Meaning and pupillometry

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The role of physiological arousal in meaning maintenance

Willem Sleegers

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Chapter 1

Introduction

> *"I checked it very thoroughly," said the computer, "and that quite definitely is the answer. I think the problem, to be quite honest with you, is that you've never actually known what the question is."*
>
> — Douglas Adams*, The Hitchhiker's Guide to the Galaxy*

On the Day of the Answer, Deep Thought revealed the answer to Life, the Universe, and Everything. No longer did the Magratheans have to wonder about who they were and what their purpose is in life. Or so they thought. After 7.500.000 years of computing, the super computer revealed, with infinite majesty and calm, that the answer is 42.

The story by Douglas Adams exemplifies the incessant need for people to seek out answers to questions of meaning. People are motivated to discover answers that relate to their identity, their place in society, the working of the world, and many other questions. In fact, I will argue in this dissertation that meaning can be found even in the most trivial of questions and their answers. The main idea that will be discussed is that people experience meaning through the experience of understanding. This idea is captured in a theoretical model called the Meaning Maintenance Model (MMM, Heine, Proulx, & Vohs, 2006; Proulx & Heine, 2006; Proulx & Inzlicht, 2012), which will serve as the guiding framework of this dissertation. According to the MMM, meaning is expected relations. Through the adoption of beliefs people come to expect events to unfold in accordance with those beliefs. As long as this occurs, there is meaning.

The Magratheans expected to hear the answer to Life, the Universe, and Everything. They likely expected to receive a deep and complex answer that they would immediately recognize as the correct answer. Instead, they received a number. This was not only disappointing because it does not appear to answer the question, but it was also unexpected. It violated their expectations in terms of not receiving an answer and also in terms of the kind of answer. If meaning can be found in understanding, then events violating that understanding constitutes a loss of meaning. Hence, ironically, in their quest for meaning, the Magratheans found the opposite.

The loss of meaning is a negative experience. In certain cases it is accompanied by despair, while in other cases it might be merely unpleasant. Nevertheless, the loss of meaning is not desirable. As a result, people respond in various ways to reduce the unpleasantness. The MMM specifies several strategies people can perform to restore meaning. Some of these strategies, as will become clear later, do not address the meaning violating source directly. Instead, the focus appears to be on the unpleasant psychological state, rather than solving the source of the

discrepancy. It is for this reason that the negative state following a meaning violation is a vital component of the MMM. According to the MMM, the violation of meaning causes aversive psychophysiological arousal which motivates compensatory behavior to reduce it. Although not mentioned by Douglas Adams, the Magratheans likely showed signs of elevated psychophysiological arousal such as increased heart rate, elevated skin conductance, and enlarged pupil size in their moment of despair. To rid themselves of this unpleasant state, they took action: the construction of a new super computer that will calculate the question, rather than the answer.

Our main question is whether physiological arousal indeed plays a role in the quest for meaning. A significant amount of accumulated work in the existential psychology literature suggests the presence of a state of psychophysiological arousal in responding to lost meaning. In this dissertation I review the evidence for this view, present new studies that were aimed to build upon this literature, and address new questions related to the role of arousal in people's search for meaning.

I did not conduct this work alone. The work presented in this dissertation was conducted by me and my supervisors, dr. Travis Proulx and dr. Ilja van Beest, so I will from this moment on abandon the 'I' noun in favor of 'we'. In our work, we address such issues as what the underlying physiological structures are that produce the aversive arousal experienced after the loss of meaning, as well as the structures that might promote efforts to regain it. We also conducted multiple empirical studies to gain a better understanding of the role of arousal in responding to meaning violations. To this end, we used pupillometry as a proxy for physiological arousal. Recent developments in eye tracker technology have made pupillometry an affordable and easy-to-use tool to investigate psychophysiological arousal. Although far from a new method, pupillometry has not yet been widely applied to the investigation of meaning violations; hence, in this dissertation, we explore the capabilities of this method in the context of meaning.

We applied pupillometry to several areas of interest. We tested whether different kinds of meaning violations elicit a physiological arousal response as assessed with an eye tracker. These included such experiences as being socially excluded, the violation of held beliefs, as well as perceptual anomalies. Additionally, and importantly, we investigated how arousal relates to different meaning seeking or restoration strategies. Before discussing these studies in detail, we provide a theoretical background that further elaborates on the Meaning Maintenance Model, pupillometry as a tool to measure psychophysiological arousal and how pupillometry can be used to investigate the role of arousal in responding to meaning violations.

1.1 The Meaning Maintenance Model

The Meaning Maintenance Model (MMM) is an integrative model that incorporates multiple theoretical frameworks in the existential psychology literature to explain both what meaning is and how people respond to lost meaning. The central idea is that people adopt meaning frameworks, that is, sets of beliefs that allow them to make sense of the world. These meaning frameworks are imperfect, so it frequently happens that people are confronted with events that do not fit in their meaning frameworks—thereby violating their sense of meaning. Traumatic experiences, disconfirmed beliefs, unpredictable situations, and perceptual anomalies are but a few of the types of events that constitute a meaning violation. The result is a state of aversive psychophysiological arousal that motivates people to reduce this state of discomfort. The MMM describes various ways to reduce the discomfort and in doing so, integrates numerous theories from the threat compensation literature such as cognitive dissonance theory (Festinger, 1957), terror management theory (Greenberg, Pyszczynski, & Solomon, 1986), uncertainty management theory (van den Bos & Lind, 2002) and related existential threat phenomena (e.g., reactive approach motivation; McGregor, Nash, Mann, & Phills, 2010; assumptive worlds; Janoff-Bulman, 1992; disequilibrium; Piaget, 2000; imbalance; Heider, 1958). As will be made clear, the MMM's central tenet is that underlying the threat compensation theories in this literature is the presence of a common type of psychological threat—the violation of expectations—that induces aversive physiological arousal and motivates subsequent compensatory behavior. The section below offers a more detailed overview of MMM and the role of arousal in the loss of meaning and its restoration.

1.1.1 Meaning

According to the MMM, meaning is that what allows people to make sense of their experiences. This particular interpretation of meaning might seem rather unusual. How do prominent sources of meaning such as social relationships, parenthood, religious activities, personal development, or one's career relate to sense-making? Closer inspection, however, reveals that events people regularly categorize as meaningful often consist for a large part of the attempt to make sense of them. People consider the most meaningful events to be those events that shook their foundations the most or that provided the largest change in their thinking. Few will deny, for example, the incredible influence of becoming a parent on one's thinking and its meaningfulness.

The idea that meaning constitutes sense-making is not without precedence.

In a review by Park (2010) on the definition of meaning, the sense-making aspect of meaning was seen as the most commonly shared component of what constitutes meaning. Although Park focused particularly on meaning making efforts following trauma, it is clear from the various definitions of meaning she collected that sense-making is an important component. To illustrate, Graham, Lobel, Glass, and Lokshina (2008) define meaning as "a process that involves changing appraisals of specific situations or global beliefs about the world or self", Nolen-Hoeksema, McBride, and Larson (1997) as "attempts to understand the loss and his own reaction to the loss", and DuHamel et al. (2004) as "integration of the event into the worldview of the individual through accommodation and/or assimilation". In each of these definitions it is clear that sense-making is an important aspect of meaning.

But what is it that gives people the impression that something makes sense? From the perspective of the MMM, the answer is relationships. Meaning can be understood as the adoption of mental representations of relationships between committed propositions. Take water for example. Water can be understood as wet when touched, fluid at room temperature, and refreshing when thirsty. This collection of relationships between water and various attributes provides an understanding of water. The idea of meaning as relationships stems from both philosophy and psychology. Existential philosophers such as Camus, Heidegger, and Kierkegaard saw the importance of relations in constructing meaning (Camus, 2004; Heidegger, 2001; Hong & Hong, 2000). For example, Camus understood the "fundamental impulse of the human drama" as a need for consistent "systems of relations". Psychologists followed suit by postulating various terms that refer to the adoption of sets of expected relations to understand phenomena. In typical psychological fashion, the terms for these vary greatly but seem to refer to the same process. Examples are paradigms (Bruner & Postman, 1949), scripts (Nelson, 1981), narratives (McAdams, 2001), worldviews (Thompson & Janigian, 1988), systems (Jost, Banaji, & Nosek, 2004), assumptive worlds (Janoff-Bulman, 1992), and also meaning itself (Baumeister, 1991). These terms all refer to sets of expected relationships between propositions.

Meaning is, however, more than simply relationships. According to the MMM, meaning is *expected* relationships. People expect that water feels wet and that it feels refreshing to drink after a hot day. This expectation of specific relationships reflects the motivational component of meaning. People are committed to their expectations, which is particularly noticeable in the experienced discomfort upon seeing their expectations violated. The expected relations also vary in how committed people are to them. Some expectations are held with greater certainty and are considered more important than others. For example, many people

associate good events with good people and bad events with bad people (Lerner, 1980). This belief is important to them, as observed by the extent to which people defend this worldview when they observe events that do not match it, such as in the case of victim derogation following robberies or sexual assault (van den Bos & Maas, 2009). Other beliefs are more trivial, like beliefs related to the color of playing cards (Bruner & Postman, 1949). People expect that a two of hearts is colored red. Sometimes, however, they might be faced with a trick deck (likely while participating in a psychology experiment). Although this violates their expectations, it would be unjust to put this on the same par as facing the violations of beliefs in a just world. Nonetheless, the MMM posits meaning is found in each of these expected relations. All beliefs that shape expectations provide meaning, and any violation of those beliefs result in lost meaning.

1.1.2 The loss of meaning

Due to imperfect meaning frameworks it frequently happens that expectations are violated. We see bad things happen to good people, we find out that we were wrong about another person's character, perhaps even about ourselves, or we discover certain factual beliefs to be entirely mistaken. When these expectations are violated, a loss of meaning is experienced. This loss of meaning is a negative experience. Just like beliefs vary in the commitment by which they are held, so does the extent of discomfort. This can range from traumatic events, like sexual assault or natural disasters, to trivial violations of expectations like the aforementioned trick playing cards. In the case of trauma, Janoff-Bulman (1992) has made the case for a double-dose of anxiety following trauma. The first dose of anxiety relates to the threat of the event towards our well-being. This reaction is straightforward—a negative event occurs that poses a physical threat, so we react appropriately defensively. The second dose of anxiety relates to the shattering of worldview assumptions. Not only did something bad happen, but it is also not understood. Often asked questions such as "Why did this happen?" or "How could this happen to me?" follow traumatic events. Scientifically, these questions are relatively easily answered; certain natural disasters, for example, are well-understood. Yet there is nonetheless a violation of expectations. These are expectations such as an incorrect sense of invulnerability (Weinstein, 1987) or beliefs like the aforementioned belief in a just world (Lerner, 1980). How can something as bad as a natural disaster happen to so many good people? It is the violation of these expectations that creates a second dose of anxiety.

Traumatic events are but one example of situations in which an expectation, and therefore meaning, is violated. At other times, people might discover that

their sense of control is vastly overestimated (Langer, 1975), that they behave in ways inconsistent with who they think they are (Steele & Liu, 1983) or even their own attitudes (Festinger, 1957), or that significant life events could have very easily turned out differently (Kray et al., 2010). In the interpersonal domain, people might be faced with often unexpected social exclusions (Williams & Nida, 2011), violations of stereotypes (Mendes, Blascovich, Lickel, & Hunter, 2002), betrayal (Koehler & Gershoff, 2003) or any breach of social contract. Additionally, people might be faced with perceptual anomalies (Bruner & Postman, 1949), or they discover that facts about the world they believe to be true might be wholly false, such as the fact that chameleons do not change their color to match their surroundings, that Vikings did not wear horned helmets, or that the capital of Australia is Canberra, not Sydney.

Psychologists have long investigated the experience associated with the aforementioned events, and similar to the various ways that the initial beliefs are described (e.g., world views, schemas, narratives, etc.), the described experience following those events is equally varied. In other theories this aversive state has been referred to as disequilibrium (Piaget, 2000), imbalance (Heider, 1958), dissonance (Festinger, 1957), anxiety (Janoff-Bulman, 1992), terror (Greenberg, Solomon, & Pyszczynski, 1997a), uncertainty (van den Bos, 2001), and anxious uncertainty (McGregor et al., 2010). It is one of the central tenets of the MMM that all these various terms refer to the same psychological discomfort, caused by the violation of expectations. In the case of cognitive dissonance, one could entertain the possibility that the most commonly researched cause of cognitive dissonance—the observation that one's own behavior is not in line with one's attitude—constitutes a violation of expectations. People's need for consistency shapes their expectations about the behaviors they will perform, given the attitudes they hold. Thus, observing that one's behavior is not in line with one's attitude violates the expectancy that the behavior will be in line with that attitude. Similarly, in the case of terror management theory it might not be that the thought of death inherently causes a sense of terror, but rather that any encounter with death violates specific expectations. These expectations can be found in commonly observed beliefs in immortality and other overly positive self-related beliefs (Perloff & Fetzer, 1986; Taylor & Brown, 1988; Weinstein & Klein, 1996). This is not to say that specific sources of violations of meaning do not have unique attributes that may moderate defensive reactions to their occurrence, but there appears to be a commonality across the various phenomena that can potentially be attributed to the violation of expectations.

Besides integrating numerous threat compensation theories, the notion that a violation of expectations is the cause for a loss of meaning also leads to novel pre-

dictions. Specifically, it leads to the prediction that any violation of expectations, no matter how trivial or its source, constitutes a loss of meaning. This prediction that even trivial expectations cause meaning has been supported by multiple studies. Violated expectations resulting from visual anomalies (Proulx & Heine, 2008; Proulx & Major, 2013), absurd literature (Proulx, 2009) and incongruous word-pairings (Randles, Proulx, & Heine, 2011) elicit identical behavioral responses that have been observed in response to other meaning violations, such as being confronted with one's own mortality (Proulx, Heine, & Vohs, 2010). These findings lend support for the MMM's tenet that the violation of expectations is central to the loss of meaning.

1.1.3 Restoring meaning

Naturally, after a loss of meaning has occurred, people are motivated to restore meaning. A wide variety of behaviors have been observed following the loss of meaning. Some examples of these behaviors are that socially excluded people increase their social affiliative efforts to again be included (Carter-Sowell, Chen, & Williams, 2008; Maner, DeWall, Baumeister, & Schaller, 2007; Williams, 2007, 2009), people who experience cognitive dissonance change their attitudes to resolve the inconsistency responsible for their dissonance (e.g., Festinger, 1957; Harmon-Jones, Gerdjikov, & Harmon-Jones, 2008), and sometimes people appear to affirm meaning frameworks unrelated to the initial source of the meaning violation, such as affirming a moral value following perceptual anomalies (Proulx & Major, 2013). This latter form of compensatory behavior, termed fluid compensation (Allport, 1943), has seen a lot of academic interest and seems to occur after many different kinds of meaning violations. It has been observed following dissonance (Steele & Liu, 1983), mortality salience (Pyszczynski, Greenberg, & Solomon, 1999), personal uncertainty (van den Bos & Lind, 2002), as well as absurd jokes (Proulx et al., 2010), and a secretly switched experimenter (Proulx & Heine, 2008). Consequently, it appears that meaning violations can be resolved with fluid compensation behaviors.

According to the MMM, people can adopt five different strategies to restore meaning: assimilation, accommodation, affirmation, abstraction, and assembly. The first two strategies can be distinguished from the other strategies in that they directly or indirectly address the meaning violation. Assimilation refers to reinterpreting the meaning violation in such a way that it fits within the existing meaning framework, while accommodation refers to adjusting the existing meaning framework to incorporate the meaning violation. This can be illustrated by the common belief in a just world. One frequently hears of horrible events such as car accidents

or sexual assaults in which there is one or more victims. The initial reaction, and source of the meaning violation, is that the victims did not deserve such fate. If the world was truly good, no such bad thing would happen to them. However, using an assimilation strategy, one can interpret the scenario by assuming the victims are to blame. Perhaps the driver was irresponsible, having had a drink too many, or perhaps the sexual assault victim dressed too provocatively, thus 'asking for it'. By blaming the victim, the world view is maintained, and the meaning violation resolved. Alternatively, one's view can accommodate the meaning violation. Adopting the belief that the world is not always just, and that people can simply be at the wrong place at the wrong time, incorporates the meaning violation and thus also resolves it. This latter strategy is, however, a more effortful one, and people are likely to favor reinterpreting an event than to change their meaning frameworks.

The third strategy, affirmation, consists of the increased tendency to declare one's commitment towards a specific value or belief after a meaning violation. Often this involves the affirmation of beliefs related to the source of the meaning violation. For example, violations regarding our sense of control in one domain can elicit increased affirmation of control in other domains (Kay, Whitson, Gaucher, & Galinsky, 2009) or violations in social justice beliefs can lead to affirmation of the social system, even though it's the social system that is responsible for the injustice (Jost et al., 2004). However, an additional, and novel, tenet of the MMM is that meaning frameworks are radically substitutable, meaning that the loss of meaning in one domain can be regained by affirming meaning frameworks of another domain. For example, students who see themselves arguing for a tuition increase later affirm unrelated moral and political beliefs (Steele & Liu, 1983) or seeing reverse colored playing cards leads to the affirmation of liberal political beliefs, at least for those who are committed to those beliefs (Proulx & Major, 2013). Or, as the vast literature on terror management has shown, meaning violations related to death can elicit affirmations of seemingly unrelated values, such as one's cultural identity (Burke, Martens, & Faucher, 2010). It thus appears that meaning violations can lead to the affirmation of beliefs unrelated to the source of meaning violation. In fact, it has been demonstrated that a range of different meaning violations can elicit an identical affirmation response. This has been demonstrated with the bond for prostitute measure. In this measure, participants set a bond (ranging from $0 to $999) for a prostitute arrested for having sex in a bathroom stall. Assuming that many adhere to the norm that such an act is inappropriate and thus violates their values regarding sexual conduct, not to mention potential civil laws, this offers an opportunity to affirm that particular value. And indeed, people show an increased affirmation of that value by setting a higher bond, no

matter the kind of meaning violation. It has been demonstrated in the case of mortality salience (e.g., Rosenblatt, Greenberg, Solomon, Pyszczynski, & Lyon, 1989), absurd humor (Proulx et al., 2010), surrealism (Randles, Heine, & Santos, 2013), an unexpected and unnoticed change in experimenter (Proulx & Heine, 2008), cognitive dissonance (Randles, Inzlicht, Proulx, Tullett, & Heine, 2015), meaningless word-pairs (Randles et al., 2011) and arguing against one's own self-unity (Proulx, 2009).

The final two strategies, abstraction and assembly, refer to the creation of meaning. Abstraction involves finding patterns in the environment to find structure and thus, potentially, meaning. Proulx (2009) demonstrated that in response to a meaning violation (reading an absurd story or arguing against a unitary self-concept) can lead to increased performance on learning novel patterns in an artificial grammar task. Relatedly, one can go beyond trying to detect patterns and create a new meaning framework altogether. One particular display of this strategy is increased creativity following meaning violations (Maddux, Adam, & Galinsky, 2010; Markman, Lindberg, Kray, & Galinsky, 2007). Experimental work on this topic has shown that, for example, thinking about how events could have easily turned out different increases abstract thinking and creative problem solving (Galinsky & Moskowitz, 2000). One may also refer to the somewhat informally observed relationship between experienced anxiety and high-quality creative work of certain artists, like Van Gogh or Beethoven.

1.1.4 The state of meaninglessness

As previously noted, many events can constitute a meaning violation and a variety of behaviors are performed following the loss of meaning. In-between meaning violations and the compensatory behavior they induce is the experience of meaninglessness. But what exactly does this state of meaninglessness entail? According to the MMM, the state of meaninglessness is a state of aversive psychophysiological arousal. Unlike the tenet that meaning violations consist of the violation of expectations and that meaning violations in one domain can be addressed by the affirmation of values in unrelated domains, the specific claim that meaning violations result in aversive psychophysiological arousal has received relatively less attention (although see Proulx & Heine, 2008). Nevertheless, several lines of research offer empirical support for the MMM's prediction of aversive arousal following meaning violations.

Previous psychological phenomena that are reinterpreted as meaning violations in the MMM were already considered to result in physiological arousal. Festinger (1957) suggested that the experience of dissonance should be accompa-

nied by elevated levels of arousal and this relationship has indeed been found (Croyle & Cooper, 1983; Elkin & Leippe, 1986; Gerard, 1967; Harmon-Jones, Brehm, Greenberg, Simon, & Nelson, 1996; Losch & Cacioppo, 1990). Similar increases in arousal have been found following self-view inconsistencies (Ayduk, Gyurak, Akinola, & Mendes, 2012), worldview violations (Townsend et al., 2010), category-based violations (Mendes, Blascovich, Hunter, Lickel, & Jost, 2007), and unexpected social rejection (Gunther Moor, Crone, & van der Molen, 2010). These elevations in arousal were assessed with a variety of different measures of arousal, such as finger amplitude, galvanic skin response, and heart rate.

Further evidence can be found in so-called misattribution of arousal studies. In these studies, participants are given an opportunity to attribute any felt arousal to a secondary source, thus eliminating the need for compensatory behavior (Inzlicht & Al-Khindi, 2012; Kay, Moscovitch, & Laurin, 2010; Losch & Cacioppo, 1990; Proulx & Heine, 2008; Zanna & Cooper, 1974). For example, Proulx and Heine (2008) introduced participants to a particular experimenter, who changed halfway throughout the experiment without notification. This change was unnoticed by the participants, but nonetheless violated their expectations as seen in the increased affirmation of a moral belief relative to the control condition. Some of the participants were given a placebo and believed that it could produce mild arousal or anxiety. As a result, they attributed the arousal from the meaning violation to the placebo and did not feel the need to affirm one of their moral beliefs. In a different study it has been demonstrated that the effect of a meaning violation on compensatory behavior is also reduced when participants receive a sedative (Cooper, Zanna, & Taves, 1978). These findings demonstrate the role of arousal in producing compensatory behaviors following meaning violations.

