, Greenhouse-Geisser correction has been applied. Epsilon values (ϵ) are reported, as well as uncorrected degrees of freedom, and corrected *p*-values. As a measure of effect size, partial eta square (η_p^2) is reported. Multiple correlational analyses (3.4) have been subject to Bonferroni correction.

RESULTS

Manipulation Check

Participants indicated following the instructions: During the internal-relevant focus, the internal focus was dominant (all $p \leq 0.001$). During the external-irrelevant focus condition, the external attentional focus was also dominant, but the differences did not reach statistical significance (all $p > 0.1$). During the exercise condition without attentional focus, participants reported to focus on internal-irrelevant stimuli more often than on any other category (all $p \leq 0.001$).

Analysis of participants' habitual attentional focus revealed a preferred focus on internal-irrelevant (e.g., daydreaming, imagining music, etc.) stimuli during physical activity. Participants indicated that during recreational physical activity, they usually focused on average on internal-relevant stimuli M = 27.13% (SD = 27.87), on external-relevant M = 15.43% (SD = 20.44), on internal-irrelevant M = 38.30% (SD = 25.68) and on external-irrelevant stimuli M = 21.70% (SD = 16.33) of the time. Also, habitual attentional focus was unrelated to personality variables BIS, BAS, FFFS, trait anxiety, dysfunctional attitudes, depressive symptomatology, BMI, minutes of recreational exercise, and general activity in MET minutes (all $p > 0.1$).

Figure 1 depicts participants' mean responses to the focus-reinforcing questions on whether the force production of their quad muscles (condition A) or the brightness in the track simulation (condition B) has changed.

Self-Reported Affect and Exertion

A 4 (*conditions: internal-relevant focus, external-irrelevant focus, exercise control condition, inactive control condition*) × 5 (*time*: *T1/during activity/T2/T3/T4*) repeated measures ANOVA (DV: affect as measured by the Feeling Scale) revealed a significant main effect of *time* of the measurement [$F(4, 460) = 9.51$, $p \leq 0.001$, $\eta_p^2 = 0.11$, $\epsilon = 0.80$]. No main effect of *condition* [$F(3, 115) = 0.38$, $p > 0.1$, $\eta_p^2 = 0.01$, $\epsilon = 0.91$], nor an interaction *time* × *condition* [$F(12, 460) = 1.50$, $p > 0.1$, $\eta_p^2 = 0.04$, $\epsilon = 0.80$] was observed.

A 4 (*conditions*) × 4 (*time*) repeated measures ANOVA (DV: subjective exertion, RPE) revealed a main effect of *time* [$F(3, 348) = 73.19$, $p \leq 0.001$, $\eta_p^2 = 0.39$, $\epsilon = 0.91$], a main effect of *condition* [$F(3, 116) = 3.11$, $p \leq 0.05$, $\eta_p^2 = 0.08$], and an interaction *time* × *condition* [$F(9, 348) = 7.22$, $p \leq 0.001$, $\eta_p^2 = 0.16$, $\epsilon = 0.91$]. *Post hoc* tests revealed significant increases in subjective exertion from pre- to post-activity and a decrease of perceived exertion until the end of the recovery phase, but only in the exercise conditions (all $p \leq 0.001$).

Regarding PAAS and its subscales (positive affect PA, negative affect NA, fatigue FTG, tranquility TRQ), a 4 (*conditions*) × 4 (*time*) repeated measures MANOVA and subsequent ANOVAs display the same pattern of a persistent main effect of *time* [PA: $F(3, 345) = 45.61$, $p \leq 0.001$, $\eta_p^2 = 0.28$, $\epsilon = 0.82$; NA: $F(3, 345) = 10.91$, $p \leq 0.001$, $\eta_p^2 = 0.09$, $\epsilon = 0.78$; FTG: $F(3, 345) = 18.76$, $p \leq 0.001$, $\eta_p^2 = 0.14$, $\epsilon = 0.81$; TRQ: $F(3, 345) = 26.57$, $p \leq 0.001$, $\eta_p^2 = 0.19$, $\epsilon = 0.91$; but not of *condition*: PA: $F(3, 115) = 0.28$, $p > 0.1$, $\eta_p^2 = 0.01$; NA: $F(3, 115) = 0.18$, $p > 0.1$, $\eta_p^2 = 0.01$; FTG: $F(3, 115) = 0.17$, $p > 0.1$, $\eta_p^2 = 0.00$; TRQ: $F(3, 115) = 0.42$, $p > 0.1$, $\eta_p^2 = 0.01$]. Only the subscale positive affect showed an interaction of *time* × *condition* [PA: $F(9, 345) = 2.79$, $p \leq 0.01$, $\eta_p^2 = 0.07$, $\epsilon = 0.82$; NA: $F(9, 345) = 0.24$, $p > 0.1$, $\eta_p^2 = 0.01$, $\epsilon = 0.78$; FTG: $F(9, 345) = 0.34$, $p > 0.1$, $\eta_p^2 = 0.01$, $\epsilon = 0.81$; TRQ: $F(9, 345) = 0.87$, $p > 0.1$, $\eta_p^2 = 0.02$, $\epsilon = 0.91$].