Recent theorizing suggests that the aversive arousal may consist of specific neurocognitive structures in the brain that form the Behavioral Inhibition System (BIS). The BIS was described by Gray (1982) in his book entitled “The Neuropsychology of Anxiety” (since updated Gray & McNaughton, 2003). Any kind of threat activates the BIS and produces behavioral inhibition, heightened arousal, and increased vigilance. This stops ongoing behavior and focuses attention on the environment to scan for further threats and solutions. Several potential brain structures have been identified to underly BIS activation. These studies suggest the involvement of the anterior cingulate cortex (ACC). The ACC receives input several brain areas related to the processing of emotional and motivational factors, such as the limbic lobe, which includes the orbitofrontal cortex and the amygdala (Bush, Luu, & Posner, 2000; Morecraft & van Hoesen, 1998; Pandya, van Hoesen, & Mesulam, 1981; van Hoesen, Morecraft, & Vogt, 1993; Vogt, Sikes, & Vogt, 1993). The exact function of the ACC is still controversial but it appears to relate

to such processes as conflict monitoring (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Yeung, Botvinick, & Cohen, 2004) or prediction errors following from expectations derived from one's learning history (reinforcement-learning theory; Holroyd & Coles, 2002).

Not only has the ACC been linked to the underlying source of meaning, expectations, but the ACC has also already been empirically linked to meaning violations. The ACC is activated when people are made aware of their mortality (Quirin et al., 2012), when people experiences cognitive dissonance (Kitayama, Chua, Tompson, & Han, 2013; van Veen, Krug, Schooler, & Carter, 2009), when people have less control (Salomons, Johnstone, Backonja, & Davidson, 2004), and during social exclusion (Bolling, Pelphrey, & Vander Wyk, 2012; Bolling et al., 2011; Eisenberger, Lieberman, & Williams, 2003; Gunther Moor et al., 2012; Lelieveld, Moor, Crone, Karremans, & van Beest, 2012; Masten et al., 2009). This has led to the suggestion that the ACC, and more generally the BIS, is the root cause of the aversiveness that follows from meaning violations (Proulx & Inzlicht, 2012); and that it is this state of aversive arousal that motivates subsequent compensatory behavior to alleviate that aversive arousal.

The subsequent compensatory behavior is theorized to in turn activate the behavioral activation system (BAS). The BAS is wholly different from the BIS and instead of focusing on threats, it focuses on rewards, non-punishment, and escape from punishment. The BAS is a state associated with feelings of hope, elation and happiness. It is believed that the BAS is responsible for the compensatory behaviors that follow in response to meaning violations. Activation of the BAS results in a down regulation of the BIS, thus serving a palliative function.

1.2 Limitations of the meaning-physiological arousal link

The main idea of the MMM is that meaning violations cause a common syndrome of aversive arousal which motivates subsequent compensatory behavior, thereby reducing the aversive arousal. Although there is an abundant literature demonstrating a link between meaning violations and a psychophysiological reaction, the relationship between the physiological reaction and the compensatory, palliative, response is empirically weaker. Indeed, studies in which the the entire process of meaning violation, physiological response, and compensatory behavior is tested are rare.

The absence of such studies is unlikely due to a lack of interest from researchers in the field. Rather, this absence is likely due to challenges associated

with the methodological requirements to test this relationship. For instance, one of the lines of evidence offering support for the role of arousal in responding to meaning violations is the use of the misattribution of arousal paradigm. Multiple studies have shown that when participants can misattribute their arousal to a source secondary source, the typical relationship between the primary source and outcome measure disappears (e.g., Croyle & Cooper, 1983; Fazio, Russell, Zanna, & Cooper, 1977; Proulx & Heine, 2008). Ironically, although this paradigm is one of the most convincing pieces of evidence for the relevance of arousal in responding to meaning violations, its very mechanism can also prevent the demonstration of relating the arousal to compensatory behaviors. That is, most assessments of physiological arousal consist of placing electrodes or using special equipment that puts varying demands on the participant. These assessment techniques are likely to evoke arousal in and of itself, thus providing participants with a source to attribute any felt arousal to. This eliminates the possibility for manipulated meaning violations to induce the expected compensatory behavior. This unfortunate possibility has been demonstrated by Croyle and Cooper (1983). They first conducted a typical counter-attitudinal essay experiment and revealed the standard cognitive dissonance effect—students in the high choice condition arguing in favor of a lower drinking age became more in favor of a lower legal drinking age than those who had no choice. In their second study they used skin conductance to assess the arousal associated with cognitive dissonance and found such relationship, but the relationship between cognitive dissonance and attitude change disappeared. The authors interpreted this absence of an effect due to participants misattributing their arousal to the physiological recording device.

A further limitation of physiological assessments is that they often require a relatively long period of measurement time to attain a reliable signal. This conflicts with the typical design setup of studies in the literature on compensatory behavior. The standard study consist of a between-subjects design, in which the presence or absence of a meaning violation is manipulated, followed by a few minutes delay, after which the compensatory response is assessed. This kind of methodological design is practically incompatible with most physiological arousal recording techniques, whose designs often consist of a within-subjects design and consist of many repeated trials. Applying such techniques to a typical compensatory response study would involve a substantial delay between the meaning violation and compensatory behavior, as well as a loss of power due to the use of a between-subjects design. For these reasons, it should be no surprise that evidence for this link is mixed.

Therefore, a potential solution might reside in the use of physiological assessment techniques that do not have the limitation of placing a large and noticeable

burden on the participant and that can be used to investigate a wide range of psychological phenomena. Such a technique is pupillometry. Recent advances in eye trackers have made the technique both affordable and easy to use. More importantly, eye trackers have become significantly less intrusive, thus making it less likely for participants to attribute their arousal to the eye tracker device. Pupillometry also has a productive historical background that demonstrates the reliability of the tool in assessing arousal.

1.3 Pupillometry

The human eye serves first and foremost for seeing. Through the pupil, light enters the eye and reaches the retina. Here a cascade of chemical and electrical events trigger nerve impulses that are transmitted through the optic nerve to visual cortices in the brain, ultimately resulting in vision. Of particular interest is the pupil. The pupil determines the amount of light that enters the eye by varying its size through two sets of muscles, the sphincter and dilator pupillae. According to Steinhauer, Siegle, Condray, and Pless (2004) these two muscles are differentially influenced by activity in the sympathetic and parasympathetic branches of the nervous system. Increased sympathetic activity increases the activity of the dilator muscle, prompting dilation, increases in parasympathetic activity increases activity of the sphincter muscle, prompting constriction. Alternatively, inhibition of parasympathetic activity lessens constriction of the sphincter muscle, resulting in dilation. Thus, increases in pupillary diameter can be caused by activity in either division of the autonomic nervous system.

The most likely causes for changes in pupil size are the light reflex and the accommodation reflex. The light reflex is the change in pupil size in response to the intensity (luminance) of light that falls on the retina. The accommodation reflex is the change in pupil size resulting from focusing between near and far objects. Yet, aside from the relatively large changes in pupil size caused by these reflexes, there are also small, visually insignificant fluctuations in pupil diameter that do not seem to serve any visual function. Instead, these small fluctuations, often less than 0.5 mm, reflect cognitive processes and serve as the basis for the technique called pupillometry. The relationship between pupil size and cognitive processes was proposed near the end of the 19th century (e.g., Schiff, 1875) and shortly after the turn of the century Oswald Bumke concluded that:

> “Every active intellectual process, every psychical effort, every exertion of attention, every active mental image, regardless of content, particu-

larly every affect just as truly produces pupil enlargement as does every sensory stimulus" (Translated in Hess, 1975, pp. 23-24)

1.3.1 Measuring pupil size

In the 1960s pupil size was measured using motion picture photography (Hess & Polt, 1964; Kahneman & Beatty, 1966). This method consists of first taking a picture of a ruler at a distance equal to that of the pupil which is to be recorded. Then, the camera was centered on the iris and pictures of the pupil were taken once every 0.5 to 1 second. The images were projected onto a large surface and the pupil was measured with a simple ruler. Thankfully, technological advances greatly improved on this labor- and time-intensive process. High resolution infrared video-cameras were developed that could continuously measure the size of the pupil, at a much higher frequency than before. This was usually accompanied by a head rest so that participants would not be able to move their heads and disturb the recording. Even more advanced models can also record the pupil without the use of a head rest, such as the Tobii T60 eye tracker. This eye tracker uses near infrared illumination to create reflection patterns on the cornea and pupils of the eye, which are captured by an image sensor, allowing the position of the eye and pupil size to be derived using image processing algorithms and a mathematical model of the eye.

The result is a stream of data that, among several other measurements such as gaze direction, contains the size of the pupil of each eye separately. For each data point there is also a validity score ranging from 0 to 4, indicating the certainty of the system that the estimated data is correct and belongs to the correct eye. Uncertain data can be discarded and the remaining data points of each eye can be averaged together into a single measure of pupil size. Following this, the data should be inspected for eye blinks and artifacts. Eye blinks can be observed by short gaps in the data and artifacts can be seen in rapid jumps in pupil size, often near gaps of missing data. To clean the data, gaps can be filled using linear interpolation. Blinks can cause sudden jumps in pupil size that are unlikely to be the result of cognitive processes. To solve the issue of these artifacts and noise, filters are applied that smoothen the data. After this, the average pupil size can be calculated during the period of interest. This is often the period following the presentation of a stimulus. Because the presentation of a stimulus is often accompanied by a difference in luminosity, a light reflex is likely to occur. As a result, a small window of time (up until half a second) following the presentation of a stimulus is often not used in the calculation of the average. Finally, to control for differences in pupil size at the moment of stimulus presentation, a baseline aver-

age is calculated and subtracted from the measurements following the stimulus presentation. The end result is a measure indicating the change in pupil size after specific stimuli. These can then be compared and interpreted.

1.3.2 The meaning of pupillometry

In his monograph entitled 'Attention and Effort', Kahneman (1973) suggested that pupil dilation can be a psychophysiological marker of mental effort. This idea was later confirmed by Beatty (1982), who performed a review on the variety of ways pupil size was used to assess cognitive demands. These ways include processes related to memory, language, reasoning, and perception. To illustrate, trying to memorize larger sequences of numbers was associated with greater pupil size than memorizing smaller numbers (Kahneman & Beatty, 1966); and the same finding was found for multiplication exercises (Ahern & Beatty, 1979, 1981; Hess & Polt, 1964), language exercises (Wright & Kahneman, 1971), and perceptual exercises (Hakarem & Sutton, 1966; Kahneman & Beatty, 1967), with more difficult exercises being associated with greater pupil size.

More recent studies have provided evidence that the pupil is also associated with emotional arousal. One important psychological construct related to emotional arousal is the experience of pain. Multiple studies have been conducted that link the size of the pupil with noxious stimulation and self-reported pain (Chapman, Oka, Bradshaw, Jacobson, & Donaldson, 1999; Ellermeier & Westphal, 1995; Höfle, Kenntner-Mabiala, Pauli, & Alpers, 2008). For example, the pupil dilates when one is being subjected to painful ice spray and appears to decrease in size when the pain is experienced as less severe (Connelly et al., 2014; Walter, Lesch, Stöhr, Grünberger, & Gutierrez-Lobos, 2006). On the opposite side of the spectrum of stimuli, Aboyoun and Dabbs (1998) presented sexual stimuli to participants and found more pupil dilation in response to pictures of naked people than of clothed people, for both men and women. Bradley, Miccoli, Escrig, and Lang (2008) also investigated the relationship between pupil size and emotional arousal by presenting participants with pleasant, unpleasant, and neutral pictures. They found that pupil size increased in response to both positively and negatively valenced pictures. This crucial finding shows that pupil size is not determined by the valence direction (positive or negative), as was once believed (e.g., Hess & Polt, 1960), but that instead the pupil is determined by general arousal.

In fact, recent studies have linked pupillary reactivity to neuroaffective arousal due to its close association with the locus coeruleus-norepinephrine system (LC-NE; Aston-Jones & Cohen, 2005; Joshi, Li, Kalwani, & Gold, 2016; Murphy, O'Connell, O'Sullivan, Robertson, & Balsters, 2014; Varazzani, San-Galli, Gilardeau, & Bouret,

2015). The LC-NE system is responsible for the control of behavior by regulating engagement or withdrawal from a task through the release of NE by the LC in the forebrain. This system is relevant for such processes as stress responses, memory retrieval, attention, the sleep-wake cycle, and general state of arousal. Pupil size appears to co-vary with LC activity in both monkeys (Gilzenrat, Nieuwenhuis, Jepma, & Cohen, 2010; Joshi et al., 2016; Varazzani et al., 2015) and humans (Gilzenrat et al., 2010; Murphy et al., 2014). Additionally, Beatty and colleagues have demonstrated that pupil reactivity is consistent with LC responses (Beatty, 1982; Jackson, 1982; Richer & Beatty, 1987).

In summary, pupillometry reflects psychophysiological arousal that can be used to infer a broad range of psychological phenomena, whether it's cognitive processes such as cognitive load, memory, and language, or emotional processes such as pain and motivationally relevant stimuli. This broad applicability of pupillometry makes it an attractive tool in the investigation of meaning. In this context, from the perspective of the MMM, we are interested in the arousal response following meaning violations. Some research has been conducted that links pupil size to processes closely associated with the experience of a meaning violation. These include studies on task error (i.e., providing an incorrect answer in the task at hand) or the pupillary reaction to incongruent Stroop trials, as this too constitutes cognitive conflict. Studies using these methods have shown that both are associated with increased pupil dilation (Brown et al., 1999; Critchley, Tang, Glaser, Butterworth, & Dolan, 2005; Laeng, Ørbo, Holmlund, & Miozzo, 2011). Additionally, pupillometry has also been successfully applied to the study of social rejection (Silk et al., 2012; Vanderhasselt, Remue, Ng, Mueller, & De Raedt, 2015). But most importantly, multiple studies have demonstrated that the pupil dilates in response to violations of expectations (Preuschoff, 't Hart, & Einhäuser, 2011; Raisig, Hagendorf, & van der Meer, 2012; Raisig, Welke, Hagendorf, & van der Meer, 2010). It thus appears that pupil size can be used a valid proxy for the investigation of meaning related phenomena. With this potential, pupillometry can be used to address the role of arousal in the link between meaning violations and compensatory behavior, as well as related questions.

1.4 Main research questions

In this dissertation we are interested in the role of physiological arousal in responding to violations of meaning, using the MMM as our guiding theoretical framework. The integrative efforts of the MMM have produced various novel contributions to the literature, but certain aspects, particularly those related to the

role of arousal, have not yet received equal attention. Consequently, multiple questions remain. What are the underlying physiological structures that govern the reaction to meaning violations and the compensatory behavior that follows? Is the physiological response identical across multiple kinds of meaning violations? How does it relate to specific compensatory behaviors, such as assimilation, accommodation, and affirmation? In this dissertation, we review the existing literature and report empirical studies to address these questions. In so doing, we hope to expand the literature on existential psychology more generally, and the MMM specifically.

In our empirical work we use pupillometry as a proxy for physiological arousal. We test whether meaning violations reliably induce a change in pupil size consistent with the theorized aversive arousal response as predicted by the MMM. We will use a variety of meaning violations, such as perceptual anomalies, social exclusion, and belief feedback, as well as multiple ways to assess compensatory behavior. According to the MMM, we should find that meaning violations cause an increase in physiological arousal, i.e., increase in pupil size, and that this arousal predicts the occurrence and magnitude of compensatory behavior.

Finally, at the same time we see these studies as further validation of pupillometry as a tool in the study of psychological phenomena. Pupillometry already has a rich history as a way of assessing mental events but recent technological developments are making it easier and cheaper to use, potentially resulting in an increased popularity of this technology. For that reason, it is fruitful to better understand to what extent this tool can be applied in typical psychological experiments. We hope this dissertation will provide more insight into pupillometry as part of the experimenter's toolkit.

1.5 Overview of chapters

This section contains an outline of the work we have done on the topic of physiological arousal and meaning violations. Each chapter is based on individual papers that are either published or currently in the submission process. Consequently, they can be read separately or together as a set of studies that address the questions of this dissertation. Below follows an overview of each chapter.

Chapter 2 is a theory paper in which we review the literature on the underlying physiological structures responsible for reacting to meaning violations. In line with the MMM, we show that the current literature is consistent with and shows support for the view that compensatory behaviors are palliative efforts to reduce the aversive physiological arousal induced by meaning violations. We discuss the

relevant literature to show that meaning violations consistently induce a state of aversive arousal and theorize on the underlying physiological substrates responsible for this state. Additionally, we discuss the potential underlying physiological substrates responsible for compensatory behavior and the potential for a palliative function of compensatory behavior to reduce the aversive experience of meaning violations.

In Chapter 3 we investigated the role of arousal in response to belief-feedback and assimilation. We applied pupillometry to the context of receiving positive and negative feedback about commonly held, but incorrect, beliefs, i.e., misconceptions. We hypothesized that negative feedback should result in greater pupil dilation compared to receiving positive feedback, thereby demonstrating a state of arousal following a meaning violation. Additionally, we investigated the role of commitment towards the beliefs, expecting that negative feedback would result in greater pupil dilation when commitment towards the belief is higher. Crucially, however, we tested how arousal relates to one of the MMM's meaning seeking strategies, specifically that of assimilation. By providing ambiguous feedback we could investigate whether people show a tendency to assimilate negative feedback in such a way as to prevent a disconfirmation of their beliefs. Aside from providing data on the validity of pupillometry in the context of belief disconfirmation, this chapter reveals an initial relationship between physiological arousal and meaning.

In Chapter 4 we investigated the link between meaning violations, arousal, and another compensatory behavior: affirmation. Using perceptual anomalies—reverse colored playing cards—we investigated whether these anomalies cause an increase in pupil dilation, thereby demonstrating that even trivial violations induce a state of arousal. Additionally, we investigated whether these meaning violations lead to an increased affirmation of a moral value and tested whether this affirmation could be predicted by the physiological response to the meaning violation. We also investigated the role of extremism. Adherence to extreme values might in part be explained by an extreme tendency to affirm values following meaning violations. We investigated this possibility by measuring extremism regarding multiple moral values and linking it to the pupillary response following a meaning violation. This chapter thus informs not only on the role of arousal and compensatory behavior, but also the psychological phenomena of extremism.

In Chapter 5 we investigate the crucial link between physiological arousal and a third form of compensatory behavior, accommodation. We use the hindsight bias, or the 'knew-it-all-along' effect, to investigate whether unexpected answers to factual questions elicit greater pupil dilation and whether this increase in arousal is associated with an increased likelihood to show the hindsight bias, seen as a compensatory accommodation effort. This design addresses some often

found methodological shortcomings in studies investigating the role of arousal in predicting behavioral outcomes such as compensatory responses.

In Chapter 6 we applied the use of pupillometry to the social domain to inform us on whether meaning violations induce an identical physiological reaction in a different domain of meaning violations. Two competing hypotheses are tested regarding social exclusion. Being socially excluded can be predominantly a conflict of expectations, as being excluded for seemingly no reason likely constitutes of a violation of the norm to include people, or it can be predominantly a pain-based response, as social pain has been likened to physical pain. We used pupillometry to see whether we could find support for either the first interpretation, a conflict-based process, or the second interpretation, a pain-based process, thereby informing us on the role of arousal in the social domain of meaning violations.

In Chapter 7 the aforementioned studies and their results will be summarized and related to the research questions of this dissertation. Limitations and implications of this dissertation will be discussed, as well as ideas for future research.

Chapter 2

The Comfort of Approach

Self-soothing effects of behavioral approach in response to meaning violations

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Abstract

People maintain systems of beliefs that provide them with a sense of belongingness, control, identity, and meaning, more generally. Recent research shows that when these beliefs are threatened a syndrome of negatively valenced arousal is evoked that motivates people to seek comfort in their ideologies or other personally valued beliefs. In this paper we will provide an overview of this process and discuss areas for future research. Beginning with the neural foundations of meaning violations, we review findings that show the anterior cingulate cortex is responsible for detecting inconsistencies, and importantly, that this is experienced as aversive. Next, we evaluate the evidential support for a psychophysiological arousal response as measured by cardiography and skin conductance. We discuss how current theorizing proposes that subsequent behavioral approach ameliorates the negative arousal and serves as an effective, well-adapted coping response, but we also aim to further integrate this process in the existing threat-compensation literature. Finally, we speculate on whether approach motivation is likely to result when one feels capable of handling the threat, thereby incorporating the biopsychosocial model that distinguishes between challenge and threat into the motivational threat-response literature. We believe the current literature on threat and meaning has much to offer and we aim to provide new incentives for further development.

Keywords: meaning violation, threat, approach motivation, avoidance motivation, BIS/BAS

Over the course of the last half a century, research on coping has identified a plurality of ways that people deal with stress (Zimmer-Gembeck & Skinner, 2011). To illustrate, people commonly find comfort in actions such as seeking out social contacts, engaging in wishful thinking, eating comforting foods and taking hot showers. As we will argue in this review, people will also approach and affirm committed values, ideals, ideologies, and worldviews. Generally, comfort is sought in response to threatening experiences, and we believe that the threat-compensation literature has much to offer on the topic of self-comforting strategies. In this literature an integrative picture is emerging that states motivational processes underlie the response to a certain class of stressors we describe as meaning violations (e.g., McGregor et al., 2010; Proulx & Inzlicht, 2012). It is argued that when faced with a meaning violation, people show an initial defensive reaction marked by anxiety, vigilance, and avoidance, which subsequently switches to a motivational state of behavioral approach that ameliorates this anxiety, thereby serving a palliative, self-comforting function. In this review, we will provide an overview of the neuroaffective and psychophysiological processes that have been linked to the typical compensation behavior of the threat-compensation literature, and suggest directions for future research in this field.