Post hoc tests revealed a decrease in negative affect and tranquility, while positive affect, fatigue and tranquility stayed the same, from pre- to post-exercise. Until *10 min after* the exercise, RPE and positive affect decreased, negative affect remained unchanged, and fatigue and tranquility increased. Until the last measurement T4, RPE increased again, positive affect further decreased, negative affect increased again, fatigue further increased, and tranquility decreased again. Regarding condition D, positive affect decreased from *before* to *after* to *10 min after* the inactivity (sitting on the ergometer) and remained stable until *30 min after* (all $p \leq 0.05$). Results are depicted in **Figures 2A–F**.

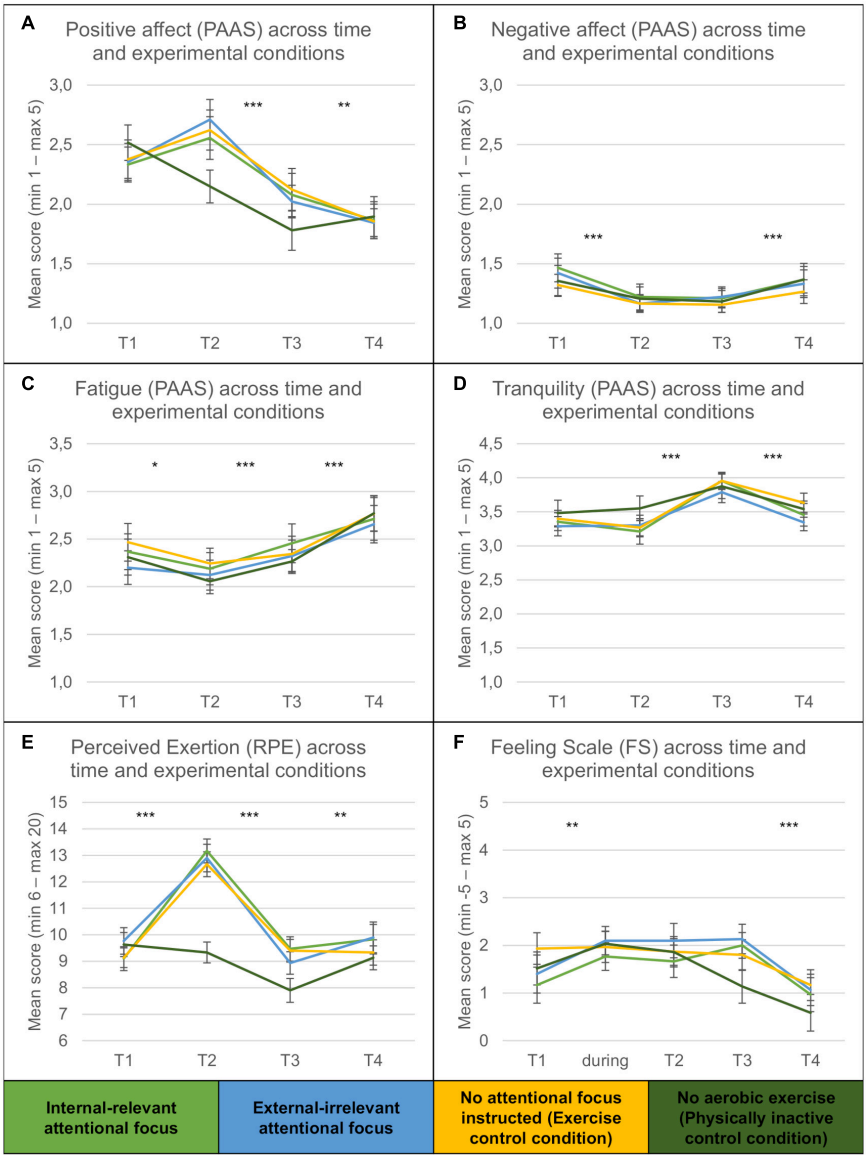


FIGURE 2 | (A–F) Positive affect (range 1–5), negative affect (1–5), fatigue (1–5), tranquility (1–5), rating of perceived exertion (6–20), and subjective positive feeling (−5 to 5) before (T1), after (T2), + 10min after (T3), + 30min after (T4) the cycling exercise. Asterisks indicate significant differences between time points, regardless of exercise condition (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$). Condition D (physically inactive) is depicted for additional reference. Vertical bars denote +/− standard errors.

Physiological Responses to Different Attentional Focus Conditions

It has been hypothesized that attentional focus instructions might influence physiological activity elicited during aerobic exercise due to additional demands placed upon the active person.

Physiological Responses (PEP, CO, SV, RSA, HF, RMSSD, HR, LVET)

Descriptively, physiological parameters during baseline and aerobic exercise were in the expected physiological ranges (Goedhart et al., 2006; Willemsen et al., 1996), e.g., HR during rest (sitting, baseline) $M = 77.81$ bpm, $SD = 11.79$; HR during rest (sitting on bicycle) $M = 84.62$ bpm, $SD = 12.73$; HR during cycling at moderate intensity $M = 121.17$ bpm, $SD = 8.95$; PEP during rest (sitting, baseline) $M = 109.96$ ms, $SD = 16.66$; PEP during rest (sitting on bicycle) $M = 108.00$ ms, $SD = 20.40$; PEP during aerobic exercise $M = 65.04$ ms, $SD = 10.44$; SV during rest (sitting, baseline) $M = 155.96$ cm^3, $SD = 57.36$; SV during rest (sitting on bicycle) $M = 150.22$ cm^3, $SD = 46.64$; SV during aerobic exercise $M = 180.44$ cm^3, $SD = 55.58$. **Figures 3A–F** depict physiological changes across time and experimental conditions.

Using Pillai's trace, there was not a significant effect of *condition* on any physiological parameter [PEP, CO, SV, RSA,

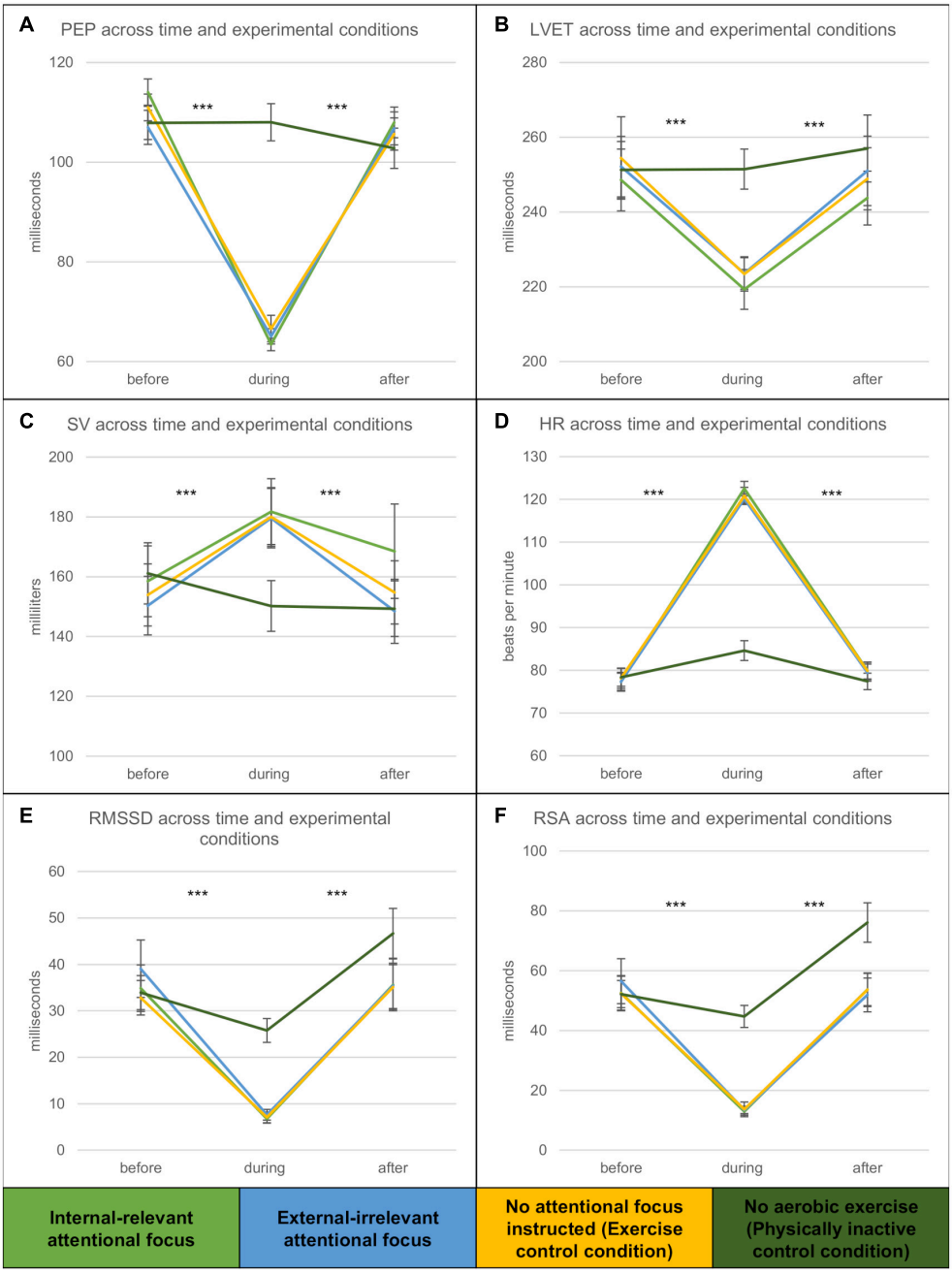


FIGURE 3 | (A–F) Changes in PEP (ms), LVET (ms), SV (cm^3/ml), HR (bpm), RMSSD (ms), and RSA (ms) across time (before, during and + 10min after the (in-) activity) and experimental conditions. Asterisks indicate significant differences between time points, regardless of exercise condition (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$). Condition D (physically inactive) is depicted for additional reference (Note: Since physical inactivity in condition D has been shorter than the exercise in ABC, data from a later point in time is depicted for condition D to keep times congruent). Vertical bars denote +/− standard errors.