2.1 Defining meaning violations

The threat-compensation literature is filled with psychological theories aimed at describing and understanding people's reactions to particular types of threat (Proulx & Inzlicht, 2012). Of these threats, traumatic experiences (e.g., sexual abuse, natural disasters, violent attacks) undoubtedly rank among the most impactful. These experiences threaten core motivations such as our desire to avoid death and attain personal control—two motives that have received much attention in the social psychological literature, framed in terms of prominent perspectives such as terror management theory (Burke et al., 2010) and compensatory control theory (Kay et al., 2009). Traumatic experiences, however, do not simply create a single dose of proximal anxiety. In addition to the clear physical hazards they often represent, they also impact the way in which we understand ourselves and our world. Instead of living in a safe and just world—a common assumption—they force us to realize we live in a world of danger and injustice. This implication initiates a second dose of anxiety (Janoff-Bulman, 1992), whereby the threat to physical safety is compounded by shattered assumptions. Although the context of a traumatic experience easily evokes the understanding that related cognitions are important for well-being, Bruner and Postman (1949) used a relatively trivial

perceptual anomaly to reach similar conclusions. They presented people with reverse colored playing cards (e.g., a black two of hearts) an experience that did not match their expectations and elicited signs of personal distress.

Cognitive dissonance theory has formally described this mismatch between beliefs and experiences along with the aversive feeling of dissonance that results (Festinger, 1957; or see Brehm, 2007). Subsequent theorists have developed this focus on cognitive consistency and uncertainty. For example, lay epistemic theory (Kruglanski, Orehek, Dechesne, & Pierro, 2010), self-verification theory (Swann & Read, 1981), and uncertainty management theories (e.g., Uncertainty Reduction; Hogg, 2007; Uncertainty Management; van den Bos, 2001; van den Bos & Lind, 2002) all focus on a motivation to replace dissonant cognitions with consonant cognitions and perceived clarity. One way to achieve this is by assimilating experiences so that they are consistent with one's expectations. Bruner and Postman (1949) found that people often reported not seeing a black two of hearts, but actually an expectancy-congruent black two of spades. Alternatively, they could have accommodated their understanding by realizing they were perceiving an altered deck of playing cards. This form of dissonance reduction was commonly reported in classic cognitive dissonance paradigms where participants—mostly students—were induced to behave in ways that contradicted their attitudes (e.g., argue in favor of a tuition increase). Subsequent accommodation of the dissonant behavior took place in the form of a change in attitude toward the tuition fee, thereby resolving the dissonance. In sum, assimilation, and accommodation can be seen as compensatory responses to resolve inconsistencies in cognitions.

Psychologists have furthermore observed that in addition to assimilation and accommodation, people can show a heightened commitment to alternative beliefs or values following many of the same inconsistencies that elicit assimilation or accommodation behaviors. For example, arguing for a tuition increase results in a change in attitude toward the tuition fee, but not if participants are first given the opportunity to affirm of unrelated values such as political beliefs (Steele & Liu, 1983). Hundreds of subsequent studies have shown active affirmation of values following reminders of mortality (Burke et al., 2010), lack of control (e.g., Kay, Gaucher, McGregor, & Nash, 2010), and the experience of uncertainty (e.g., van den Bos et al., 2006).

The abundance of threat-related theories almost invariably led to the development of more integrative perspectives. According to the Meaning Maintenance Model (MMM; Heine et al., 2006; Proulx & Inzlicht, 2012), any inconsistency between experience and expectation evokes a syndrome of negative arousal that motivates compensation efforts. According to the Reactive Approach Motivation model (RAM; McGregor et al., 2010), threats represent cues to goal conflicts that

cause anxious uncertainty and in turn elicits an approach motivation to resolve the anxiety. More generally, these integrative models all frame threat-compensation effects in terms of discrepancies between perceptions, beliefs, or conflicting motivations. We see these discrepancies as affecting meaning, or the expected relationships that allow us to make sense of our experiences. To distinguish between threats that stem from negatively self-relevant situations (e.g., a dangerous predator, a robber) and sources of inconsistency (e.g., paradigm violations; Bruner & Postman, 1949; prediction errors; Hajcak & Foti, 2008) that affect psychological motivation, we refer to the latter as meaning violations. While meaning violations may also have negatively self-relevant implications (e.g., worldview-violating personal tragedies; Janoff-Bulman, 1992), the presence of inconsistency may be both necessary and sufficient to evoke the state of uncertainty that underlies the common aversive reactions, whether they follow from existential reminders, lack of control, behavioral dissonance, epistemic uncertainty or goal conflicts. This is followed by a compensatory reaction that resolves the aversive uncertainty caused by the meaning violation.

2.2 The physiology of meaning violations

2.2.1 Behavioral approach and frontal asymmetry

In 1982, Gray (1982) published "The Neuropsychology of Anxiety" (since updated; Gray & McNaughton, 2003) that describes anxiety as activity of the behavioral inhibition system (BIS). A threat, however, generated, activates the BIS and produces behavioral inhibition, heightened arousal, and increased vigilance. As a result, ongoing behavior is halted and the environment is scanned for further threatening cues. In contrast to the behavioral inhibition system, a second system is responsible for reengaging behavior, known as the behavioral approach system (BAS; also known as the behavioral activation system). The BAS responds to reward cues, non-punishment and escape from punishment. This state is marked by attentional narrowing and feelings of hope, elation, and happiness.

Gray's model of anxiety is mainly a neuropsychological model and, and while it is based in large part on animal models, several human neurophysiological substrates have been proposed to underlie the BAS and BIS. Some of these substrates are now being investigated in the context of meaning violations. These involve the frontal areas of the brain, potentially the lateral and orbital regions of the prefrontal cortex. This is based on studies showing asymmetrical activation in frontal areas during approach and avoidance motivations (see Coan & Allen, 2003; Davidson, 1992). Various psychological states elicit a frontal asymmetry that is consis-

tent with a BAS state interpretation. For instance, Sutton and Davidson (1997) measured prefrontal asymmetry using EEG and linked this to self-report measures of BIS and BAS, using the BIS/BAS scale developed by Carver and White (1994).

The BAS scale assesses people's tendency to experience positive affect and behavioral activation in goal-oriented situations. The BIS scale assesses the tendency to experience negative affect and behavioral inhibition in the face of threats. Sutton and Davidson (1997) found that greater left prefrontal activation was correlated with higher levels of BAS strength, whereas those with greater relative right prefrontal activity reported greater BIS strength. They also ruled out alternative explanations such as positive and negative affect confounds that are associated with BAS and BIS, respectively. These findings have also been shown in a study by Harmon-Jones and Allen (1997), who linked frontal cortical activity to self-report measures of BIS and BAS. To gain more insight into the underlying structures responsible for the asymmetry, Pizzagalli, Sherwood, Henriques, and Davidson (2005) performed a source localization study and found a correlation between activity in the dorsolateral prefrontal and medial orbitofrontal regions and a bias for reward-related cues (also see Berkman & Lieberman, 2010). This further supports not only the relationship between frontal asymmetry and BAS, but also provides some insight into the anatomical details of this relationship.

At first, however, it was believed that frontal asymmetry was related to emotional valence, with greater left frontal asymmetry being linked to positive affective processing styles and vice versa (Fox, 1991; Jones & Fox, 1992; Wheeler, Davidson, & Tomarken, 1993). Yet, the previously discussed studies show the functioning is less related to emotional valence, and actually favor a motivational orientation interpretation. One particular study by Berkman and Lieberman (2010) has demonstrated that prefrontal asymmetry is associated with action motivation and not with stimulus valence. In their study, they compared approach/avoidance actions vs. stimulus valence using a novel goal pursuit task. Functional magnetic resonance imaging (fMRI) revealed an increased left activation in the dorsolateral prefrontal cortex during approach (vs. avoidance) actions irrespective of the valence of the stimulus. No such asymmetry was observed for pleasant compared to unpleasant stimuli. Additionally, individual differences in approach-avoidance motivation moderated the effect such that increasing trait approach motivation was associated with greater left-sided asymmetry during approach actions.

This interpretation, that frontal asymmetry reflects BAS, is further bolstered by studies linking frontal asymmetry to psychological constructs related to BAS motivation, such as depression and anger. Depression is argued to consist partially of a lack of motivation to approach. Consistently, depression has been linked to lower levels of relative left frontal activity (Allen, Iacono, Depue, & Arbisi,

1993; Henriques & Davidson, 1990). Anger, despite having a negative affective valence, has also been linked to greater left frontal activity (Harmon-Jones, 2003; Harmon-Jones & Allen, 1998). The link between anger and frontal asymmetry has also been supported through means of transcranial magnetic stimulation; which has shown that decreasing activity in the left prefrontal cortex lowers a memory bias for angry faces (van Honk & Schutter, 2006). Frontal asymmetry has also been shown in people who are in a promotion-oriented state (i.e., focused on gaining reward instead of avoiding losses), as opposed to an avoidance orientated state (Amodio, Shah, Sigelman, Brazy, & Harmon-Jones, 2004). Finally, affecting frontal asymmetry through biofeedback techniques has been shown to increase self-reported affect and facial muscle activity in response to emotionally evocative film clips (Allen, Harmon-Jones, & Cavender, 2001). These findings thus support the interpretation that frontal asymmetry is related to behavioral activation.

2.2.2 Behavioral inhibition and the anterior cingulate cortex

Although many studies show a link between frontal asymmetry and behavioral activation-related outcome measures, the link between frontal asymmetry and behavioral inhibition is not always shown (Coan & Allen, 2003). Often studies lack the potential for greater insight into to the anatomical functioning of the underlying structures (Davidson, 2004), mostly due to the fact that non-spatial sensitive measures such as EEG are being used (see Berkman & Lieberman, 2010, for an exception). EEG studies have, however, found other potential markers for BIS activation, and these markers have also been linked to meaning violations. These markers suggest the involvement of the anterior cingulate cortex (ACC). The ACC receives input from the limbic lobe, including the orbitofrontal cortex and the amygdala, as well as other nociceptive sources. For this reason it has been argued that the ACC serves a critical function for emotional and motivational factors (Bush et al., 2000; Morecraft & van Hoesen, 1998; Pandya et al., 1981; van Hoesen et al., 1993; Vogt et al., 1993). The exact function of the ACC is still controversial. Research on error related negativity (ERN) suggests various possibilities. The ERN is a negative voltage deflection measured over the fronto-central scalp that appears to reflect activation of the ACC (Dehaene, Posner, & Tucker, 1994; Miltner, Braun, & Coles, 1997). The ERN is elicited when people commit errors, or specifically, when they receive feedback about having committed an error, and usually appears between 250 and 300 ms after the feedback (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990; Gehring, Goss, Coles, Meyer, & Donchin, 1993; Nieuwenhuis, Holroyd, Mol, & Coles, 2004). Various models of the function of ERNs exist and they suggest that the ERN reflects either a conflict monitor-

ing function (Botvinick et al., 2001; Yeung et al., 2004) or an evaluative function based on expectations developed during learning history (reinforcement-learning theory; Holroyd & Coles, 2002). In the latter construal, the ERN is an indication that events are worse than anticipated, or better than expected. Luu, Collins, and Tucker (2000) have proposed that the ERN may signify affective processing in response to errors. This proposal is based on evidence that the magnitude of the ERN is affected by motivational and affective variables. Individuals with symptoms of depression (Chiu, Deldin, Pearl H. Chiu, & Patricia J. Deldin, 2007), obsessive-compulsive disorder (Gehring, Himle, & Nisenson, 2000; Hajcak, Franklin, Foa, & Simons, 2008; Hajcak & Simons, 2002), and generalized anxiety (Hajcak, McDonald, & Simons, 2003, 2004) show greater ERNs. Additionally, ERN activity has been associated with stronger skin conductance responses (Hajcak et al., 2004) and a more pronounced startle response following threat (Hajcak & Foti, 2008), while removal of this brain structure is associated with flat affect and a lack of distress (Corkin, Twitchell, & Sullivan, 1979; Critchley et al., 2003). Similar to previously mentioned studying linking self-reported BAS to frontal asymmetry, Amodio, Master, Yee, and Taylor (2008) have linked self-reported BIS to ACC functioning. They found that self-reported BIS was uniquely related to the ERN in a Go/No-Go task, but not self-reported BAS. Moreover, BIS was also related to the N2, a negative potential that peaks about 250 ms after the onset of a No-Go trial; and is believed to arise similarly from the ACC (Nieuwenhuis, Yeung, van den Wildenberg, & Ridderinkhof, 2003; van Veen & Carter, 2002). These findings, and those discussed earlier, point toward the ACC being a crucial component of the BIS.

One of the most relevant findings in the threat-compensation literature has been that the ACC responds similarly to what we describe as meaning violations. For example, Quirin et al. (2012) showed that by letting participants answer questions about their fear of death, increased ACC activation could be observed (as well as activation in the amygdala and the caudate nucleus). The ACC activated relative to answering questions about dental pain, indicating this effect can go beyond that of negatively self-relevant events. ACC activation has also been demonstrated in response to the experience of cognitive dissonance. For example, Kitayama et al. (2013) asked participants to make decisions regarding CDs that differed in attractiveness, sometimes facing an easy choice (between two CDs that differ greatly in attractiveness, i.e., no cognitive dissonance) and a sometimes difficult choice (between two CDs that are similar in attractiveness, i.e., cognitive dissonance). They found that the cognitive dissonance eliciting choices resulted in activation of the dorsal ACC. Additionally, they found that these choices also resulted in activation of areas related to emotional distress (left anterior insula). Furthermore, they could predict a change in attitude toward the CDs that resolves the cogni-

tive dissonance with activity in the posterior cingulate cortex. A similar setup was used by van Veen et al. (2009) to also predict attitude change based on neural activity in the cingulate cortex. They scanned participants with fMRI while they argued that the scanner environment—an uncomfortable environment—was, in fact, comfortable. Activity in the dorsal ACC, as well as activity in the anterior insula, predicted their change in attitude. These findings point toward a role of the ACC in resolving cognitive dissonance.

Additional studies have linked the ACC to meaning violations. For example, Salomons et al. (2004) manipulated the controllability over a painful stimulus and found that having less control was associated with increased ACC activity. Goal uncertainty has also been found to affect the ACC (Tullett et al., 2013), and a line of research has revealed that the ACC also plays a prominent role in how people respond to experiences of social isolation. In this line of research, participants play a ball tossing game (ostensibly) with other participants, who at a certain point stop throwing balls to the participant, or do so with such a low frequency that the participant experiences a lack of social inclusion. These studies consistently show cues of ostracism (not receiving the ball) evoke activity in the ACC (Bolling et al., 2012, 2011; Eisenberger et al., 2003; Gunther Moor et al., 2012; Masten et al., 2009). Some argue that part of the role of the ACC is due to the unexpected nature of not receiving a ball, and thus point to violation of expectations (e.g., Bolling et al., 2011). Indeed, expectancy violation as been argued to be the root cause of the aversiveness that follows from meaning violations (Proulx & Inzlicht, 2012) and is related to ACC activity (Oliveira, McDonald, & Goodman, 2007).

2.2.3 Behavioral inhibition and the cardiovascular threat response

Physiological indications of meaning violations are not limited to neural responses. The biopsychosocial model (BPSM) of arousal regulation (Blascovich, 2008; Blascovich & Tomaka, 1996) defines specific patterns of cardiovascular responses to threats. Specifically, the model states that when an individual faces a threat (i.e., negative appraisal of the situation) a malignant pattern of increasing cardiac or myocardial performance should occur, accompanied by stable or increasing vascular resistance caused by activation of the pituitary-adrenal-cortical (PAC) axis. PAC activity is thought to be under the control of the brain centers previously discussed as BIS (Gray & McNaughton, 2003).

Substantial evidence has accumulated supporting the contention that meaning violations also produce marked changes in sympathetic nervous activity. As early as the late 1960s, it has been shown that participants forced to choose be-

tween similar alternatives—and therefore experience cognitive dissonance—show greater decreases in finger pulse amplitude (Gerard, 1967), an index of a physiological readiness response as blood flows away from the periphery of the body. As well, studies showing that performing attitude-discrepant behaviors also leads to an increased galvanic skin response (GSR; Croyle & Cooper, 1983; Elkin & Leippe, 1986; Harmon-Jones et al., 1996). Losch and Cacioppo (1990) have offered additional evidence that cognitive dissonance increases arousal as measured by GSR, and have further shown that subsequent attitude change only occurs when people experience this arousal as explicitly unpleasant.

Other meaning violations, produce similar modes of arousal. For example, uncertainty about interacting with out-group members has revealed patterns of cardiovascular reactivity consistent with threat (Blascovich, Mendes, Hunter, Lickel, & Kowai-Bell, 2001), and so too has the case of uncertainty produced by the possibility of experiencing an electric shock (Monat, Averill, & Lazarus, 1972). Similarly, cardiovascular responses indicating aversive arousal have been observed in participants interacting with partners that violate expectancies (Mendes et al., 2007, 2002), social threat (Hawkley, Williams, & Cacioppo, 2011; van Beest & Scheepers, 2013) and a combination of these dimensions: unexpected social rejection (Gunther Moor et al., 2010).

2.3 Approach as a palliative

After the initial aversive response to a meaning violation, people show an array of compensatory behaviors. Often, these are direct attempts to resolve the source of the violation. For example, people excluded from social interaction increase their interest in interaction with other people—strangers included (Maner et al., 2007)—and they try to fit in with others more by increasing their compliance (Carter-Sowell et al., 2008; Williams, 2007, 2009). Or, in the case of behavioral dissonance, students who are asked to argue in favor of a tuition increase will subsequently change their attitudes to resolve this attitudinally inconsistent behavior (Harmon-Jones et al., 2008). Alternatively, people may compensate for meaning violations in a manner wholly unrelated to the initial source of the violation, by, for example, increasing their commitment to unrelated personal values. This latter process, termed fluid compensation (Allport, 1943), has received much attention and is the basis of several integrative models that now see the pursuit of committed values as a palliative effort to subdue the negative arousal caused by meaning violations (McGregor et al., 2010; Proulx & Inzlicht, 2012).

2.3.1 Palliative compensation

What is palliative about the pursuit of committed values? As we have discussed, the initial response to threat is the activation of the behavioral inhibition system that increases vigilance, arousal, and avoidance. Behavior is halted and the environment is scanned for an opportunity to either escape from the threat or address the threat directly. Instead of behavioral inhibition, the person under threat would prefer a state of behavioral activation, which will ensue once an opportunity to act has been detected. Such action can be directly aimed at resolving the threat (domain-specific compensation), or can also involve indirect, relatively abstract goals and values (domain-general compensation) that are associated with positive affect. In other words, BIS must be turned into BAS. The defining characteristic of BAS is the approach of a new goal, be it a change in attitude or the affirmation of abstract ideals.

More recent research has demonstrated that the response to meaning violations may indeed result in an increased approach motivation. McGregor et al. (2010) have shown that in response to uncertainty about academic aptitude, students show a rightward error bias in the line-bisection task, which indicates increased left cerebral hemisphericity. Increased activation in the left hemisphere is in turn associated with the motivation to approach (Drake & Myers, 2006; Nash, McGregor, & Inzlicht, 2010), as described earlier. In a second study, they showed that students also associated their own self more with an approach motivation after the uncertainty manipulation, as measured through an adapted implicit association test (Greenwald, McGhee, & Schwartz, 1998), especially if the students' ideals have been made salient (McGregor, Prentice, & Nash, 2012).

Research on the predicted positive affect associated with the motivation to approach has so far not been thoroughly investigated. Existing research is mostly limited to correlational work that does not fully disentangle positive affect caused by the positive associations in the environment (e.g., the presence of food or an attractive person) or the actual approach oriented mindset. Nonetheless, many studies do show there is a link. Anhedonia—a diminished capacity to experience pleasure—has been associated with a decreased approach motivation, and could even serve as a better measure of hedonic deficit than commonly used measures of anhedonia (Germans & Kring, 2000). More generally, approach motivation has been linked to well-being (see Elliot, 2008, ch. 24) and many models link approach to positive emotional states such as excitement and elation, whereas an avoidance motivation is linked to anxiety and fear (Carver, 2004).

Additional evidence for the positivity associated with approach comes from research comparing a personal goal either in approach-oriented terms or avoidance-

oriented terms. An approach-oriented goal (e.g., "I will try to be more entertaining at parties") versus an avoidance-oriented goal (e.g., "I will try not to be such a bore at parties") leads to greater reports of subjective well-being. These results have been found for a variety of types of goals, ranging from general goals to specific life goals such as academic and social pursuits (Elliot, Gable, & Mapes, 2006; Elliot & Sheldon, 1997). Furthermore, it has been shown that neural correlates of well-being indicate a link to approach motivation. Greater left vs. right superior frontal activation has been associated with hedonic well-being and positive affect (Urry et al., 2004). More direct evidence for this contention can be found in a study by Nash, Inzlicht, and McGregor (2012). They used EEG to measure approach-related frontal asymmetry and subsequently measured ERN as a result of errors during a Stroop task and a multi-source interference task. In both tasks they found that a higher leftward frontal EEG asymmetry predicted a reduced ERN amplitude. A higher rightward frontal asymmetry predicted the opposite, an increased ERN amplitude. This BIS marker is therefore affected by motivational orientation in such a way that approach seems to reduce the experience of conflict. Although more evidence is required, there is support for the contention that the motivation to approach is associated with positive affect and could serve as an effective comforting strategy.