HF, RMSSD, HR, LVET; $V = 0.14$, $F(16, 142) = 0.69$, $p > 0.1$, $\eta_p^2 = 0.07$] but a significant effect of *time* [$V = 0.97$, $F(16, 62) = 108.41$, $p \leq 0.001$, $\eta_p^2 = 0.97$] and no interaction *time* × *condition* [$V = 0.31$, $F(32, 126) = 0.72$, $p = 0.86$, $\eta_p^2 = 0.16$]. Subsequent ANOVAs confirm this pattern for each of the dependent variables (*time*: all $p \leq 0.001$; *condition*: all $p > 0.1$; *time* × *condition*: $p > 0.1$; for detailed results, please see **Supplementary Material**).

Post hoc tests revealed that PEP, RSA and LVET were significantly reduced during aerobic exercise and returned to baseline levels in the recovery period (all $p \leq 0.001$), as is expected for aerobic exercise. HR, SV, and CO increased during aerobic exercise to meet physiological demands and returned to baseline level after cessation of the activity (all $p \leq 0.001$). As it is already evident in the MANOVA results, these patterns did not differ between nor interacted with the experimental exercise

conditions. The physically inactive condition D, however, differed from the exercise conditions, such that the analyzed parameters did not notably change during the session (see **Figure 3**).

In-Depth Analysis of Recovery and Parasympathetic Reactivation (RSA, RMSSD, HRR)

To evaluate RSA during the recovery period, and therefore parasympathetic reactivation after the activity, in a more detailed fashion, an additional 3 (*exercise conditions*) × 11 (*time*: 30 s periods from 180 to 480 s after the end of the activity) rmANOVA has been conducted, revealing a main effect of *time* [$F(10, 860) = 4.28$, $p \leq 0.001$, $\eta_p^2 = 0.05$, $\epsilon = 0.61$], but not of *condition* [$F(2, 86) = 0.04$, $p > 0.1$, $\eta_p^2 = 0.00$], nor an interaction *time* × *condition* [$F(20, 860) = 0.90$, $p > 0.1$, $\eta_p^2 = 0.02$, $\epsilon = 0.61$].

To further evaluate HRV using a time-based parameter (RMSSD), a 3 (*exercise conditions*) × 11 (*time*: 30 s periods from 180 to 480 s after the end of the activity, log-transformed data[5]) rmANOVA demonstrated a significant main effect of *time* [$F(10, 870) = 6.09$, $p \leq 0.001$, $\eta_p^2 = 0.07$, $\epsilon = 0.71$], but not of *condition* [$F(2, 87) = 0.02$, $p > 0.1$, $\eta_p^2 = 0.00$], and no interaction of *time* × *condition* [$F(20, 870) = 0.98$, $p > 0.1$, $\eta_p^2 = 0.02$, $\epsilon = 0.71$].

Lastly, a 3 (*exercise conditions*) × 7 (*time*: Baseline/Warmup/Activity/Cooldown/HRR180/HRR330/HRR480) repeated measures ANOVA (DV: mean heart rate) revealed a significant main effect of *time* [$F(6, 522) = 579.59$, $p \leq 0.001$, $\eta_p^2 = 0.87$, $\epsilon = 0.60$], but neither a main effect of *condition* [$F(2, 87) = 0.10$, $p > 0.1$, $\eta_p^2 = 0.00$], nor an interaction of *time* × *condition* [$F(12, 522) = 0.36$, $p > 0.1$, $\eta_p^2 = 0.01$, $\epsilon = 0.60$]. *Post hoc* tests also confirmed that there is no difference between any of the conditions in heart rate, nor heart rate recovery after the exercise (i.e., returning to baseline levels; all $p > 0.1$).

Correlational Analyses Using Self-Reported Attentional Focus

Pearson correlation analyses have been performed to discover a possible relationship between self-reported attentional focus and affect (FS, PAAS) and perceived exertion (RPE) in conditions C (exercise without attentional focus instruction) and D (no exercise, no attentional focus instruction). For example, a stronger focus on external-relevant stimuli has been associated with more subjective exertion after the exercise, in condition C. In condition D, after the inactivity, a stronger attentional focus on internal-relevant stimuli has been associated with more subjective exertion, whereas a focus on internal-irrelevant stimuli has been associated with less subjective exertion. **Table 3** depicts full results on Pearson correlation coefficients for the relationships between self-reported attentional focus and affect (FS, PAAS) and perceived exertion (RPE) in experimental conditions C and D.