2.4 Individual differences in palliative compensation

We have thus far reviewed evidence for the proposition that meaning violations induce a state of anxiety and inhibition, which in turn must be overcome by approach-oriented behavior. We now address the extent to which this process is impacted by individual difference factors, with specific emphasis on the BPSM of threat and challenge (Blascovich & Tomaka, 1996). The BPSM of arousal distinguishes between physiological states associated with threat and challenge. Challenge results when an individual evaluates one's own resources as meeting the demands of the situation. Threat is the result of demands that we (subjectively) determine cannot be met. This distinction is often discussed as an either/or reaction, in that a situation is either perceived as challenging or threatening. However, this model can be linked to the response to meaning violation findings we have reviewed here. Instead of a meaning violation being immediately categorized as something that can be overcome, we argue that meaning violations (e.g., experiences of mortality reminders, behavioral dissonance, or perceptual errors) are responded to as initially 'threatening', that is, affecting our appraisal of the situa-

tion as a conflict that potentially exceeds our demands. After this initial response, various factors influence whether the meaning violation is dealt with, or in BPSM terminology, is seen as a challenge that can be met. Support for this integration is not new and initial steps have already been made by Blascovich (2008). He has argued that threat can be mapped onto behavioral inhibition avoidance and challenge onto behavioral approach. The question becomes: which factors influence the transition from threat to challenge?

2.4.1 Self-esteem

One such factor is self-esteem. Self-esteem can be considered a trait that determines the extent to which one feels they possess the resources necessary to cope with obstacles and attain goals. High self-esteem should make one feel capable of dealing with obstacles, which are therefore experienced as more challenging and less threatening, facilitating the switch to a behavioral approach state. High levels of trait self-esteem are linked to behavioral approach (Baumeister, Tice, & Hutton, 1989; Heimpel, Elliot, & Wood, 2006) and it has also been shown that people with high self-esteem favor approach-oriented goals over avoidance-oriented goals (Cavallo, Fitzsimons, & Holmes, 2009; Tice, 1991). With low self-esteem, the transition to approach might take longer, or fail to occur at all.

In general, self-esteem is related to positive outcomes in life (Swann, Chang-Schneider, & Larsen McClarty, 2007; Taylor, Lerner, Sherman, Sage, & McDowell, 2003a, 2003b), but self-esteem has also been specifically linked to increased defensiveness against meaning violations. In response to mortality reminders, for example, people with high levels of self-esteem do not show the typical defensive behavior seen in response to these violations (Pyszczynski, Greenberg, Solomon, Arndt, & Schimel, 2004). For low self-esteem people, however, we observe the opposite. They appear more cautious and inhibited following meaning violations (Cavallo et al., 2009; McGregor, Nash, & Inzlicht, 2009; Vohs & Heatherton, 2001), and it appears as though they reside longer in the BIS state than people with high self-esteem. This has negative consequences for well-being, and could even result in serious psychological disorders, as prolonged exposure to anxious arousal can lead to depression and PTSD (Pyszczynski & Kesebir, 2011; Routledge, Ostafin, Juhl, Sedikides, & Cathey, 2010).

2.4.2 Neuroticism

A second important factor that influences the transition from BIS to BAS is the personality trait neuroticism, such that many of the responses to meaning vi-

olations are enhanced for those high in neuroticism. Neurotic people are more likely to interpret evocative cues as a violation. For example, they find reminders of sex a greater violation of meaning because it possibly reminds them of their mortality (Goldenberg, Pyszczynski, McCoy, Greenberg, & Solomon, 1999) and they respond more strongly when their mortality is made more salient explicitly (Arndt & Solomon, 2003). Physiologically, they respond with increased severity to experiences that arouse uncertainty by demonstrating a higher negativity response after receiving no feedback about how they performed, as compared to receiving positive or negative feedback about their performance (Hirsh & Inzlicht, 2008). In fact, more than half a century ago, Eysenck (1951) already proposed that neuroticism is linked to general cortical arousability.

Although the conceptualization of a general physiological arousal is too vague and likely inaccurate, research has accumulated that demonstrates reliable biological correlates to neuroticism (Canli, 2004; DePascalis, 2004). Several theories suggest that neuroticism is the result of an especially sensitive neural comparator, a mechanism that detects mismatches between actual and expected states of the world (Carver & Scheier, 1990; Eisenberger, Lieberman, & Satpute, 2005). As discussed in an earlier section, the ACC is responsible for the detection of violated expectations or conflicts in general. People high in neuroticism should therefore show increased activity in the ACC in response to discrepancies; a prediction supported by the findings of Eisenberger et al. (2005). They found that activity in the ACC during a discrepancy detection task was positively correlated with self-reported neuroticism. In line with the use of the BPSM in this review, neuroticism has been linked to threat appraisals of stressors, as opposed to challenge appraisals (Schneider, 2004). As a result, they will show prolonged BIS activation and could benefit from strategies aimed at adopting an approach orientation.

2.4.3 Value and goal commitment

A final example of an individual difference factor that is relevant to dealing with meaning violations is the extent to which one is committed to readily activated values and goals. Fluid compensation processes imply that as long as a given meaning violation does not require an immediate response, there is always the possibility of pursuing more abstract and situation-independent goals, such as reaffirming one's ideals and establishing new goal pursuits. Having these values and goals readily available might affect the appraisal of violations in terms of challenge. Support for this idea can be found in an experiment performed by Inzlicht and Tullett (2010), who primed participants with religion or let participants affirm their religious convictions. Interestingly, this led to reduced ERN

activity (i.e., reduced BIS activation) compared to the control conditions, but only for committed believers. The presence of a readily available value to pursue can be interpreted as having the resources to deal with the meaning violation—to feel challenged instead of threatened. This effect on ERN activity has also been found for trait levels of religious zeal and belief in God (Inzlicht, McGregor, Hirsh, & Nash, 2009). Additionally, the affirmation of personal values buffers neuroendocrine and psychological stress responses, especially so among people with high self-esteem (Creswell et al., 2005). Adopting meaningful ideologies, values, or worldviews could therefore be an important step in not just living a philosophically satisfying life, but also defending oneself against various meaning violations.

2.5 Future directions

It is clear that much progress has been made in the threat-compensation literature in determining how people respond to various meaning violations. However, certain areas remain relatively underinvestigated.

Research on the palliative function of approach motivation is limited. Although it has been shown that approach motivation leads to reduced signs of BIS activation (Nash et al., 2012), this has only been shown in the case where approach is measured before a meaning violation. Nash et al. (2012) measured baseline levels of approach-related left frontal EEG activity and found that this predicted a reduced ERN amplitude in response to conflicts in a task that followed. Ideally, we would also observe physiological markers of approach following meaning violations. Current research has thus far only demonstrated indirect measures of approach motivation, for example through self-report, implicit measures of approach, or the line-bisection task (McGregor et al., 2010). Direct measures of BAS activation have yet to be investigated.

The findings we have presented here mostly relate meaning violations to only a few possible neural substrates of BIS and BAS activation. However, BIS and BAS are complex psychological states that involve many different brain areas. These include structures related to regulatory functions such as the frontal areas (e.g., dorsolateral prefrontal cortex, inferior frontal regions), but also areas related to stress such as the amygdala, insula, substantia nigra, and bed nucleus of the stria terminalis complex (Schlund, Hudgins, Magee, & Dymond, 2013; Schlund, Magee, & Hudgins, 2011). Although these structures could undoubtedly enhance our understanding of how people respond to meaning violations, the threat-compensation literature has yet to research the link between meaning violations and these structures more concretely.

Most importantly, the literature is in need of experimental designs in which the full process, from violation to approach, is tested. These experiments would involve participants being presented with a meaning violation: a reminder of mortality, goal uncertainty, the loss of control, perceptual anomalies, or cognitive conflict more generally. This should result in activation of the BIS as reflected by activity in the ACC or related neural structures and peripheral measures of arousal such as cardiac activity or skin conductance. After a delay, or when an opportunity is presented to affirm one's personal values, the motivation to approach should be made visible, through measures such as the line bisection task (indirectly) or neural activity in the prefrontal lobe (directly). Following this approach state, measures of BIS should show reduced activity, thereby confirming the palliative function of approach. So far no studies have been reported that fully present this process.

Further research might also focus on practical applications of these findings. Research on individual differences has shown that readily available sources of meaning can help reduce anxiety following threats. Also, framing goals in an approach-oriented manner is conducive to well-being. These findings could potentially translate to therapeutic settings where greater emphasis is put on having valued sources of meaning in one's life. Abstract sources—ideologies, moral systems, worldviews—have the benefit of being relatively easily accessible and their abstract nature might also make them less likely to be thwarted by situational constraints (see McGregor et al., 2012). Their pursuit can largely go unhindered, therefore serving as an effective coping strategy.

2.6 Conclusion

Meaning violations evoke a stress response that begins with a defensive reaction marked by anxiety, vigilance, and avoidance—a state of behavioral inhibition. People respond to this aversive state by approaching their values, ideologies, and worldviews. We suggest, in line with the BPSM of arousal regulation and other threat compensation theories, that all meaning violations initially cause an inhibitory threat-response that subsequently switches to a state of approach; especially when factors such as self-esteem, personality, and the availability of commitments impact one's appraisal of the situation. Nevertheless, it is not the content of affirmed values, ideologies, or worldviews that alleviates stress, but rather the state of approach that people find comforting. This integration of findings across the threat-compensation literature is but one among many in a recent surge of integrative efforts in this field (e.g., Jonas et al., 2014). We expect these developments will provide new insight into the this literature, as well as well related

fields of research.

Chapter 3

Assimilation and Arousal

Pupillary Response to Error Feedback about Misconceptions

Based on Sleegers, W.W.A., Proulx, T., & van Beest, I. (2017a). *Assimilation and arousal: Pupillary response to error feedback about misconceptions*. Manuscript submitted for publication.

Abstract

People adopt many beliefs that are contrary to scientific findings, i.e., misconceptions. These misconceptions are prevalent and resistant to change. Several cognitive processes have been proposed to explain the prevalence and resistance of misconceptions, but empirical evidence remains scarce. Working from the Meaning Maintenance Model (MMM), we argue that people are motivated to affirm their existing beliefs and assimilate ambiguous feedback as though it confirmed these beliefs. In two experiments, we presented participants with multiple misconceptions and provided feedback about the veracity of each misconception. Using pupillometry, we demonstrate that participants show an increase in arousal when they receive belief-violating feedback. Crucially, we also demonstrate physiologically distinctive responses to clear and ambiguous feedback. We find the pupil responds to ambiguous confirmatory feedback as though it were wholly confirmatory. No such assimilation response was found when feedback violated the beliefs. Additionally, we show a moderation by commitment towards the misconception. When the feedback is confirmatory, increasing levels of commitment are associated with a faster diminishing of arousal, but not when feedback is violating. In accordance with the MMM, these findings demonstrate that people respond with increased arousal to disconfirming feedback, which is moderated by relative commitment to the beliefs, and assimilate ambiguous information to appear convergent with expectations.

Keywords: assimilation bias; pupillometry; misconceptions; error-feedback; arousal

People believe a great many things about a great many topics. A sizable portion of these beliefs are inconsistent with historical and scientific findings, that is, they are misconceptions (Hamza & Wickman, 2007; Taylor & Kowalski, 2004). For example, people believe that during the Middle Ages most people died around the age of 30, that Marco Polo imported pasta from China, and that humans use only 10% of their brain.

Though these beliefs are incorrect, they remain common; with prevalence rates ranging from 28% to 71% (Lilienfeld, Lynn, Ruscio, & Beyerstein, 2010). Despite this high prevalence, research on misconceptions is relatively scarce. Most of the research on misconceptions has been conducted in the field of educational psychology because of potential challenges that misconceptions pose for educators (Hughes, Lyddy, & Lambe, 2013). For example, it has been conjectured that misconceptions negatively impact the learning of new information (Chew, 2006; Hammer, 1996; Posner, Strike, Hewson, & Gertzog, 1982) and serve as indicators for a need of more critical thinking. Another challenge is that misconceptions are highly resistant to change. Exposure to psychology courses has been found to reduce several misconceptions but fails to eliminate many others (Gregg, Winer, Cottrell, Hedman, & Fournier, 2001; Lamal, 1995; Landau & Bavaria, 2003). To illustrate, 30% of students believe that someone experiencing schizophrenia has a 'split personality', even after completing psychology courses that teach this belief is false (Gardner & Dalsin, 1986).

Not much is known about the origin of misconceptions and their persistence. Some research has attempted to identify their sources. These studies reveal that people attribute their misconceptions to sources such as the media, personal experience, reading, and classroom learning (Higbee & Clay, 1998; Landau & Bavaria, 2003; Taylor & Kowalski, 2004). Several cognitive biases have also been argued to lay at the foundation of the adoption and persistence of misconceptions, such as illusory correlations, a tendency to infer causation from correlation, selective sampling and confirmation bias (Lilienfeld et al., 2010; Schick Jr. & Vaughn, 2014). Importantly, support for these suggestions is limited due to lack of empirical investigation and "have generally been more supported by argument rather than empirical evidence" (Hughes et al., 2013, p. 22; Chew, 2006).

Confirmation bias in belief feedback

One of the proposed reasons for why people maintain misconceptions is the confirmation (Hughes et al., 2013) or verification (Poletiek, 2001) bias. Confirmation bias is the tendency to search for, interpret, favor, and recall information in a way that confirms one's preexisting beliefs or hypotheses. This bias manifests it-

self in different ways, such as neglecting disconfirming evidence, an unwillingness to change the belief in face of contradicting evidence, or even by altering perceptions (Rassin, 2008). Naturally, when evidence is clear, cognitive biases such as the confirmation bias can be overridden. When evidence is ambiguous, however, judgments are more likely to succumb to prior beliefs (Risinger, Saks, Thompson, & Rosenthal, 2002), in that they are interpreted in such a way that they are assimilated into these existing beliefs (Lord, Ross, & Lepper, 1979). This is also more likely when commitment towards the prior belief is high (Jonas, Schulz-Hardt, Frey, & Thelen, 2001). These findings support the probable involvement of the confirmation bias in the persistence of misconceptions.

However, even if a confirmation bias is one of the underlying cognitive processes that play a role in the persistence of misconceptions, such a bias fails to explain why people are motivated to assimilate events into existing beliefs. Hence, in the present paper we will apply a more general model that describes humans as meaning seekers through the adoption of a variety of beliefs: the Meaning Maintenance Model (MMM).

The Meaning Maintenance Model

According to the MMM, people have a need to adopt a variety of beliefs that allows them to perceive the world in a comprehensible manner—a sense of meaning (Proulx & Inzlicht, 2012). These beliefs range from highly important beliefs such as beliefs about the existence of an afterlife to more trivial beliefs such as the color of a Two of Diamonds playing card (e.g., Proulx & Major, 2013). Each belief in some way organizes people's perceptions of the world and shapes their expectations for what may happen in any given situation.

Frequently it happens that one's expectations are not met, and events unfold differently from what was expected—a meaning violation. These violations elicit a state of negative arousal that motivate compensatory behavior to counteract this aversive state. The MMM describes an array of possible compensatory behaviors following a meaning violation. For example, the meaning violation can be solved by assimilating the violation into an existing worldview, which is done by reinterpreting the event in such a way that it fits in the existing worldview. Alternatively, beliefs can be accommodated to fit in the violation, in which case the belief itself is adjusted. Third, people can affirm beliefs unrelated to the belief that was violated. For example, following exposure to reverse colored playing cards, people become more supportive of positive discrimination (if they are committed to the belief that social inequality is unjust; Proulx & Major, 2013). The affirmation of an unrelated belief shows that people are not always motivated to correct their incorrect be-

liefs. Instead, it has been theorized that the main motivation to maintain meaning following meaning violations is to reduce the negative arousal experienced as a result of the violation (Sleegers & Proulx, 2015). This aversive physiological arousal has consistently been demonstrated following expectancy violations, whether it is an expectancy violation caused by a perceptual anomaly (Sleegers, Proulx, & van Beest, 2015), cognitive dissonance (Gerard, 1967), self-view inconsistencies (Ayduk et al., 2012), social justice worldview violations (Townsend et al., 2010) or category-based violations (Mendes et al., 2007).

Physiological response to inconsistent feedback

A vast number of studies have shown that inconsistent feedback, when interpreted as such, increases physiological arousal. Negative feedback increases ACC activation in the brain (e.g., Miltner et al., 1997; Yeung et al., 2004) and also affects sympathetic nervous system markers, such as skin conductance, cardiography, and pupillometry (Critchley et al., 2005; Hajcak et al., 2003, 2004). In our studies we will use pupillometry as a marker of physiological arousal. Pupillary reactivity (i.e., changes in pupil size) can serve as an index of neuroaffective arousal. This relationship between pupil size and arousal stems from its association with the locus coeruleus-norepinephrine (LC-NE) system. This system plays a role in the regulation of engagement or withdrawal from a task by releasing NE through projections from the LC in the forebrain (for a review, see Aston-Jones & Cohen, 2005). Research has shown that pupil size correlates with LC activity in monkeys (Rajkowski, Kubiak, & Aston-Jones, 1993) as well as in humans (Gilzenrat et al., 2010), and work by Beatty and colleagues on the pupillary system has demonstrated that pupil reactivity is consistent with LC responses to task-events (Beatty, 1982; Jackson, 1982; Richer & Beatty, 1987). The link between pupil size and the LC-NE system allows researchers to infer a broad range of both cognitive and emotional processes from the extent of pupil dilation. Notably, the pupil dilates in response to task error (Brown et al., 1999; Critchley et al., 2005) and violations of expectations (Preuschoff et al., 2011; Raisig et al., 2012, 2010; Sleegers et al., 2015). Sleegers et al. (2015) have shown, for example, that repeated presentations of reverse-colored playing cards (e.g., black Two of Spades) cause an increase in pupil dilation relative to normal playing cards. Based on these findings, it seems that pupillary reactivity can serve as an index for physiological arousal in a broad array of psychological processes, including cognitive biases that relate to the experience of inconsistency.

One such bias that can be empirically demonstrated, using pupillometry, is the confirmation bias. As prior research has shown (Risinger et al., 2002), events

are likely to be assimilated into prior beliefs when the belief violation is ambiguous. When feedback is ambiguous, it can be interpreted as either confirming or violating the expectations that follow from prior beliefs. Given that people are motivated to maintain these belief systems, especially when they are highly committed to their belief (Jonas et al., 2001), they will be likely to assimilate this ambiguous feedback in such a way that it wholly confirms these existing beliefs. Consequently, this interpretation should affect physiological arousal levels following feedback. If the ambiguous feedback is interpreted as confirmatory, the feedback should not evoke elevated levels of arousal, while if feedback is interpreted as violating, elevated levels of arousal should follow.

3.1 Hypotheses

In two studies we use pupillometry to investigate the impact of clear and ambiguous feedback about misconceptions on arousal, with an aim to gain greater insight into the psychological processes that underlie the persistence of false beliefs. Consistent with prior work and the MMM, we hypothesize that (H1) when participants receive feedback about the veracity of their beliefs, they will show an increase in pupil dilation when the feedback is belief-violating relative to when the feedback is confirmatory, and that (H2) relative commitment to these beliefs will moderate the pupillary response, heightening both the increased (violation) and decreased (confirmation) arousal that corresponds to belief veracity feedback. Finally, we also hypothesize that (H3) ambiguous feedback will be interpreted as assimilating to existing beliefs, thus evoking a pupillary response identical to the pupillary response following wholly confirmatory feedback. In both studies, we report how we determined our sample size, all data exclusions, all manipulations, and all measures.

3.2 Study 1

In Study 1, we investigated whether negative feedback indeed elicits greater pupil dilation than positive feedback (H1) and that this is enhanced under high level of commitment towards the misconception (H2).

3.2.1 Method

Participants and design

Participants were 30 psychology undergraduates (86.67% females) from Tilburg University, aged 17 to 28 (M = 20.57, SD = 2.79). All received course credit for participation. We employed a within-subjects design to test the effect of feedback and commitment on pupil dilation. Sample size was based on prior research (e.g., Bradley et al., 2008; Laeng et al., 2011; Partala & Surakka, 2003) and no data was collected after data analysis.

Procedure

Participants were welcomed into the lab and seated in standardized cubicles. The eye tracker was calibrated using the calibration extension from E-Prime 2. Hereafter, the misconceptions task began and throughout this task the participants' pupil size was recorded. At the end, we assessed demographics, debriefed, and thanked participants for their participation.

Materials

Task. The task contained 50 trials. Trials began with a fixation cross (Courier New, 30pt, black) that was displayed for 2000 ms on a gray background, followed by a fact (i.e., the misconception; Arial, 18pt, black). Participants could press the '1' key to indicate that the fact is correct or '2' for incorrect, with a response window of 10s. Next, participants answered three commitment questions about the misconception. Hereafter the words "Your answer is..." appeared. When the participant fixated on the words for 1500 ms, the words disappeared and the feedback appeared. The feedback was either a red 'Incorrect' or a green 'Correct' and was visible for 1500 ms.

Misconceptions. Participants were presented with 50 misconceptions in random order. These were selected from a list of 83 pretested misconceptions. The pretest was administered via Qualtrics (Provo, UT) to 25 Dutch participants that were recruited using social media (age range: 20 - 74, M = 34, SD = 18.40, 7 male, 12 female, 6 unknown). The misconceptions were collected from various sources (e.g., Internet, books, literature). Misconceptions were presented one by one and accompanied by two questions. The first question assessed whether the participant thought the statement was 'true' or 'false'. The second question assessed their level of certainty (1 'absolutely not sure' to 10 'very sure'). For each misconception, we

calculated the percentage of participants who responded with 'true' and selected the 50 misconceptions that were believed to be 'true' by most participants.

Because misconceptions are always false it was possible for participants to notice this pattern and adopt a response style of always responding with 'false'. To address this potential problem in the present study, we rephrased a portion of the misconceptions (28%) so that the correct answer for those misconceptions would be 'true'.

Commitment. To assess commitment, we asked three questions about each misconception: "How certain are you of your answer?", "How important is the fact to you?", "How much fun do you think the fact is?". Each question consisted of a Likert scale that ranged from 1 ('Not at all') to 7 ('Completely'). The commitment measure was created by averaging the responses on the certainty, importance, and fun measure together. Cronbach's α was calculated for each of the 50 misconceptions and was found to be acceptable ($M = 0.74$, $SD = 0.11$).

Pupillometry. Pupil data was collected using a Tobii T60 eye tracker (Tobii, Stockholm, Sweden). The Tobii T60 is integrated in a $17''$ TFT monitor and records at a rate of 60 Hz. Each measurement has a validity indication that ranges from 0 (the system is certain that all data belongs to the particular eye) to 4 (gaze data is missing or incorrect). Only recordings with a validity score of 0 were used. Pupil size from each eye were averaged together to create a single pupil size score and filtered with a modified repeated median filter (outer width: 25, inner width 15) using the 'robfilter' package (Fried, Schettlinger, & Borowski, 2014). Gaps (e.g., blinks) were filled using linear interpolation using the 'zoo' package (Zeileis & Grothendieck, 2005). Hereafter, the pupil size was controlled for baseline differences by subtracting the average pupil size during a 500 ms pre-trial period from the subsequent pupil measurements (Beatty & Lucero-Wagoner, 2000), so pupil size descriptives should be interpreted as pupil size change relative to the baseline period.

Data analysis

The 'lme4' package (Bates, Mächler, Bolker, & Walker, 2015) was used for the mixed model analyses in combination with 'lmerTest', which adds *p*-values and degrees of freedom for the *t*-test on the model parameters.

We defined random intercepts for each participant in our models. Feedback was effect coded and added as a categorical predictor (correct/incorrect) and commitment was added as a (mean centered) covariate. Both their main effects and

interactions were investigated. In the case of an interaction, both simple slopes were analyzed and the effect of feedback at both the minimum and maximum level of commitment.

3.2.2 Results

Response descriptives

Participants believed that about half of the facts were true (M = 53.47%, SD = 10.84). This shows that participants did not adopt a response style of predominantly indicating the facts to be false.

Pupil dilation

To test our main hypotheses about the role of feedback and commitment on pupil dilation, we performed a linear mixed model with feedback, commitment, and their interaction term as fixed effects. The analysis revealed a main effect of feedback, $t(1436.90) = 10.403$, $p < .001$, $b = 0.033$, 95% CI [0.027, 0.039], no effect of commitment, $t(1454.70) = -0.54$, $p = .59$, $b = -0.0015$, 95% CI [-0.0067,

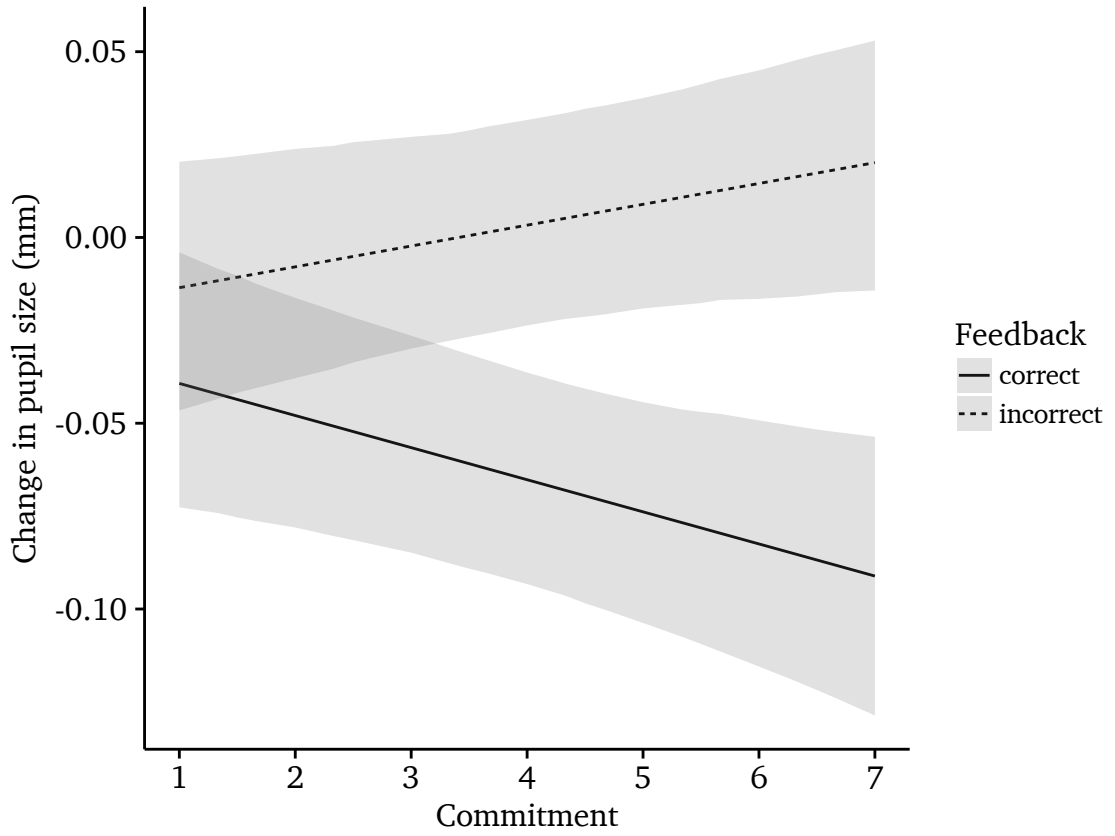

Figure 3.1: Average pupil dilation in response to positive and negative feedback as a function of commitment in Study 1. Error bars reflect 95% confidence intervals.

0.0043], and an interaction effect between feedback and commitment, $t(1433.70) = 3.147$, $p = .0017$, $b = 0.0070$, 95% CI [0.0030, 0.012], see Figure 3.1. The average pupil size in response to negative feedback was greater ($M = 0.0046$, $SD = 0.13$) than to positive feedback ($M = -0.067$, $SD = 0.15$). Simple slope analyses revealed that commitment was negatively linked to the average pupil size when the feedback confirmed the participant's belief, $t(1456.40) = -2.22$, $p = .026$, $b = -0.0085$, 95% CI [-0.016, -0.00074], but not when the feedback was in violation with the participant's belief, $t(1457.90) = 1.70$, $p = .090$, $b = 0.0055$, 95% CI [-0.0017, 0.012]. Additionally, there was no effect of feedback at the lowest level of commitment, $t(1431.90) = 1.89$, $p = .059$, $b = 0.013$, 95% CI [-0.0010, 0.027], but there was at higher levels of commitment, with the largest effect of feedback at the highest level of commitment, $t(1436.30) = 7.01$, $p < .001$, $b = 0.055$, 95% CI [0.038, 0.073]. At the lowest level of commitment, the average pupil size in response to negative feedback was similar to the average pupil size in response to positive feedback (negative feedback: $M = 0.046$, $SD = 0.093$; positive feedback: $M = 0.038$, $SD = 0.12$), but when commitment was high, there was greater pupil dilation in response to negative feedback ($M = -0.021$, $SD = 0.18$) than to positive feedback ($M = -0.13$, $SD = 0.13$).

3.2.3 Discussion

In Study 1, we found increased pupillary dilation following belief-violating feedback about a held misconception compared to receiving confirmatory feedback. This response was moderated by commitment towards the misconception, such that there was a negative relationship between pupil size and confirmatory feedback, and that the pupil size difference between violating and confirmatory feedback was largest at higher levels of commitment. These findings support our hypothesis, and more broadly the MMM, that the violation of expectations causes an increase in physiological arousal (H1), and the effect of feedback was larger at higher levels of commitment, indicating that relative commitment to misconceptions moderates the increase in arousal (H2). We also found that when response feedback was negative, commitment was not significantly related to the amount of pupil change. This finding suggests the presence of a negativity bias, which we will return to in the General discussion of this chapter.

3.3 Study 2

In Study 1, we found that we can distinguish between feedback that violates or confirms misconception beliefs using pupillometry. In Study 2 we use this

technique to further delve into the cognitive processes underlying this response to feedback about misconceptions. In addition to presenting participants with positive and negative feedback, we additionally manipulated the ambiguity of this feedback by adding the possibility that the participant's belief was partly correct or partly incorrect. We opted for manipulating the ambiguity of the positive and negative feedback, rather than only 'partly correct' or only 'partly incorrect', in order to investigate whether the framing of the feedback affects the pupillary response. Semantically the two ambiguous options should be processed identically, but framing effects have been shown to be prevalent (e.g., Schwarz, 1999), hence we decided to include both options and test for the possibility of a framing effect.

We predict that ambiguity provides an opportunity for participants to interpret the ambiguous feedback as a violation, as a confirmation, or as genuinely ambiguous. According to our hypothesis (H3), if people are indeed motivated to assimilate information in a way that confirms one's pre-existing beliefs and expectations, we should see that participants are more likely to interpret ambiguous feedback as wholly confirmatory, therefore showing the same degree of pupil dilation in response to ambiguous and confirmatory feedback. In contrast, if people view ambiguous feedback as genuinely ambiguous or violating feedback, then we should see greater pupil dilation in response to this feedback compared to confirmatory feedback, where the greater dilation may even equal the pupillary response to wholly violating feedback.

3.3.1 Method

Participants

We recruited a total of 51 undergraduate psychology students from Tilburg University who took part for course credit. They had an average age of 19.65 (*SD* = 1.84, min = 17, max = 24) and again the majority of the participants were female (82.35%).

Design

The design of the present study was similar to that of Study 1, except that we added an extra feedback factor called feedback ambiguity (clear/ambiguous) on top of the previous feedback factor (correct/incorrect), creating four different feedback options: correct, incorrect, partly correct, partly incorrect.

Procedure

The general procedure was otherwise identical to that of Study 1.

Materials

Task. Since we added an extra factor, we doubled the number of trials to 100. The increase in trials led to a longer study and increased burden for the participant. To counteract this increased burden, we shortened some of the durations in the misconceptions task. Both the initial fixation cross duration and the required fixation time before the feedback period was lowered to 1000 ms.

Unlike Study 1, participants were given false feedback instead of accurate feedback to make sure that all feedback options were presented equally often. Additionally, the feedback was now presented in black, rather than the previously used green color for positive feedback and red color for negative feedback. Since we used ambiguous stimuli in this study, we did not want the color to indicate how the feedback should be interpreted. The task was identical in every other way.

Misconceptions. More common misconceptions were selected to reach a total number of 100 misconceptions. The majority of misconceptions from Study 1 were used, as well as new misconceptions from various sources (e.g., van Maanen, 1994). A full list of the used misconceptions is available in section 8.1 of the Supplemental Materials.

Commitment. The commitment measure was again created by averaging the responses on the certainty, importance, and fun measure. Cronbach's α scores were acceptable (M = 0.68, SD = 0.11).

3.3.2 Results

Response descriptives

Participants again believed, on average, that the majority of facts were true (M = 67.86%, SD = 8.86). This indicates participants did not adopt the response style of simply stating each fact was false.

Pupil dilation

We first reproduced the original analysis from Study 1 by subsetting the data and only taking trials in which the feedback was clear (e.g., 'correct' and 'incorrect'). This revealed an effect of feedback, $t(2470.40) = 7.03$, $p < .001$, $b = 0.017$, 95% CI [0.012, 0.022], no effect of commitment, $t(2447.40)$ = -0.92, p = .358, b = -0.0020, 95% CI [-0.0061, 0.0028], and an interaction effect, $t(2475.10)$ = 2.76, p = .0058, b = 0.0049, 95% CI [0.0013, 0.0084], thus replicating the results from Study 1, see Figure 3.2. There was greater pupil dilation in response to

negative feedback (M = 0.088, SD = 0.14) than to positive feedback (M = 0.053, SD = 0.14). Inspecting the interaction effect, we again found that commitment was negatively linked to the average pupil size when the feedback was positive, $t(2525)$ = -2.46, p = .014, b = -0.0069, 95% CI [-0.013, -0.0018], but not when the feedback was negative, $t(2513.30)$ = 1.05, p = .29, b =0.0029, 95% CI [-0.0026, 0.0081]. Additionally, we replicate the finding that there is no significant effect of feedback at the lowest level of commitment, $t(2474.20)$ = 0.66, p = .51, b = 0.0036, 95% CI [-0.0064, 0.016], but there is at higher levels of commitment, with the largest effect at the highest level of commitment, $t(2474.40)$ = 5.26, p < .001, b = 0.033, 95% CI [0.041, 0.070]. At the lowest level of commitment, the average pupil size in response to negative feedback was similar to the average pupil size in response to positive feedback (negative feedback: M = 0.095, SD = 0.13; positive feedback: M = 0.048, SD = 0.13), but when commitment was high, there was greater pupil dilation in response to negative feedback (M = 0.060, SD = 0.12) than to positive feedback (M = 0.022, SD = 0.076).

We extended this model by adding ambiguity of feedback (i.e., clear/ambiguous) as a second predictor and tested its interaction with feedback (correct/incorrect).

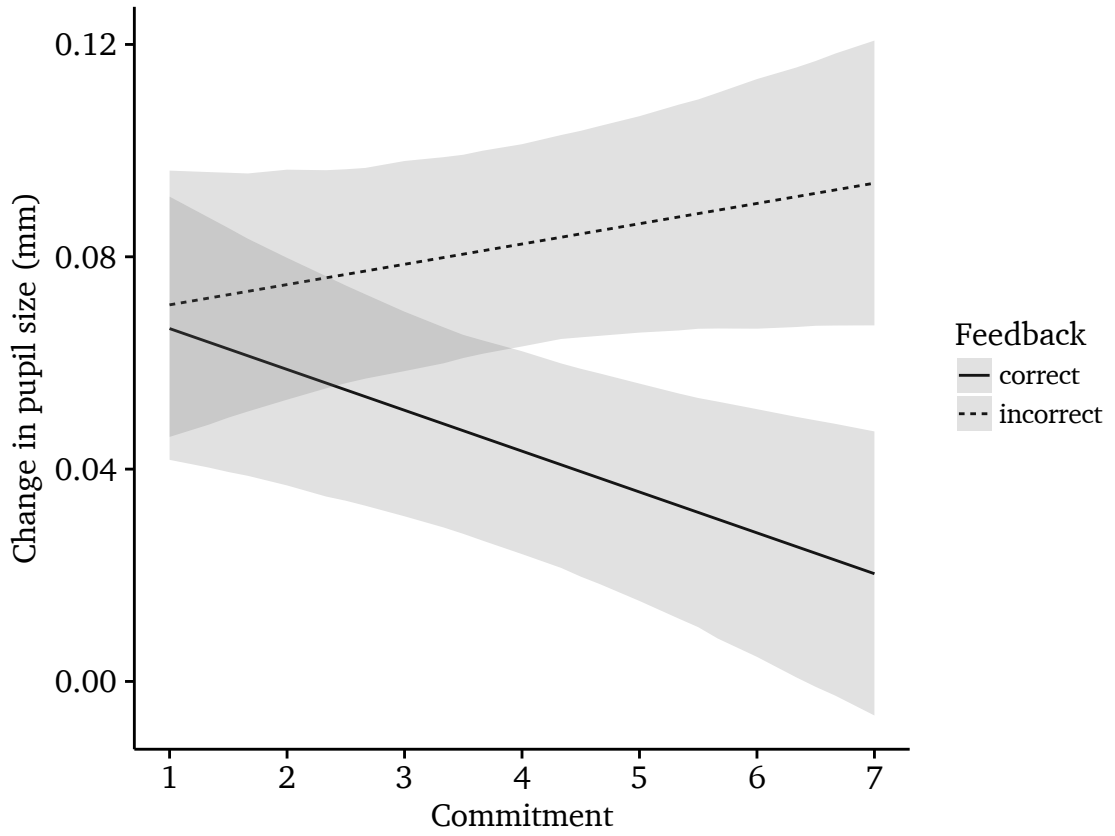

Figure 3.2: Average pupil dilation in response to positive and negative feedback as a function of commitment in Study 2. Error bars reflect 95% confidence intervals.

We again found a significant main effect of feedback and its interaction with commitment (see previous model). There was no three-way interaction between feedback, feedback clarity, and commitment, $t(4988) = -0.44$, $p = .66$, $b = -0.00054$, 95% CI [-0.0031, 0.0020], but we did find an interaction effect between feedback accuracy and feedback clarity, $t(4985) = -2.47$, $p = .014$, $b = -0.0041$, 95% CI [-0.0073, -0.0011]. When participants receive feedback that confirms their belief, there is no significant effect of feedback ambiguity on pupil change, $t(4985) = 0.37$, $p = .72$, $b = 0.00087$, 95% CI [-0.0039, 0.0056]. However, when feedback violates the belief, clear feedback elicits greater pupil change than ambiguous feedback, $t(4985) = -3.13$, $p = .0018$, $b = -0.0074$, 95% CI [-0.012, -0.0027]. Additionally, ambiguous negative feedback results in greater pupil dilation than ambiguous positive feedback, $t(4985) = 3.73$, $p < .001$, $b = 0.0089$, 95% CI [0.0041, 0.014], see Figure 3.3. These results are largely consistent with our hypothesis that people are motivated to interpret ambiguous feedback as confirming their committed beliefs, thus displaying an assimilation bias.

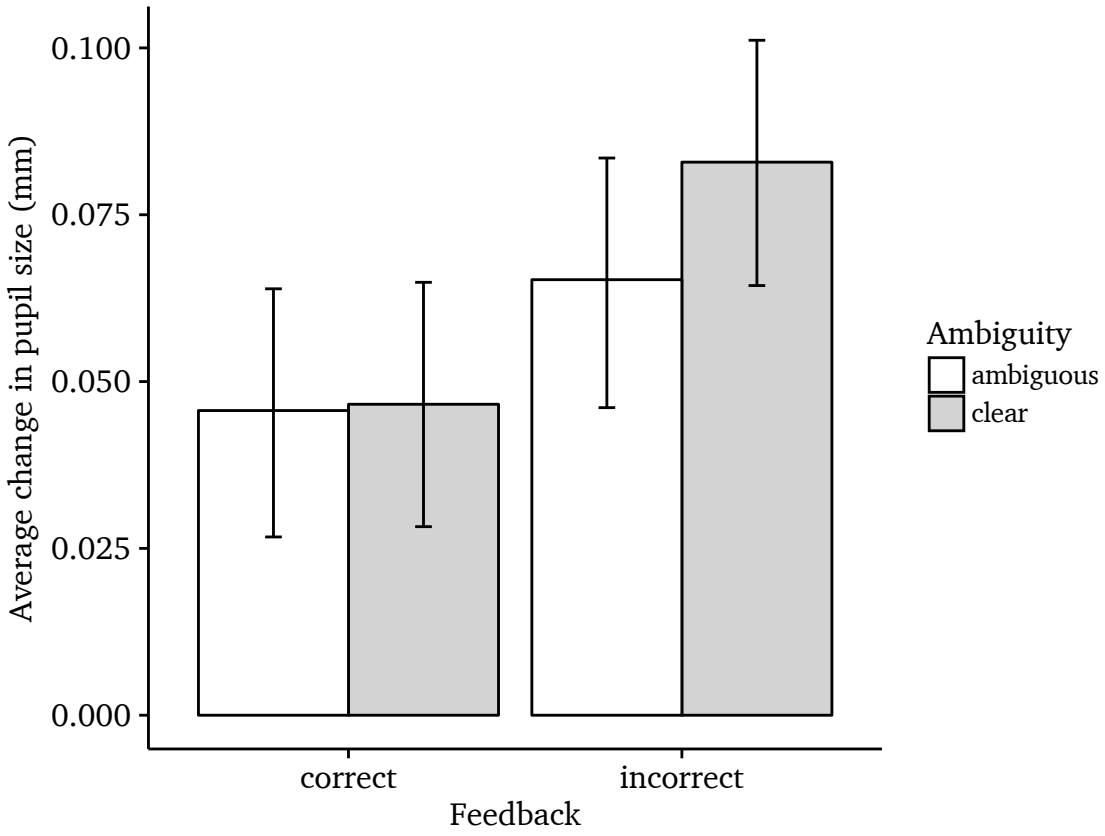

Figure 3.3: Average pupil dilation in response to feedback accuracy (correct/incorrect) and feedback clarity (clear/ambiguous) in Study 2. Error bars reflect 95% confidence intervals.

3.3.3 Discussion

Consistent with Study 1, we again found an increase in pupil dilation in response to feedback that violates beliefs relative to feedback that confirms beliefs. We replicated that this arousal was moderated by commitment when this feedback was confirmatory. When feedback was confirmatory, increasing levels of commitment were associated with less pupil dilation. Crucially, we found that when the confirmatory feedback is ambiguous ('partly correct'), the pupillary reaction is identical to the reaction in response to clear positive feedback (i.e., 'correct'), as though it had been interpreted as wholly confirmatory. This finding is consistent with the presence of an assimilation bias. We also found that when feedback is ambiguously negative, the amount of pupil dilation is lessened, but greater compared to positive feedback, suggesting that ambiguously negative feedback is interpreted as partially confirmatory. This finding is also consistent with a general assimilation bias.