Lastly, Pearson correlation analyses have been performed to examine the relationship between the self-reported time spent with an internal-irrelevant, internal-relevant, external-irrelevant, external-relevant focus and physiological responses at baseline (pre), during the activity (peri) and 10 min after the activity (post). For example, in condition C, a stronger focus on internal-irrelevant stimuli has been associated with a shorter PEP (i.e., less milliseconds), pre-, peri-, and post-exercise; and with a higher average HR peri- and post-exercise. In condition D, a stronger focus on internal-irrelevant stimuli was associated with higher RMSSD before and after the period of inactivity. **Table 4** depicts Pearson correlation coefficients for the relationships between the self-reported time spent with an internal-irrelevant, internal-relevant, external-irrelevant, external-relevant focus and physiological responses. However, please note that *p*-values are reported uncorrected and none of the significant correlations would survive Bonferroni correction.

DISCUSSION

We investigated the affective and physiological effects of attentional focus during an acute bout of moderate cycling exercise. It was hypothesized that the attentional focusing might resemble an additional task, increasing the total psychophysiological demands of the activity and therefore possibly influencing affective and physiological responses. To test this hypothesis, attentional focus was experimentally manipulated to be directed at internal-relevant or external-irrelevant stimuli during a cycling task. The presented results question the importance of participants' attentional focus during exercise for affect, subjective exertion and physiological responses and recovery.

In general, the attentional focus manipulation can be considered successful: experimentally induced focus has also been reported to be dominant in the respective conditions. Furthermore, it is also evident that the track simulation gave ample brightness changes to focus on, and that participants displayed a natural cycling performance, with a non-linear flow of force production. It is also reasonable to assume that most participants were engaged in the task until the end, given the displayed variance in answers (**Figure 1**): Since it could be expected that mentally absent (e.g., focusing on internal-irrelevant stimuli, i.e., daydreaming) participants would not have noticed any changes in force production or brightness, the answer "constant" would have occurred much more frequently than data suggests.

Although the attentional focus manipulation can be considered successful, neither participants' affective reaction toward the cycling exercise, nor their perceived exertion, nor any physiological parameter differed by experimental condition, apart from the inactive control condition. This is not in line with previous studies reporting an additive effect of combined mental and physical challenges (Roth et al., 1990; Taelman et al., 2011), but rather supportive of contrary research (e.g., Wasmund et al., 2002; Greig et al., 2007). Therefore, it seems reasonable to assume that attentional focusing cannot be considered an adequate challenge to sufficiently influence the cardiovascular reactions to exercise. Although the task of attentional focusing has been designed as an active task with reinforcement—i.e., being regularly reminded and asked to state out loud if the quality of the ambient light or the

[5]Especially when using Ultra-Short Term HRV measurements, it is recommended to log-transform the data before applying parametric methods (e.g., Esco and Flatt, 2014; Pecchia et al., 2018). Using raw data does not alter the presented results.

TABLE 3 | Pearson correlation coefficients for self-reported focus of attention and subjective exertion (RPE), positive affect (PAAS), negative affect (PAAS), and positive affect (Feeling Scale).

		Pre	Post	+10 min	+30 min	Pre	Post	+10 min	+30 min	Pre	Post	+10 min	+30 min	Pre	Peri	Post	+10 min	+30 min
		Subjective exertion (RPE)				Positive affect (PAAS)				Negative affect (PAAS)				Positive affect (FS)				
Condition C	Internal relevant	0.40*	0.11	0.14	0.26	−0.10	−0.08	0.07	0.12	0.10	0.08	0.12	−0.06	−0.40*	−0.15	−0.28	−0.12	0.01
	External relevant	0.26	0.40*	0.48**	0.33	−0.15	−0.09	−0.04	−0.03	−0.06	0.13	0.16	−0.14	−0.36	−0.14	−0.42*	−0.29	0.04
	Internal irrelevant	−0.16	−0.24	−0.27	0.02	−0.06	−0.21	−0.29	−0.36	0.09	0.13	0.08	0.22	0.10	0.16	0.09	−0.13	−0.21
	External irrelevant	0.00	0.23	0.13	−0.18	−0.05	0.09	0.06	0.15	−0.07	−0.22	−0.19	−0.17	0.11	0.23	0.14	0.32	0.20
Condition D	Internal relevant	0.12	0.45*	0.40*	0.06	−0.05	0.18	0.00	−0.03	−0.10	0.13	0.01	−0.23	0.02	0.08	0.06	0.28	0.26
	External relevant	0.22	0.31	0.01	0.33	−0.28	−0.18	−0.20	−0.24	0.12	0.06	0.08	0.00	−0.30	0.14	0.16	0.02	−0.14
	Internal irrelevant	−0.22	−0.57**	−0.41*	−0.16	0.16	−0.07	0.12	0.15	0.10	−0.06	0.02	0.31	0.18	−0.14	−0.02	−0.18	−0.17
	External irrelevant	0.20	0.35	0.25	0.06	−0.15	−0.02	−0.11	−0.08	−0.10	−0.09	−0.08	−0.23	−0.32	0.00	−0.24	−0.12	−0.01

*Calculated separately for condition C (exercise without attentional focus instruction) and condition D (control condition without exercise and attentional focus instruction). Please note that p-values are reported uncorrected and none of the significant correlations would survive Bonferroni correction. *p < 0.05, **p < 0.01, ***p < 0.001.*

TABLE 4 | Pearson correlation coefficients for self-reported focus of attention and pre-ejection period (PEP), average HR, heart rate variability (RMSSD and HF), left-ventricular ejection time (LVET), stroke volume (SV), cardiac output (CO), and respiratory sinus arrythmia (RSA).