3.4 General discussion

In two studies we investigated the physiological response to feedback about held misconceptions. The results generally support predictions following from the MMM. By observing and manipulating both the valence and clarity of the feedback we demonstrated that feedback-violating beliefs (i.e., being mistaken) led to an increase in pupil size compared to feedback confirming beliefs (i.e., being correct). We also found that the amount of arousal was moderated by commitment towards the misconception belief. At low levels of commitment, we found no effect of feedback on arousal, but at higher levels of commitment there was an increasingly larger difference in arousal between confirming and violating feedback. Additionally, positive feedback was associated with less arousal with increasing levels of commitment, to the extent that committed expectation were being confirmed. When the feedback was negative, commitment did not affect the level of arousal. This could be an indication of a negativity bias in response to explicitly disconfirmatory feedback (e.g., Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001), whereby otherwise negative feedback evokes greater arousal regardless of the extent of belief commitment.

We also observed that ambiguity affected arousal levels in response to both confirmatory and violating feedback. When feedback was confirmatory but ambiguous ('partly correct'), the amount of pupil dilation was identical to that in response to wholly confirmatory feedback ('correct'). Moreover, when feedback was belief-violating but ambiguous ('partly incorrect'), this led to less pupil dila-

tion compared to whole violating feedback ('incorrect'), but to more pupil dilation compared to feedback that wholly confirmed beliefs. These findings are consistent with an assimilation bias. Assimilation bias is a ubiquitous phenomenon, with many studies demonstrating this bias, but there have not been any empirical investigations of an assimilation bias in response to misconceptions, despite their presupposed relevance (Hughes et al., 2013). Our studies thus contribute to this literature by demonstrating an assimilation bias in response to feedback about misconceptions, as assessed with a direct psychophysiological measure.

Assimilation vs. negativity bias

Several of the findings also point at a negativity bias. This negativity bias refers to the notion that negative stimuli have a greater effect on one's psychological state and processes than do neutral or positive stimuli. Myriad studies have demonstrated this bias (for reviews, see Baumeister et al., 2001; Cacioppo, Gardner, & Berntson, 1999; Peeters & Czapinski, 1990; Taylor, 1991). We found that disconfirmatory feedback resulted in greater pupil dilation, compared to confirmatory feedback, irrespective of whether it was clear or ambiguous. Clear disconfirmatory feedback did lead to greater pupil dilation compared to ambiguous disconfirmatory feedback. Additionally, commitment did not moderate the amount of pupil dilation when feedback was clearly disconfirmatory, which could be interpreted as negativity trumping the effect of commitment.

However, visual inspection of the moderating effect of commitment shows a positive slope, indicating that commitment may be positively related to pupil dilation in response to disconfirmatory feedback. More participants or a larger number of trials might have revealed that commitment would also moderate disconfirmatory feedback. Nevertheless, the fact that a moderating effect was observed in response to confirmatory feedback, and not disconfirmatory feedback, does indicate a relatively robust response to otherwise negative feedback. Evolutionarily speaking, it is adaptive for bad to have a greater impact than good. Ignoring or missing the possibility of a positive outcome may merely result in regret or a missed opportunity. In contrast, ignoring or missing danger may result in physical harm or even death. Consequently, we would indeed expect that in response to negative feedback, there should be less variance, and thus less moderation by extraneous factors such as commitment. Our results are thus both in support for an assimilation bias, as well as a negativity bias.

Limitations

A possible limitation is that we provided direction for participants on how to interpret the ambiguity by giving valenced information ('partly correct'/'partly incorrect'). This potentially made the ambiguous feedback less ambiguous. Although beyond the scope of the present research, this suggests that it may be possible to vary the impact of ambiguity on arousal, sometimes even matching that of clear negative feedback. In fact, Holroyd, Hajcak, and Larsen (2006) demonstrated that ambiguous feedback elicited heightened feedback error-related negativity to the same extent as negative feedback. Additionally, Hirsh and Inzlicht (2008) revealed individual differences in response to ambiguous feedback, with some individuals reacting more strongly to ambiguous feedback than negative feedback (see also Gu, Ge, Jiang, & Luo, 2010). We suggest that these differences in findings could be due to variations in the level of ambiguity.

3.5 Conclusion

In two studies we presented participants with feedback about their misconceptions. In keeping with the MMM, we observed that feedback violating beliefs elicits more physiological arousal, as measured through pupil dilation, than feedback confirming beliefs. This response was moderated by a commitment towards the misconception, but only when the feedback was confirmatory. Higher levels of commitment led to less physiological arousal when the feedback was confirmatory, but not when it violated beliefs. This points to an additional bias towards generally negative stimuli. Importantly, we also found evidence for an assimilation bias. Ambiguous confirmatory feedback was interpreted in the same manner as wholly confirmatory feedback, while ambiguously belief-violating feedback appeared to be partially interpreted as confirmatory. With this data we have empirical support for the role of an assimilation bias in response to feedback about misconceptions.

Chapter 4

Extremism and Meaning Violations

Extremism Reduces Conflict Arousal and Increases Values Affirmation in Response to Meaning Violations

Based on Sleegers, W.W.A., Proulx, T., & van Beest, I. (2015). Extremism reduces conflict arousal and increases values affirmation in response to meaning violations. *Biological Psychology*, *108*, 126-131. doi:10.1016/j.biopsycho.2015.03.012

Abstract

In the social psychological threat-compensation literature, there is an apparent contradiction whereby relatively extreme beliefs both decrease markers of physiological arousal following meaning violations, and increase the values affirmation behaviors understood as a palliative responses to this arousal. We hypothesize that this is due to the differential impact of measuring extremism on behavioral inhibition and approach systems following meaning violations, whereby extremism both reduces markers of conflict arousal and increases values affirmation unrelated to this initial arousal. Using pupil dilation as a proxy for immediate conflict arousal, we found that the same meaning violation (anomalous playing cards) evoked greater pupil dilation, and that this pupillary reaction was diminished in participants who earlier reported extreme beliefs. We also found that reporting extreme beliefs was associated with greater affirmation of an unrelated meaning framework, where this affirmation was unrelated to physiological markers of conflict arousal.

Keywords: meaning; threat; extremism; pupil; affirmation; inhibition

In the social psychological threat-compensation literature, there is an apparent contradiction whereby relatively extreme beliefs both decrease arousal following meaning violations, and increase affirmation behaviors understood as palliative responses to this arousal. In this literature, it has been commonly demonstrated that people affirm their values following violations of how they understand themselves and their world (i.e., meaning violations; for a review, see Proulx & Inzlicht, 2012). For example, after being presented with playing cards that violate people's expectations—by reversing the color of the card such as a black two of hearts (Bruner & Postman, 1949)—people show an heightened commitment to beliefs relevant to social equality (Proulx & Major, 2013). These affirmation efforts are understood as palliative responses to a syndrome of negative physiological arousal caused by the meaning violation (Proulx & Inzlicht, 2012). Although research on the mediating effect of this arousal is limited, studies have shown a link between meaning violations and arousal. For instance, cardiovascular measures indicate a threat response when interacting with partners who violate one's expectations (Mendes et al., 2007, 2002) and when social rejection is unexpected (Gunther Moor et al., 2010). On a neural level, it has been shown that the anterior cingulate cortex (ACC) is active when expectations are violated (Oliveira et al., 2007), and also during other kinds of meaning violations, such as mortality salience (Quirin et al., 2012), cognitive dissonance (Kitayama et al., 2013; van Veen et al., 2009), lack of control (Salomons et al., 2004), and social isolation threats (Eisenberger et al., 2003; Nash, Prentice, Hirsh, Mcgregor, & Inzlicht, 2014).

It has also been demonstrated that the physiological response to meaning violations is affected by the extremity of the beliefs one possesses. People holding relatively extreme beliefs display reduced 'distress signals' such as error related negativity (Inzlicht et al., 2009; Inzlicht & Tullett, 2010)—an index of ACC activity (Dehaene et al., 1994; Gehring et al., 1993). Yet they also demonstrate greater affirmation following meaning violations (e.g., mortality reminders; Weise, Arciszewski, Verlhiac, Pyszczynski, & Greenberg, 2012; or anomalous playing cards; Proulx & Major, 2013). If compensatory affirmation is indeed a palliative response to arousal following meaning violations, how can extreme beliefs both reduce markers of conflict arousal and increase affirmation efforts? In this study, we apply a novel perspective from the threat-compensation literature to aid in the understanding of this apparent contradiction (for an extensive overview of this perspective, see Jonas et al., 2014).

According to this perspective, any given meaning violation evokes arousal that primarily activates the Behavioral Inhibition System (BIS; Gray & McNaughton, 2003)—a system that produces heightened anxiety, avoidance motivation, and in-

creased vigilance. After a delay, the Behavioral Approach System (BAS) becomes predominantly active and initiates behavior that underlies compensatory efforts such as the affirmation of values (McGregor et al., 2010). Each system is associated with distinct physiological substrates. The BIS' neural substrates consist of the septa-hippocampal region and the amygdala, which are innervated by serotonergic projections of the raphe nucleus and noradrenergic projections of the locus coeruleus (LC; Aston-Jones & Cohen, 2005 and Amodio et al., 2008). Importantly, LC activity can be derived from autonomic measures of arousal such as pupil dilation (Rajkowski et al., 1993). Indeed, research has shown that task-processing is accompanied by changes in pupil dilation consistent with LC functioning (e.g., Gilzenrat et al., 2010; Jepma & Nieuwenhuis, 2011; Smallwood et al., 2011). Pupil size has also been linked to increased physiological arousal (Bradley et al., 2008; van Steenbergen, Band, & Hommel, 2011) and specific BIS-related constructs such as surprise (Preuschoff et al., 2011), fear and avoidance (White & Depue, 1999), and conflict detection (Critchley et al., 2005; Laeng et al., 2011). Conversely, the BAS' main substrate is the dopaminergic neurotransmitter system with projections in the lateral and orbital regions of the prefrontal cortex (Rolls, 2000).

Following from this distinction, we posit that extremism differentially affects these behavioral systems. Intuitively, it could be reasoned that those with extreme values should be well-equipped to deal with violations of meaning, and would not be motivated to display strong compensatory reactions. Nevertheless, the relevant literature leads us to postulate that those who hold extreme beliefs will initially display diminished conflict arousal BIS, in response to meaning violations, even as they subsequently demonstrate heightened BAS induced affirmation. This prediction is consistent with previous theorizing that BIS and BAS are discrete systems (e.g., Gray & McNaughton, 2003; Jonas et al., 2014) that are triggered independently following the experience of violation (Hirsh, Mar, & Peterson, 2012). While BAS-initiated behaviors may serve a palliative function with regards to initial BIS activation, these subsequent BAS behaviors may not be caused by BIS conflict-detection arousal, nor must they vary in any linear manner with the magnitude of this initial arousal—in fact, they likely show an inverse linear relationship for those with extreme beliefs, insofar as this extreme disposition differentially impacts distinct BIS and BAS systems as they respond to threat.

4.1 Hypotheses

We conducted a single experiment that could demonstrate the extent to which extremism has a dampening effect on initial markers of conflict-detection BIS activation (pupillary dilation), and an amplifying effect on BAS-activated compensation behaviors (values affirmation) in response to the same meaning violation. Participants were exposed to repeated meaning violations (anomalous playing cards) during which time their pupil dilation was measured; followed by several opportunities to affirm moral values. Our first hypothesis was that meaning violations would increase pupil dilation, and that this relationship would be moderated by extremism, such that participants with extreme values would show a diminished pupil response compared to those upholding moderate views. Our second hypothesis was that participants with extreme beliefs would demonstrate greater affirmation of moral values, which would not be moderated by pupillary dilation.

4.1.1 Method

Participants

Sixty-eight students at Tilburg University in the Netherlands (18-32 years of age; 33 male) participated. We excluded participants on the basis of two criteria. First, we excluded participants with over 20% missing eye tracker data to increase the reliability of our results. Second, we excluded participants who reported seeing the anomalous feature of the anomalous playing cards during the experiment, leaving 22 participants in the experimental condition and 31 participants in the control condition. This latter exclusion criterion is based on previous research using implicit perceptual anomalies (e.g., Proulx & Heine, 2008; Proulx & Major, 2013), and follows from findings demonstrating that the explicit recognition of anomalous perceptual features leads participants to accommodate their relevant schemata and subsequently expect future anomalies (e.g., Bruner & Postman, 1949). As such, explicitly noted and subsequently expected anomalies no longer constitute expectancy violations, and we reasoned that the relatively small number of participants who explicitly noted the anomalies would not be suited to testing the effect of pupillary dilation and compensatory affirmation on expectancy violations. We assessed the explicit anomaly-awareness of participants by means of a typical funnel debriefing, whereby participants are asked whether they notice anything generally out of the ordinary regarding the cards, and if so, what it is that they believe is out of the ordinary. If they made an explicit mention of the

colors of the cards, we excluded them from the analyses.

Design

The study consisted of a 2 (cards: normal vs. normal + anomalous) between subjects design. We opted for a between subjects design to be able to optimally compare the pupillary response to normal and anomalous playing cards, as the initial presentation of an expectancy-violating stimulus may affect subsequent reactions to the same type of stimulus. To minimize this possibility, we used a task that draws the attention away from the anomalous feature, and we excluded participants who reported noticing the anomalous feature (see Section 4.1.1.1 and Footnote 1). Research has shown that conscious awareness of anomalies is not needed for compensatory efforts to be evoked (Proulx & Heine, 2008; Randles et al., 2011).

Procedure

Participants were seated in illuminated cubicles, in front of the eye tracker monitor at a distance of approximately half a meter. They began by answering an ideological extremism and positive discrimination attitudes questionnaire, followed by a card task. Participants in the control condition were presented with normal playing cards while participants in the experimental condition saw both normal and reverse colored playing cards. This was followed by two affirmation measures. At the end of the experiment, participants were verbally debriefed, and asked whether they noticed any anomalous features during the card task. If so, they were asked to specify what they thought was anomalous.

Materials

Card task. Participants viewed 260 trials that started with a fixation cross (2000 ms), followed by a playing card for a duration of 1000 ms. Participants were instructed to memorize each card's parity, but to respond only to intermittent probe-trials on which they had to indicate the parity of the card seen in the previous trial, pressing '1' for 'odd' and '2' for 'even' using their preferred hand (see Smallwood et al., 2011). The parity of the card was determined by the cards value, with Aces being valued at either 1 or 11, face cards at 10, and the remaining cards valued according to their number. Probe trials appeared between 2 and 5 non-probe trials in a fixed-random pattern and consisted of a card-sized frame with a question mark displayed within. The experimental condition contained 77 reverse colored playing card trials.

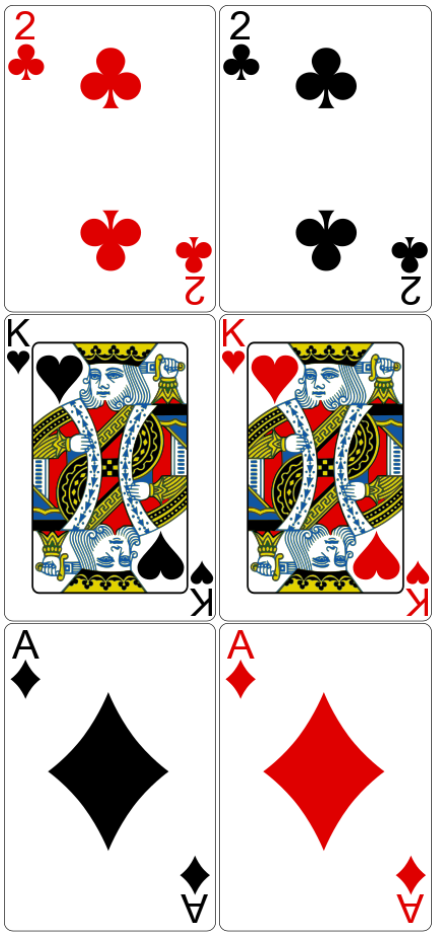

Figure 4.1: A subset of the playing cards, both anomalous (left column) and normal (right column).

The cards were standard poker-sized playing cards, 320 x 425 pixel in size. Anomalous card were created by reversing the color of the card. Hearts and diamonds were colored black, and clubs and spades were colored red. Figure 4.1 contains several examples.

Pupillometry. Pupil data were collected using a Tobii T60 eye tracker (Tobii, Stockholm, Sweden) and E-Prime Professional 2.0 software (Psychology Software Tools, Inc., Sharpsburg, PA). The Tobii T60 is integrated in a 17″ TFT monitor and records various pupil characteristics for each eye, non-intrusively, at a rate of 60 Hz. Each measurement has a validity indication that ranges from 0 (the system is certain that all data belongs to the particular eye) to 4 (gaze data is missing or incorrect). If the pupil size for each eye was considered valid (0), the pupil size measurements were averaged to create a single pupil size measurement. Spikes were removed with a median filter (span 10) and artifacts (e.g., blinks) were corrected using linear interpolation in SPSS (Version 20.0). Additionally, pupil size was z-transformed for each participant. To correct for differences in

baseline before the start of each trial, the average pupil size was calculated over a period of 500 ms before the presentation of the stimulus, and subtracted from each subsequent pupil size measurement of that trial. For the between subject analyses, only the trials that contained an anomalous card in the experimental condition were used and compared to their respective trials (e.g., a reverse colored two of hearts compared to a normal two of hearts) in the control condition by taking the average pupil size of the relevant trials.

Extremism. Extremism was measured using a version of the Social Conservatism Scale (Wilson & Patterson, 1968, $\alpha = .67$), consisting of 11-items describing a societal issue (e.g., 'gay rights'). For each item, participants could indicate to what extent they were in favor of, or against the particular issue. The items were anchored by '0' (totally not agree) to '100' (totally agree). Extremism was defined as the deviation from the neutral point (50), which was calculated for each item and averaged into a single extremism score.

Affirmation. Compensatory affirmation was measured in two ways. First, participants were asked to indicate their general attitude toward positive discrimination. Positive discrimination (or affirmative action) is the policy of favoring members of disadvantaged groups and was assessed by first measuring their baseline attitude using a 5-item scale ($\alpha = .74$), that consisted of concrete instances where positive discrimination may be applied (e.g., "Women must be given more opportunities, compared to men, to occupy chief executive or general management positions"). After the manipulation, their attitude toward positive discrimination was measured again with two general items ("I am in favor/against acts, policies, measures that are driven by the idea of positive discrimination"), each on a 7-point Likert scale, $\alpha = .94$. These two items were combined and the average baseline attitude was subtracted, so that higher scores indicated greater affirmation. Second, with two counterbalanced scenarios involving a crime (prostitution and viewing pornography in public), in which participants are asked to set a bond between €0 and €999 (e.g., Proulx et al., 2010, $\alpha = .73$). These items were averaged together, with higher bonds indicating greater values affirmation.

Analyses

Linear regression analyses were conducted that included the effect of condition (anomalous/normal cards), extremism (mean-centered), and their interaction term, in order to predict both pupil and affirmation responses. Additionally,

we performed a linear regression with average pupil dilation, condition, and their interaction term on both affirmation responses separately.

4.1.2 Results

Supporting Hypothesis 1, we found that anomalous cards elicited greater pupil dilation in the experimental condition (M = 0.11, SD = 0.12) than normal cards in the control condition (M = 0.03, SD = 0.13), $F(1, 49) = 6.89$, $p = .012$, $\mu_p^2 = .123$, and that this pupil reactivity was moderated by extremism, $F(1, 49) = 7.66$, $p = .008$, $\mu_p^2 = .135$ (see Figure 4.2). In the experimental condition, a higher level of extremism was associated with decreased pupil dilation, b = -0.008, $t(49)$ = -2.12, $p = .039$. In the control condition this relationship was reversed, with higher levels of extremism being associated with greater pupil dilation, but of marginal significance, b = 0.006, $t(49) = 1.78$, $p = .081$.

Supporting Hypothesis 2, extremism moderated the affirmation of positive discrimination values, $F(1, 49) = 6.42$, $p = .015$, $\mu_p^2 = .116$. In the control condition, extremism was related to less support for positive discrimination, b = -0.11, $t(49)$ = -2.68, $p = .01$ and somewhat more support in the experimental condition, although not significant, b = 0.046, $t(49) = 1.018$, $p = .314$ (see Figure

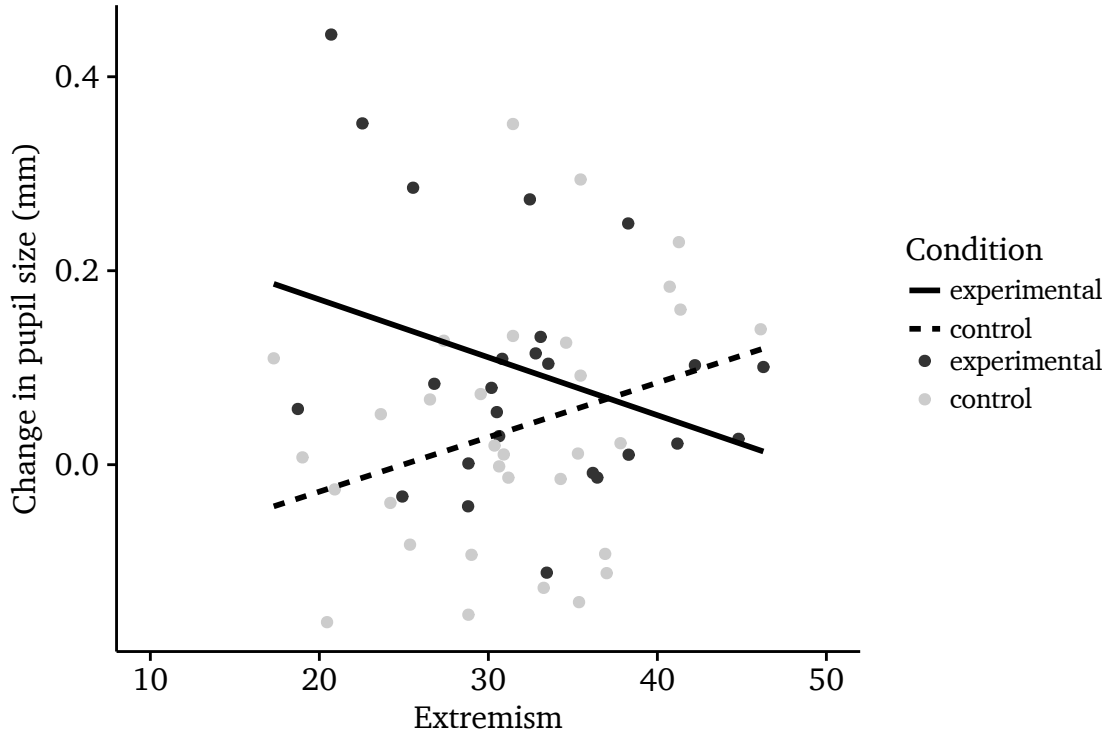

Figure 4.2: Interaction between extremism and card condition on average pupil change.

4.3). Stronger support for extremism as a moderator was found on the bond items, $F(1, 49) = 4.01$, $p = .051$, $\mu_p^2 = .076$ (see Figure 4.4). In the experimental condition, higher extremism was marginally associated with a higher bond, $b = 13.40$, $t(49) = 1.84$, $p = .071$. The simple slope in the control condition was not significant, $p = .354$. No significant moderations of pupil dilation were found on the affirmation measures, $ps > .559$. Within-cell correlations revealed non-significant correlations between average pupil size and the affirmation measure, in both the control condition ($r = -.108$ (bond), $r = -.128$ (positive discrimination) and experimental conditions ($r = -.124$ (bond), $r = -.338$ (positive discrimination)). All $ps > .05$.

Inclusion of the participants who consciously detected the anomalous cards shows similar results. Extremism moderated the pupillary response to normal and anomalous playing cards, $F(1, 59) = 6.752$, $p = .012$, $\mu_p^2 = .103$. In the experimental condition, a higher level of extremism was marginally associated with decreased pupil dilation, $b = -0.008$, $t(59) = -1.99$, $p = .051$. In the control condition higher levels of extremism were associated with greater pupil dilation, also of marginal significance, $b = 0.005$, $t(59) = 1.68$, $p = .099$. Extremism moderated responses to the positive discrimination items, $F(1, 58) = 4.41$, $p = .04$, $\mu_p^2 = .071$. In the control condition, extremism was related to less support

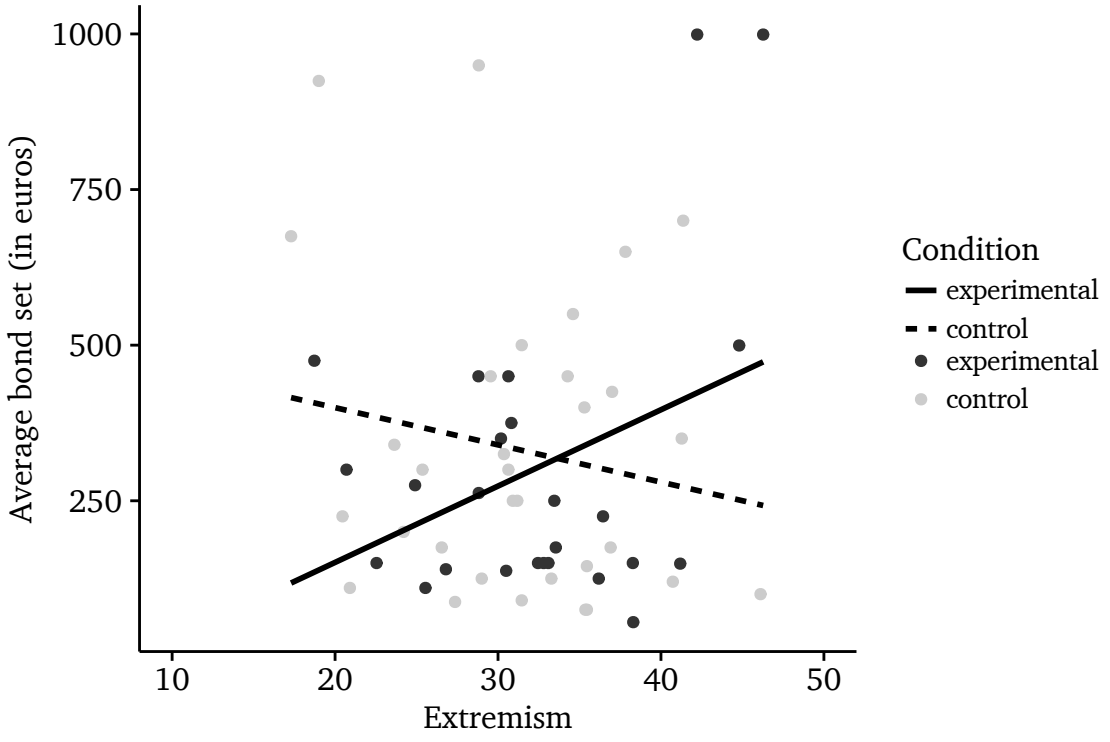

Figure 4.3: Interaction between extremism and card condition on the change in attitude toward positive discrimination.

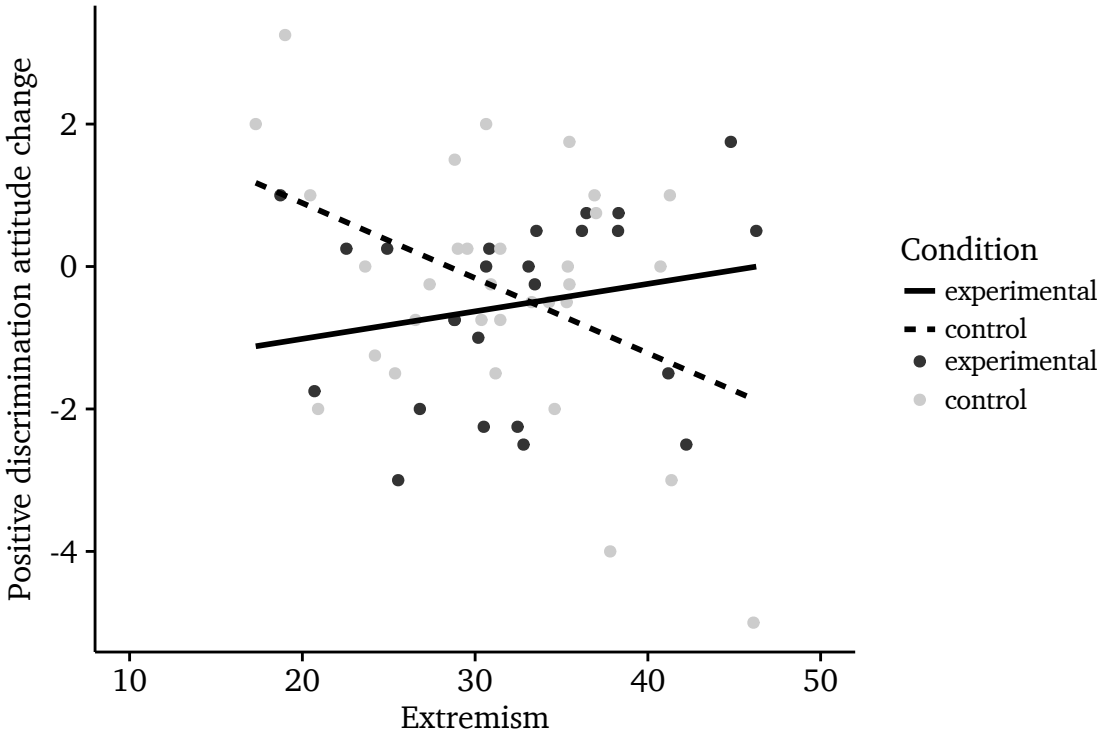

Figure 4.4: Interaction between extremism and card condition on the average bond set for a criminal act.

for positive discrimination, b = -0.10, $t(58)$= -2.70, p = .009 and somewhat more support in the experimental condition, although not significant, b = 0.014, $t(58)$ = 0.35, p = .728. The interaction with extremism and condition on the bond items was found to be of marginal significance in this re-analysis, $F(1, 58)$ = 3.581, p = .06, $\mu_p{}^2$ = .058. In the experimental condition, higher extremism was marginally associated with a higher bond, b = 12.20, $t(58)$ = 1.90, p = .062. The simple slope in the control condition was not significant, p = .46. Again, no significant moderations of pupil dilation were found on the affirmation measures, $ps > .479$.

4.1.3 Discussion

In the present study we provide the first evidence for both decreased error detection and an increased compensatory reaction in response to the same meaning violation for people with extreme beliefs. We demonstrated an increased pupillary reaction to anomalous playing cards and a moderating role of extremism—more extreme participants showed a diminished pupillary reaction. However, extremism was found to be related to greater affirmation of societal values. This shows that extremism differentially affects initial markers of BIS activation and subsequent behavior related to BAS activation. These findings support the contention that BIS and BAS are separate systems. Even though these systems are both activated

in the wake of experienced violations, researchers in the threat-compensation literature have separately investigated either BIS or BAS motivated effects. This approach has limited our understanding of how these systems differently manifest in the threat-compensation behaviors commonly reported in this literature. In this experiment, we have investigated the temporally inclusive threat-compensation response and shown that BIS activation is dampened by the presence of extreme values, and the BAS response is amplified. We show that our proxy for BIS, pupil dilation, does not appear to cause the BAS motivated responses, thus supporting our contention that BIS and BAS are distinct systems that are distinctly influenced by commitment to relatively extreme values.

Additionally, we are also among the first to show this in a setting where the error is in the stimulus and not in action tendencies that are relevant to the task. Participants did not need to react to all card trials, and on trials requiring a response, the judgment (odd/even number) involved a different and task-irrelevant feature of the card (card number vs. anomalous color of the suit). It has been suggested that meaning violations create conflicts in behavioral responses and that this motivates subsequent compensatory reactions (e.g., Harmon-Jones, Amodio, & Harmon-Jones, 2009; Hirsh, 2012). Our data shows that, although general behavioral tendencies are still likely to play a role, these need not be content-related to the ongoing task. Instead, meaning violations can elicit compensatory reactions outside of conscious awareness and without direct bearing on the task.

We found a moderating effect of extremism on both affirmation measures, yet more affirmation on the latter dependent measure. This is consistent with the literature showing a delay is required between the meaning violation and the affirmation opportunity to maximize the compensatory response (Burke et al., 2010; Jonas et al., 2014). Since we did not implement a delay, it was likely the case that some participants were still in an inhibitory state after the violation task and switched to approach soon after, responding with increased zeal to the second set of affirmation items. We must note, however, that this is only speculation, and a counterbalanced design is needed to test this interpretation.

It may be noted that our participants were students in a socially liberal country, and extremism was overwhelmingly present in what would typically be interpreted as a socially liberal direction. Although some views in the literature paint those holding conservative beliefs (by North American standards) as a group particularly sensitive to threat and uncertainty (Jost et al., 2007), our results show that people who uphold relatively liberal beliefs (by this same standard) also show a typical threat response. This suggests that relative extremism plays a content-general role in the amplification of BAS-induced affirmation, rather than one where the content (e.g., 'right' or 'left' wing) of extreme beliefs determines

the amplitude of compensation (see e.g., Brandt, Reyna, Chambers, Crawford, & Wetherell, 2014; Brandt, Wetherell, & Reyna, 2014; Greenberg & Jonas, 2003).

Limitations and future research

In this study we investigated the effects of perceptual anomalies on pupil dilation. We see perceptual anomalies as but one inconsistency among many common meaning violations, including the experience of ostracism, loss of personal control, and mortality salience. We have shown that pupil dilation is affected by the threat of perceptual anomalies, but it is not yet known whether the same reaction would occur in response to other meaning violations such as mortality salience. Future research can replicate this study's design with these other violations.

Future research should also investigate a greater variety of compensation strategies and affirmation opportunities. In our design we have used both attitudes toward positive discrimination and punishment decisions for two criminals. Both of the reported crimes contained elements of sexuality; nevertheless, we believe that those who breach any committed social norm should incur a heightened punitive, and therefore affirmative, response following a meaning violation. Future studies could include more varied crimes in order to see whether our results generalize to other punitive domains. Additionally, the affirmation of personal projects, religious affirmation, and the affirmation of explicit political values could be used to further investigate the extent to which extremism affects the tendency to affirm values, more generally, in these domains.

In contrast to previous studies using these dependent measures (e.g., Proulx & Heine, 2008), no main effects were found of condition on our bond affirmation measures. There are several reasons for this possible absence. First, our design differed in several respects from this prior research, with one notable difference being the measurement of social value attitudes prior to the experimental manipulation. Research has shown that the activation of one's values can suppress the effect of meaning violations (see e.g., Inzlicht & Tullett, 2010). Second, our relatively liberal sample could have suppressed an otherwise detectable main effect. Correlational tests, however, did not show a suppressing effect of social conservatism with the bond measures, thereby ruling out this explanation. Third, contrary to US participants, it may be the case that Dutch participants do not generally have strong enough commitments regarding prostitution for this punishment scenario to constitute a general affirmation opportunity. As such, only those of relatively extreme dispositions affirmed punitive attitudes, as shown in our data.

Finally, our conclusions regarding the relationship between BIS and BAS

activation—specifically, the lack thereof—is bounded by the specific markers that characterize the seeming contradiction that we attempted to address, namely, markers of immediate conflict-detection BIS, and subsequent BAS-activated affirmation. While these distinct systems did not appear to causally interact (i.e., BIS conflict arousal appeared unrelated to the magnitude of subsequent BAS compensation), it may still be the case that other markers of downstream BIS arousal may causally impact the extent of subsequent BAS activation (e.g., retrospective felt anxiety following explicitly experienced meaning violations; McGregor, Prentice, & Nash, 2013, 2009). Future experimental work can determine this possibility.

4.2 Conclusion

We found that extremism reduces the pupillary response to a violation and increases subsequent affirmation of personal values, demonstrating that extremism differentially impacts markers of conflict-detection BIS and BAS compensation in response to meaning violations.

Chapter 5

Pupillometry and Hindsight Bias

Physiological Arousal Predicts Compensatory Behavior

Based on Sleegers, W.W.A., Proulx, T., & van Beest, I. (2017b). *Pupillometry and hindsight bias: Physiological arousal predicts compensatory behavior*. Manuscript in preparation.

Abstract

Humans have a need for meaning, that is, they have a need to understand the world and form expectations that connect people, places, objects, and events to each other. Often, however, events unfold differently than expected, violating our sense of meaning. This causes a state of aversive arousal that motivates compensatory behavior to reduce this arousal. Although there is abundant empirical support for the link between expectancy violations and aversive arousal, it has not frequently been demonstrated that this aversive arousal predicts compensatory behavior, despite theories in the threat compensation literature (e.g., Meaning Maintenance Model; MMM) assuming such process. We believe this might be the result of misattribution processes in which arousal is mistakenly attributed to the equipment used to measure arousal and the difficulty of repeatedly measuring changes in arousal to multiple opportunities of compensatory behavior within a single experiment. To counteract these limitations, we applied a noninvasive technique to measure arousal, pupil dilation, and used hindsight bias as an instantiation of compensatory behavior. In two sessions, participants answered a series of factual questions with surprising answers. After first answering all questions, participants were presented with the true answers to the questions, during which their pupil size was measured. Following each correct answer, they were asked to indicate their previous answer. We found that pupil dilation predicted the extent to which participants adjusted their second answer to be closer to the correct answer, thus displaying compensatory behavior, and supporting the MMM and other threat compensation theories.

Keywords: meaning; pupil; compensatory behavior; misattribution; physiology-behavior link

Humans adopt a multitude of beliefs. These range from grand worldview beliefs to trivial fun facts. People believe that the world is fair, that behavior follows from attitudes, and that people eat an average of 8 spiders per year in their sleep. This range of beliefs reflects a ubiquitous need for meaning. That is, people have a need to understand the world and form expectations that connect people, places, objects, and events to each other (e.g., Baumeister, 1991; Heine et al., 2006; Proulx & Inzlicht, 2012). According to the Meaning Maintenance Model (MMM), meaning stems from the adoption of beliefs that causes one to expect relationships. People expect that water feels wet, that seasons follow a specific order, and that good things happen to good people. When these expectations are met, a sense of meaning is experienced. Their sets of beliefs, or meaning frameworks, functionally allow people to make sense of their environment and ultimately serve as guidelines for how to act.

But meaning frameworks are imperfect. It turns out the world is not always fair (Lerner, 1980) and that people do not eat 8 spiders in their sleep on an annual basis (Sneed, 2014). These events violate the sense of meaning and cause a state of discomfort, referred to by various psychologists as disequilibrium (Piaget, 2000), imbalance (Heider, 1958), dissonance (Festinger, 1957), uncertainty (van den Bos, 2001), anxiety (Janoff-Bulman, 1992), and anxious uncertainty (McGregor et al., 2010), or summarized in the MMM as disanxiousuncertlibrium (Proulx & Inzlicht, 2012). It is this state that is argued to motivate compensatory behavior to find meaning (Proulx & Inzlicht, 2012).

One form of compensatory behavior is that people can assimilate events so that they appear consistent with initial expectations. For example, a misfortune that befalls an innocent person can be interpreted as deserving rather than unfair, such as a rape victim being accused of having provoked it by dressing provocatively (Lerner, 1980). This assimilation maintains a sense of consistency with the belief of a just world. Alternatively, a disconfirmed set of expectations can be accommodated. For example, after finding out that people do not eat 8 spiders in their sleep every year, this estimate can be adjusted downwards to account for the new information, whereby they may even adopt the wholly correct belief that people do not eat any spiders during sleep. A third possible response to meaning violation is that beliefs unrelated to the initial violation are more strongly affirmed, a behavior that is also called fluid compensation (Heine et al., 2006). For example, participants that were manipulated to feel insecure about their intellect or relationships subsequently showed greater religiosity (McGregor et al., 2013), or participants who saw reverse colored playing cards (e.g., a black Two of Hearts) subsequently demonstrated greater affirmation of affirmative action (Proulx & Major, 2013). As can be seen in these examples, the violation of both broad worldviews and trivial

beliefs can evoke compensatory behavior.

Arousal motivating compensation

According to the MMM, the commonality between the various names that describe the experience of meaning violation, along with the convergent behaviors following a meaning violation, point to a common syndrome of aversive arousal underlying these behaviors. The role of arousal in cognitive conflict reduction, more generally, has been raised in the past. Festinger (1957) suggested that the dissonance reduction behaviors are motivated by aversive arousal following experiences of cognitive inconsistency, where in the case of dissonance research, these behaviors often involved attitude change to restore a sense of cognitive consistency (i.e., accommodation). Yet, just like it was the case then, direct evidence for the physiological aversive state playing a causal role in producing compensatory behavior remains limited.

If it is the case that an aversive arousal state underlies the response to meaning violations, then at least two lines of evidence should be found (see also Townsend, Eliezer, & Major, 2013). First, meaning violations should reliably induce a state of heightened physiological arousal. Second, this physiological arousal should be linked to the compensatory behavior that frequently follows a meaning violation. Evidence for the former can be found in abundance, whether it's an expectancy violation caused by a perceptual anomaly (Sleegers et al., 2015), cognitive dissonance (Gerard, 1967), self-view inconsistencies (Ayduk et al., 2012), worldview violations (Townsend et al., 2010), or category-based violations (Mendes et al., 2007).

Evidence for the second link, however, is less frequently observed. The main line of research that offers indirect support for the second link utilizes a misattribution of arousal paradigm, whereby, participants are given a possible explanation for any arousal they may experience following a meaning violation (Inzlicht & Al-Khindi, 2012; Kay, Moscovitch, & Laurin, 2010; Losch & Cacioppo, 1990; Proulx & Heine, 2008; Zanna & Cooper, 1974). For example, Proulx and Heine (2008) presented participants with an implicit perceptual anomaly (the experimenter switching midway through the experiment without the participant noticing) and then had them take a placebo. Those who were informed that the placebo caused side effects of arousal did not affirm a moral belief they held (setting a bond for a prostitute) compared to those who were not informed of such side effects. Relatedly, the effect of a meaning violation on compensatory behavior is also reduced when an actual sedative is given. For example, Cooper et al. (1978) gave some participants amphetamine, while others got phenobarbital (i.e., the sedative). Those

who received the sedative showed less attitude change following a high-choice counterattitudinal essay than those who received the amphetamine.

Self-report assessments of aversive arousal

Some additional evidence for the second link has been found using self-report measures to index the aversive arousal and its association with compensatory behavior (e.g., Laurin, Kay, & Moscovitch, 2008; McGregor et al., 2013; Plaks, Grant, & Dweck, 2005, experiment 4). For example, Plaks et al. (2005, experiment 3) violated participant's meaning by confirming or disconfirming their theories of personality. Following the confirmation or disconfirmation, participants' compensatory behavior was assessed with a task in which they had to press a button in response to seeing a row of A's. The row of A's would either turn into a row of B's or remain a row of A's. Their task was to determine the percentage of trials on which they had control over whether the A's turned into B's. By playing a greater number of trials, participants would be more certain of the correct percentage of trials they had control over. Self-reported anxiety was measured before and after the confirming or disconfirming feedback. Results showed an increase in anxiety following disconfirming feedback, which mediated the relationship between the meaning violating feedback and compensatory behavior, i.e., higher need for certainty. However, despite this example evidence for the mediational link remains elusive (also see McGregor et al., 2013, p. 550).