		Pre	Peri	Post	Pre	Peri	Post	Pre	Peri	Post	Pre	Peri	Post	Pre	Peri	Post	Pre	Peri	Post	Pre	Peri	Post	Pre	Peri	Post
		PEP			Average HR			RMSSD			HF			LVET			SV			CO			RSA		
Condition C	Internal relevant	0.20	0.21	0.27	−0.13	−0.14	−0.18	−0.06	−0.15	0.06	−0.08	−0.20	0.08	0.27	0.17	0.12	−0.05	−0.17	−0.15	−0.12	−0.21	−0.20	−0.14	−0.17	−0.02
	External relevant	0.22	0.00	0.32	−0.09	−0.07	−0.09	−0.08	−0.07	−0.04	−0.15	−0.11	−0.07	0.29	0.35	0.23	0.05	−0.15	−0.07	−0.02	−0.16	−0.09	−0.15	−0.12	−0.08
	Internal irrelevant	−0.38*	−0.19	−0.53**	0.26	0.40*	0.37*	−0.12	−0.27	−0.19	−0.11	−0.24	−0.15	−0.12	−0.29	−0.03	0.01	0.04	0.06	0.15	0.15	0.21	−0.13	−0.28	−0.19
	External irrelevant	0.22	0.05	0.32	−0.11	−0.29	−0.22	0.08	0.08	0.15	0.10	−0.20	0.10	−0.37*	0.03	−0.31	−0.32	−0.10	−0.21	−0.33	−0.18	−0.29	0.04	0.08	0.06
Condition D	Internal relevant	0.09	−0.07	−0.51	0.15	0.09	0.37*	−0.35	−0.27	−0.42*	−0.25	−0.25	−0.36	0.23	0.12	0.08	0.22	0.13	0.67	0.29	0.16	0.82*	−0.36	−0.25	−0.36
	External relevant	0.06	0.02	0.21	0.07	0.13	−0.09	−0.11	−0.12	−0.13	−0.14	−0.12	−0.13	0.01	−0.07	0.73	0.08	0.07	0.11	0.12	0.10	−0.06	−0.11	−0.07	−0.16
	Internal irrelevant	−0.09	0.22	0.25	−0.27	−0.31	−0.26	0.45*	0.45*	0.51**	0.33	0.41*	0.45*	−0.11	0.03	−0.88*	−0.31	−0.28	−0.66	−0.43*	−0.38*	−0.49	0.38*	0.41*	0.40*
	External irrelevant	−0.06	−0.45*	0.08	0.28	0.51**	0.13	−0.20	−0.34	−0.28	−0.10	−0.31	−0.25	−0.15	−0.24	0.82*	0.30	0.37*	0.17	0.43*	0.55**	0.20	−0.03	−0.28	−0.12

*Calculated separately for condition C (exercise without attentional focus instruction) and condition D (control condition without exercise and attentional focus instruction). Please note that p-values are reported uncorrected and none of the significant correlations would survive Bonferroni correction. *p < 0.05, **p < 0.01, ***p < 0.001.*

sensation of their quad muscles has changed—it is obviously not comparable to challenges such as mental arithmetic used by previous research.

With respect to physiological responses to cycling exercise, it is evident that the additional task of instructing an attentional focus did not further modulate sympathetic activation during or parasympathetic reactivation after exercise compared to exercise without attentional focus instructions. At the same time, previous literature suggesting a masked, or blunted psychophysiological response due to an additional mental task (Greig et al., 2007) could also not be supported. Not even a deliberately chosen attentional focus on internal-irrelevant stimuli seems to exert influence on the psychophysiological reactions to exercise. However, this was the case in short bouts of acute, moderate cycling exercise and can't be generalized toward higher intensities, prolonged durations, other exercise types (e.g., running) nor toward long-term effects of combined mental and physical challenges.

Another limitation of our study is the restricted sample of active females. Firstly, the results can therefore not be generalized toward a male sample. As outlined in the introduction, including male participants would have led to numerous interactions. Future studies, however, could take a step further and double the sample size to compare male to female participants in this experimental set-up. Secondly, the results cannot be generalized toward sedentary samples or high-performance athletes, with both groups possibly having a notably different approach to and knowledge about attentional focus during exercise.

Two further implications of the presented results should be discussed: Firstly, our study did not find any meaningful differences between all exercise conditions (cycling with an internal vs. external vs. no attentional focus) and could therefore not replicate previous findings. Contrary to previous studies assessing the thoughts of participants during exercise (Lind et al., 2009; Brick et al., 2014) we experimentally manipulated attentional focus: The beneficial effects of an external focus of attention might be tied to voluntariness or flexibility in the choice of attentional focus within the "external-irrelevant" category. Alternatively, the hypothesized benefits of an external-irrelevant focus of attention, or distraction, i.e., reduction in tension, increase in revitalization and positive engagement, might be most present in outdoor environments (Thompson Coon et al., 2011).

Secondly, if cardiovascular activity remains unchanged by an instructed attentional focus, this imposes the question as to what is responsible for the often-reported negative affect and increased subjective exertion after exercise with an internal focus of attention. If cardiovascular reactions are comparable, the instructed attentional focus possibly influences either sensitivity to, or appraisal processes of the physical symptoms during exercise, leading to an altered affective experience.

Although the proposed hypotheses could not be supported by the data, additional analyses, i.e., of participants' self-chosen attentional focus during exercise without attentional focus instructions, provided some insight for further research: If not specifically instructed, participants mostly chose internal-irrelevant stimuli to focus on during the exercise in a laboratory setting, suggesting this to be the most attractive distraction in this particular setting. Also, looking at the correlational analyses (**Tables 3**, **4**), internal-irrelevant focus could be associated with subjective exertion and psychophysiological responses to activity and inactivity. Although these correlations did not survive Bonferroni correction for multiple testing, they might inspire future hypotheses and experiments on the subject. Therefore, we recommend including a variety of experimentally manipulated attentional focus, e.g., on internal-irrelevant stimuli such as imagining music, philosophy, creating mental to-do-lists, or mental arithmetic, for future research, as well as assessment of self-reported attentional focus. Additional performance-based or physiological parameters (e.g., pacing, oxygen consumption; Schücker et al., 2009, 2016a,b) could also aid in entangling the effects of attention during physical activity even further. From these results, no specific recommendations can be formulated for non-professional exercisers. However, for future experimental research in sports psychology or sports physiology, these results imply that internal-relevant and external-irrelevant attentional focus are low-impact manipulations, placing no added mental demands on top of the physical demands by the exercise. Besides that, the results of this study also strongly suggest that attentional focus during exercise might generally be not as important to affect, subjective exertion or cardiovascular activity as has been suggested in the past.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because due to the informed consent form in which the possibility of raw data being published online was not explicitly stated, only group-level data, as it is provided in this manuscript, will be made accessible. All authors contributed to the article and approved the submitted version.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Ethics Committee of Ulm University (https://www.uni-ulm.de/einrichtungen/ethikkommission-der-universitaet-ulm/). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

FM prepared the manuscript, tables, and figures. CH revised it for scientific and intellectual content. FM planned the experiment, collected the data, preprocessed and analyzed the results under the supervision of CH. Both authors contributed to the article and approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fphys.2021.680149/full#supplementary-material

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary Material

SUPPLEMENT 1

VU-DAMS Configuration

Physiological data (ECG and ICG-dZ) was sampled at 1000 Hz, ICG-Z0 was sampled at 250 Hz. Using the VU-DAMS software (Vrije Universiteit; www.vu-ams.nl), ECG data was inspected for artifacts and semi-automatically artifact-corrected, i.e. each automatically detected artifact was manually checked by the experimenter. ECG artifacts (M=0.31 %, SD=0.014 throughout the recordings) were discarded and missing data extrapolated using cubic spline interpolation whenever <5 consecutive beats have been discarded. Artifact detection and rejection followed the VU-AMS guidelines and default settings implemented in the VU-DAMS software. ICG data has been semi-automatically artifact-corrected using the VU-DAMS default impedance scoring algorithm, and manually checked by the experimenter afterwards. ICG artifacts (M=4.65 %, SD=3.96 throughout the recordings) were subsequently discarded.

Heart Rate (HR), inter-beat intervals (IBI), and subsequent HRV parameters (HF, RMSSD) were extracted from the R-wave peaks in the continuous ECG signal. PEP was measured as the period from the Q-Point in the QRS complex of a heartbeat (ECG) to the B-Point (opening of the aortic valves) in the thoracic impedance changes over time DZ/DT (ICG) in milliseconds. LVET has been measured as the time from the B-point to the X-point (closure of the aortic valve) in the DZ/DT signal in milliseconds. SV has been calculated as the amount of blood ejected per beat in cm^3 using the distance between the frontal ICG electrodes and the thoracic impedance changes. CO (or minute volume) has been calculated using the formula (SV*HR*0.001). RSA was extracted using the peak-valley method (Grossman et al., 1990; de Geus et al., 1995; Willemsen et al., 1996), using the ECG signal, IBIs, and the respiration signal, calculated from thoracic impedance.

Data was cut into multiple intervals: Interval length for baseline, activity/inactivity and late recovery (i.e. second half of recovery period after activity) was set at 4 minutes from the middle of the interval (Willemsen et al., 1996; Houtveen et al., 2002) For each time period, heart rate (HR), (ultra-) short-term heart rate variability (HRV; parameters HF, RMSSD), pre-ejection period (PEP), left-ventricular ejection time (LVET), stroke volume (SV), cardiac output (CO), and respiratory sinus arrythmia (RSA), have been calculated using ECG signals and thoracic impedance (ICG) and subsequently averaged.

Initial recovery from physical activities always contains considerable drops in heart rate and overall sympathetic activation, making it impractical to evaluate post-exercise recovery as an undivided period. To gain a more reliable measure of recovery effects, this period was split into smaller 30-seconds periods, following the recommendations of Goldberger (Goldberger et al., 2006) regarding the assessment of post-exercise HRV or parasympathetic reactivation (results in Supplement, section “In-depth analysis of recovery and parasympathetic reactivation”.

Supplementary Material

SUPPLEMENT 2

Assessment of habitual and situational attentional focus (based on (Wininger and Gieske (2010), albeit with categories based on Stevinson and Biddle (1998)). Participants were asked to indicate their responses on a visual analogue scale (0-100% of the time).

Attentional Focus *(not visible to participants)*	**Instruction**: Please indicate if / how much of the time you [spend during a typical physical activity] *or* [spent during the 15 minutes of physical activity] with the following categories.
Internal-relevant	Your attention is directed inwards, i.e. how your body feels during the exercise – Examples are breathing, muscle soreness, thirst, fatigue, sweating, blisters, or nausea.
External-relevant	Your attention is directed outwards on things that are relevant for the execution of the task – Examples are strategy, track markers, water stations, lap times, the track and its conditions.
Internal-irrelevant	Your attention is directed inwards on things that are irrelevant for the execution of the task – Examples are daydreaming, imagining music, arithmetic problems, philosophy, or religion.
External-irrelevant	Your attention is directed outwards on things that are irrelevant for the execution of the task – Examples are scenery, spectators, other exercising people, or the general environment.

SUPPLEMENT 3

Training/Repetition Effects

A MANOVA (comparing sessions from weeks 1-4, regardless of experimental condition) has been performed to check for training / repetition effects and for the stability of physiological parameters at baseline acquired during this experiment. Using Pillai's trace, there was not a significant effect of the point of measurement on any physiological parameters (resting HR, HF, RMSSD, PEP, LVET CO, SV, RSA) at baseline measurements, V=0.25, F(24, 240)=0.92, p=0.58, η_p^2=0.08.

SUPPLEMENT 4

Detailed results on psychophysiological data (MANOVA, section 3.3)

DV	time	condition	time x condition
PEP	(F(2, 154)=385.48, p≤0.001, η_p^2=0.83, ϵ=0.73)	(F(2, 77)=0.78, p>0.1, η_p^2=.02)	(F(4, 154)=0.97, p>0.1, η_p^2=0.03, ϵ=0.73)
CO	(F(2, 154)=213.20, p≤0.001, η_p^2=0.73, ϵ=0.82)	(F(2, 77)=0.46, p>0.1, η_p^2=.01)	(F(4, 154)=0.46, p>0.1, η_p^2=0.01, ϵ=0.82)
SV	(F(2, 154)=12.85, p≤0.001, η_p^2=0.14, ϵ=0.96)	(F(2, 77)=0.73, p>0.1, η_p^2=.02)	(F(4, 154)=1.00, p>0.1, η_p^2=0.03, ϵ=0.96)
RSA	(F(2, 154)=121.05, p≤0.001, η_p^2=0.61, ϵ=0.74)	(F(2, 77)=0.07, p>0.1, η_p^2=.00)	(F(4, 154)=0.26, p>0.1, η_p^2=0.01, ϵ=0.74)
HF	(F(2, 154)=22.70, p≤0.001, η_p^2=0.23, ϵ=0.74)	(F(2, 77)=0.13, p>0.1, η_p^2=.00)	(F(4, 154)=0.47, p>0.1, η_p^2=0.01, ϵ=0.74)
RMSSD	(F(2, 154)=94.50, p≤0.001, η_p^2=0.55, ϵ=0.72)	(F(2, 77)=0.17, p>0.1, η_p^2=.01)	(F(4, 154)=0.41, p>0.1, η_p^2=0.01, ϵ=0.72)
HR	(F(2, 154)=857.84, p≤0.001, η_p^2=0.92, ϵ=0.65)	(F(2, 77)=0.09, p>0.1, η_p^2=.00)	(F(4, 154)=0.01, p>0.1, η_p^2=0.00, ϵ=0.65)
LVET	(F(2, 154)=18.07, p≤0.001, η_p^2=0.19, ϵ=0.93)	(F(2, 77)=0.19, p>0.1, η_p^2=.01)	(F(4, 154)=0.22, p>0.1, η_p^2=0.01, ϵ=0.93)

Erklärung

Hiermit versichere ich, Friedrich Meixner, dass ich die hier vorliegende, zur Promotion eingereichte Arbeit (kumulative Dissertation) mit dem Titel „*From Appraisal and Attention to Affective Experience: Genetic, Social and Exercise-based Influences on Emotional Evaluation and Psychophysiological Reactions*" selbständig angefertigt habe und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt sowie die wörtlich oder inhaltlich übernommenen Stellen als solche kenntlich gemacht und die zur Zeit gültige Satzung der Universität Ulm zur Sicherung guter wissenschaftlicher Praxis beachtet habe (§8 Abs.1 Nr.5 Rahmenpromotionsordnung).

Ulm, den 05.09.2022 Friedrich Florian Meixner