There are multiple potential reasons for why self-report measures fail to demonstrate a mediational link between meaning violations and compensatory behavior. The first reason is that meaning violations often do not produce increased negative affect. Researchers from different backgrounds in the compensation literature have repeatedly demonstrated an absence of negative affect, or even elevated positive affect, immediately after a meaning violation (e.g., DeWall & Baumeister, 2006; Dodgson & Wood, 1998; Pyszczynski et al., 1999; Wichman, Brunner, & Weary, 2008). This might be the result of methodological limitations, such as poor reliability, of self-report scales, but it can also be due to the phenomenon in question. According to this second possibility, self-report measures can provide a compensatory opportunity to respond to the meaning violation. By explicitly reporting that the meaning violation was in fact not distressing, one can persuade oneself to feel less distress. For example, in the case of cognitive dissonance it has been empirically demonstrated that asking about the degree of psychological discomfort has the effect of reducing the amount of dissonance felt (Elliot & Devine, 1994; Galinsky, Stone, & Cooper, 2000; Pyszczynski, Greenberg, Solomon, Sideris, & Stubing, 1993).

Physiological assessments of aversive arousal

If self-report measures are unreliable assessments of the predicted aversive arousal state, one might conclude that more direct measures such as physiological assessments should be used. However, research has shown that there is only a weak intercorrelation between self-report measures, changes in physiological arousal, and associated behavioral outcomes (Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005), indicating that here too there is a second set of potential problems. In fact, the problems associated with self-report measures easily apply to physiological assessments as well. One issue is that physiological arousal measurement tools themselves evoke arousal. The placing of electrodes on the skin or having your head put between metal braces can be arousing or at least is expected to evoke arousal. Consequently, it is possible that participants feel aroused because of the measurement tool itself or attribute arousal caused by a manipulation to the measurement tool, ironically showing the efficacy of misattribution studies that in other contexts serve as evidence for the role of arousal in the threat compensation process. For example, Croyle and Cooper (1983) performed a standard induced compliance paradigm involving the enforcement of a new legal drinking age and found the predicted pattern of attitude change—students in the high choice condition arguing in favor of a lower drinking age became more in favor of a lower legal drinking age. This effect disappeared in Study 2, which contained a physiological arousal assessment in the form of skin conductance. The authors interpreted this absence of an effect due to participants misattributing their arousal to the physiological recording device.

An additional limitation of many physiological assessment tools is that they are noisy. Repeated trials are necessary to detect a reliable signal. This means that when testing the link between physiological arousal and compensatory behavior, a significant amount of time passes in between the induction of the meaning violation and the subsequent measure of the compensatory behavior. Although the threat compensation literature has demonstrated that some time should pass before assessing compensatory behavior (e.g., Burke et al., 2010), this period is likely still too long when measuring a physiological response. Due to this elongated period between meaning violation and compensatory behavior it is perhaps no surprise then that evidence for this link is mixed.

In summary, according to many models in the threat compensation literature, and the MMM in particular, it should be the case that meaning violations induce a state of aversive arousal (link 1) and that aversive arousal motivates compensatory behavior (link 2). A myriad of findings are in support of the first link, but the second link remains uncertain in terms of direct empirical support. In the present

paper, we investigate this second link using a design that takes into account some of the limitations of prior work. We use new and improved eye tracker technology to assess aversive arousal in response to meaning violations, after which we measure compensatory behavior, and do so repeatedly to achieve higher power.

Pupillometry and psychophysiological arousal

Recent advances in eye tracker technology have led to some significant improvements over previous models. Eye trackers are now more affordable, easy to use, and, more importantly, less of a burden to participants. Unlike previous models that often required the participant's head to be fixed in place, modern eye trackers are integrated in computer monitors so that, after a short calibration procedure, it is no longer noticeable that an actual eye tracker study is taking place. This noninvasive design is much desired as it likely lowers the possibility for participants to attribute any felt arousal to the device, thereby allowing us to more reliably investigate the effect of aversive arousal on compensatory behavior.

This aversive arousal can be measured using eye tracker technology. Pupillary reactivity (i.e., changes in pupil size) can serve as an index of physiological arousal. This relationship between pupil size and arousal stems from its association with the locus coeruleus (LC)-norepinephrine (NE) system. The LC-NE system is involved in the regulation of engagement or withdrawal behavior by releasing NE through projections from the LC in the forebrain (for a review, see Aston-Jones & Cohen, 2005). Pupil size has been found to correlate with LC activity in monkeys (Rajkowski et al., 1993) and humans (Gilzenrat et al., 2010). Additionally, Beatty and colleagues have demonstrated that pupil reactivity is consistent with LC responses to task-events (Beatty, 1982; Jackson, 1982; Richer & Beatty, 1987). Further support is found in studies linking pupil dilation to arousing stimuli such as positive or negative pictures (Bradley et al., 2008) and the experience of pain (Chapman et al., 1999; Ellermeier & Westphal, 1995; Höfle et al., 2008). Importantly, pupil dilation has also been found to increase in response to task error (i.e., being mistaken; Brown et al., 1999; Critchley et al., 2005) and expectancy violations (Preuschoff et al., 2011; Raisig et al., 2012, 2010; Sleegers et al., 2015). Consequently, pupillometry is a valuable tool to assess physiological activation, in a way that is noninvasive and therefore unlikely to be seen as a potential source for felt arousal.

Pupillometry, like many other physiological assessment tools, requires repeated measurements to attain a reliable signal. As a result, a sizeable number of experimental trials is needed, which will elongate the time between a meaning violation and compensatory behavior if a standard design is used. One possi-

ble solution is to present repeated meaning violations and assess compensatory behavior after each meaning violation. Such a within subject design would potentially achieve high enough power to detect the theorized relationship between aversive arousal and compensatory behavior. However, the majority of studies on compensatory behavior (e.g., affirmation) use between subject designs in which compensatory behavior is measured once, so using common compensatory behavior assessments is not possible. Therefore, we use a different paradigm to assess assimilation compensation behaviors based on a popularly research psychological phenomenon: hindsight bias.

Hindsight bias as a compensatory response

Hindsight bias, or the 'knew-it-all-along' effect, is the tendency for individuals with outcome knowledge (hindsight) to claim that they did in fact know the outcome or estimated its occurrence with a higher probability than they would have estimated without the outcome information (foresight). Several processes have been proposed to underlie the hindsight bias (for a review, see Hawkins & Hastie, 1990). One of these proposed processes is the tendency for participants to enhance their own ego. It has been suggested that the hindsight bias is caused by a relatively automatic and unconscious sense-making process (Fischhoff, 1975) and research on individual differences in the tendency to demonstrate hindsight bias has revealed that people high in need for predictability and control more frequently show hindsight bias (Musch, 2003). These findings suggest that some motivational processes underlie the hindsight bias, similar to, or perhaps even identical to, the processes underlying compensatory responses following meaning violations. In short, hindsight bias itself can be considered a compensatory assimilation response i.e., reinterpreting experiences to be consistent with accessible meaning frameworks.

From this perspective, hindsight bias is a compensatory response to information that violates participants' expectations. For example, if participants are asked to estimate the shortest distance between Russia and America (likely to be upwards of several hundreds of kilometers), and are then given the correct answer (3.6 km), it violates their expectations. In line with the MMM, this could result in compensatory assimilation behavior. In this case, a hindsight bias that would result in the participant indicating a second response that is closer to the correct answer than their initial response.

Assessing hindsight bias as a compensatory assimilation response has the methodological benefit of allowing for a repeated measures design. Using a so-called 'memory paradigm', participants first answer a series of questions to es-

tablish their prior beliefs, which is followed by a second presentation of these questions together with their correct answers. After the presentation of the correct answer, the participant is prompted to report their original response (in hindsight). If the recalled response is different from the initial response, and closer to the correct answer (i.e., assimilated), a hindsight bias has been demonstrated. For our purposes, the advantage is that there is no limit to how many questions can be asked, except for taking into account participant fatigue and the question pool. This makes making it a viable design to repeatedly assess compensatory affirmation behaviors.

5.1 Hypothesis

In the present study we use pupillometry and the hindsight bias to investigate the directly mediating role of physiological arousal in the relationship between meaning violations and compensatory assimilation behavior. We will present participants with a series of questions that vary in how unexpected the correct answers are. Using an eye tracker, arousal levels will be assessed at the moment of the presentation of the correct answer, after which they are once again asked what they believed the answer to be. We hypothesize that when the correct answer violates the expectations of the participant, this results in greater pupil dilation. This increased pupil dilation should motivate participants to indicate a different response than initially given, in the direction of the presented correct answer, i.e., display an assimilative hindsight bias. Such relationship would support the prediction of the MMM that compensatory behaviors are a direct response to aversive arousal in response to a meaning violation.

5.1.1 Method

Participants

Students (N = 44; 31 women; M_{age} = 20.93 years) at Tilburg University participated in exchange for course credit or a monetary reward. The majority of participants (34) were undergraduate students in psychology. Sample size was based on prior research using pupillometry (e.g., Bradley et al., 2008; Laeng et al., 2011; Partala & Surakka, 2003). No additional data was collected after data analysis.

Design and procedure

The present study consisted of a full within-subjects design, with a hindsight bias paradigm to present meaning violations and to measure compensatory behavior. Specifically, we used a memory hindsight bias design (Calvillo, 2013; Pohl, 2007) in which participants answered a series of factual questions, first before seeing the correct answers and again later after seeing the correct answer to each question. Each question was presented individually. After participants indicated what they believed to be the correct answers, the eye tracker was calibrated and participants saw each question again, followed by the presentation of the correct answer to said question. Pupil size was measured during the presentation of the correct answer. Immediately following the correct answer the participant had to indicate what their original answer was. At the end, participants filled in several demographics questions.

Materials

Factual questions. The questions for the hindsight bias task were selected from various online sources and books on the topic of misconceptions (e.g., van Maanen, 1994). We selected 80 questions that we believed participants thought they could answer, but that varied in terms of whether they would answer correctly. In other words, we selected questions that varied in the extent that the correct answer would surprise them. A full list of the questions is available in section 8.2 of the Supplemental Materials.

Hindsight bias task. The hindsight bias task consisted of two parts, each part consisting of 80 trials. In the first part, a trial consisted of a single question and participants were asked to indicate what they believed to be the correct answer. Questions were presented in random order, without a time limit. In the second part of the hindsight bias task, a trial consisted of a single question, shown for a minimal duration of 3000 ms, after which the participant could click with the mouse to continue. Hereafter, there was a blank screen for a duration of 1000, 1500, or 2000 ms, followed by a fixation cross (3000 ms). After the fixation cross, the correct answer to the quest was presented for a duration of 5000 ms. Hereafter, participants were asked to indicate what their answer was, identical to that in the first part.

Hindsight bias. Hindsight bias was defined as the difference between the second and the first response to each question, with the requirement that the second response was closer to the correct answer than the first (Pohl, 2007). Because it is

not possible to get closer to the correct answer when the initial answer is already correct, these trials were removed (20.73%). We also created a percentage-based solution to reduce the influence of questions with extremely large numeric answers (e.g., “How many earthquakes occur every year?" Answer: 50000). Hence, the amount of hindsight bias was divided by the absolute distance between the correct answer of the question and the participant’s initial response. This resulted in a bias that could range from 0 to 1 or above. If the bias was greater than 1, it indicates an overcorrection (e.g., if the first response is 30, the correct answer is 40, and the second response is 45). Due to the difficulty of interpreting the meaning of such an overcorrection in terms of a hindsight bias, we chose to remove these trials (1.59%).

Pupillometry. A Tobii T60 eye tracker (Tobii, Stockholm, Sweden) was used to record pupil data. The Tobii T60 is a noninvasive eye tracker that is integrated in a $17''$ TFT monitor, resembling a standard PC monitor. It records at a rate of 60 Hz. Each measurement has a validity indication that ranges from 0 (the system is certain that all data belongs to the particular eye) to 4 (gaze data is missing or incorrect). Only recordings with a validity score of 0 were used. Pupil size from each eye were averaged together to create a single pupil size score and filtered with a modified repeated median filter (outer width: 25, inner width 15) using the ‘robfilter’ package (Fried et al., 2014). Gaps in the pupil data (for example due to blinks) were filled using linear interpolation, using the ‘zoo’ package (Zeileis & Grothendieck, 2005). Hereafter, the pupil size was controlled for baseline differences by subtracting the average pupil size during a 500 ms pre-event period from the subsequent pupil measurements (Beatty & Lucero-Wagoner, 2000). Pupil size was averaged across a period of 500 ms to 2500 ms following the presentation of the correct answer. The initial 500 ms were seen as the light reflex period.

Data analysis

Data was prepared and analyzed in R (R Core Team, 2016). We report hindsight bias descriptives to determine how often hindsight bias occurred and also tested whether pupil dilation was linked to being mistaken in order to validate the response feedback as indeed affecting the participant’s physiology. To this end, we created a binary variable that indicated whether the participant gave a correct or incorrect answer (i.e., not taking into account the magnitude of the error). We performed a linear mixed model with error (yes/no) as the predictor and average pupil size as the outcome variable. We defined random intercepts for each participant.

To investigate the hypothesis that pupil size is positively linked to the amount of hindsight bias, we performed several linear mixed model analyses in which hindsight bias served as the outcome variable and average pupil dilation in response to the question's answer as the predictor. We defined random intercepts for each participant. We only included trials with hindsight bias, that is, trials in which participants gave a second response that was closer to the correct answer than their initial answer (e.g., Pohl, 2007).

The 'lme4' package (Bates et al., 2015) was used for the mixed model analyses in combination with the 'lmerTest' package (Kuznetsova, Brockhoff, & Christensen, 2016) in order to determine *p*-values. Confidence intervals were created with Bayesian regression models using the 'brms' package (Bürkner, n.d.).

5.1.2 Results

Descriptives

Participants adjusted their second answer towards the correct answer (i.e., displayed a hindsight bias), on average, on 20.72% of the trials. Variability between participants was great, however (SD = 12.49, min = 1.49, max = 58.73). It thus appears that there were large individual differences in demonstrating a hindsight bias.

Pupil dilation and error

To test whether being mistaken was associated with an increase in pupil size, we conducted a linear mixed model with average pupil dilation as the outcome variable and error (the initial response to the question being different from the correct answer) as the predictor. This revealed a significant effect of error, $t(3354) = 2.30$, $p = .021$, $b = 0.014$, 95% CI [0.0027, 0.026], see Figure 5.1. When participants saw an answer that differed from their initial response, there was a larger change in pupil size ($M = 0.02$, $SD = 0.16$) compared to when their answer matched the correct answer ($M = 0.01$, SD = 0.015).

Pupil dilation and hindsight bias

We selected the trials in which a hindsight bias was demonstrated and conducted a linear mixed model with hindsight bias as the outcome variable and pupil dilation as the predictor. This revealed a significant positive relationship between hindsight bias and pupil size, $t(506) = 2.26$, $p = .024$, $b = 0.25$, 95% CI [0.036, 0.48], see Figure 5.2.

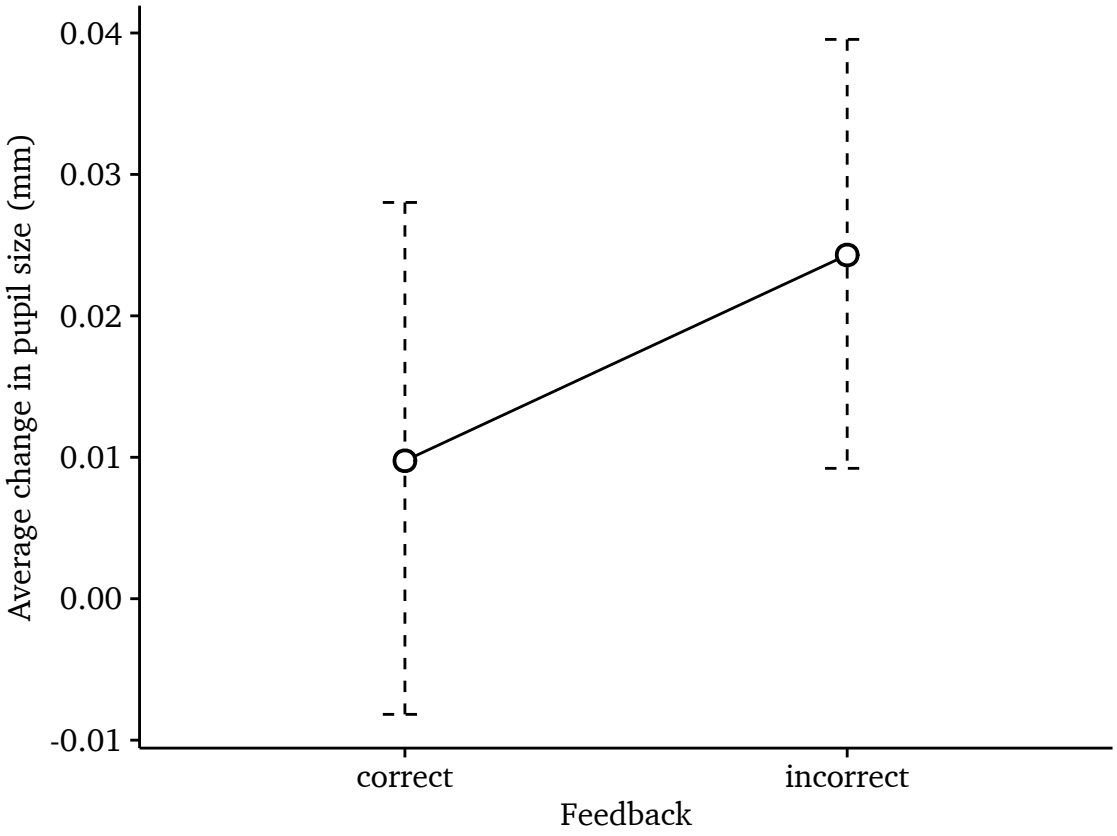

Figure 5.1: Average pupil size change in response to the correct answer. Participants either gave an initial answer that differed from the correct answer (incorrect response) or that matched the correct answer (correct response).

Because of individual differences in the number of trials that showed a hindsight bias we performed an additional analysis on the relationship between pupil dilation and hindsight bias, but only including participants who showed a hindsight bias on more than 10 trials (N = 39). This again revealed a significant positive relationship between pupil dilation and hindsight bias, $t(404) = 2.80$, $p = .0054$, $b = 0.38$, 95% CI [0.11, 0.70]. These results also confirm our hypothesis that pupil size is linked to the amount of hindsight bias following negative feedback and show that this relationship is especially visible when the participant has the tendency to display a hindsight bias.

5.1.3 Discussion

In the present study we successfully demonstrated a link between physiological arousal and compensatory behavior. Greater pupil dilation in response to an unexpected correct answer was associated with more hindsight bias. That is, participants shifted their second answer more towards the factual question's correct answer, relative to their first answer, when they showed a larger physiologi-

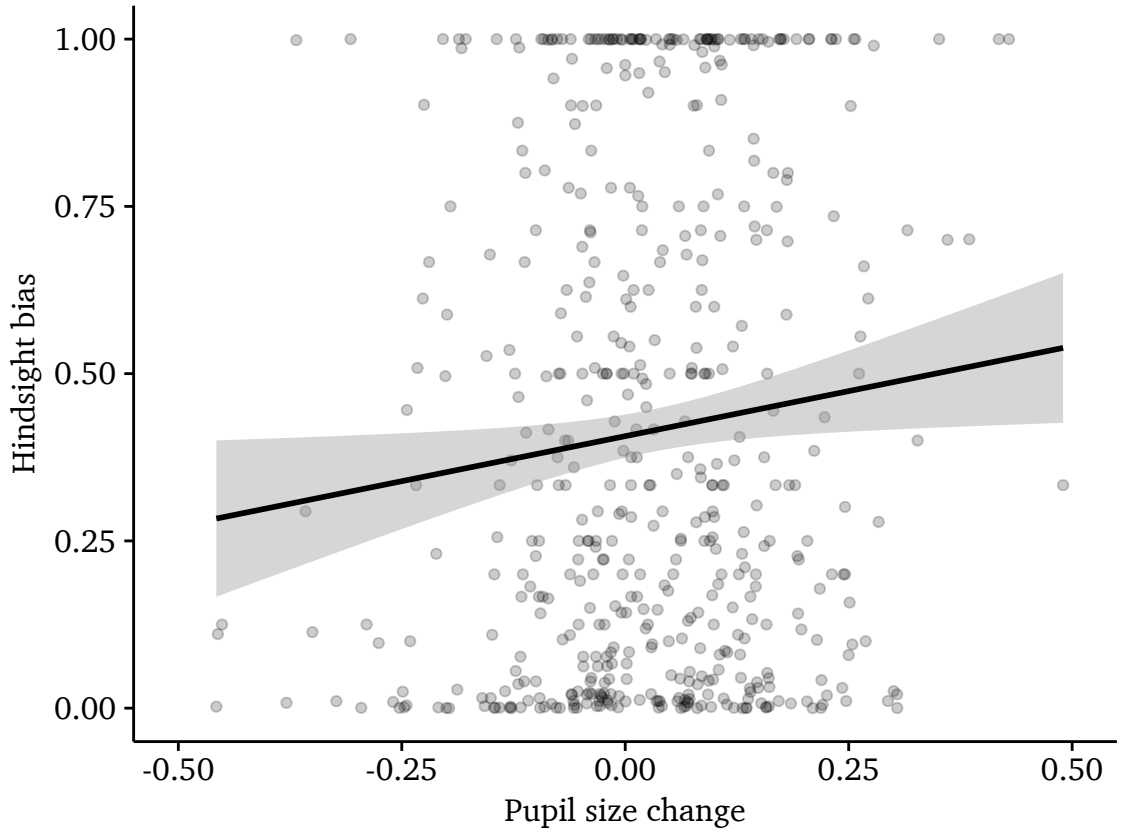

Figure 5.2: Relationship between average pupil size in response to the correct answer and amount of hindsight bias.

cal response to the correct answer of the question. This compensatory response following increased arousal is consistent with the MMM, as well as other threat compensation theories that postulate the causal role of aversive arousal (e.g., Festinger, 1957; Heider, 1958; Janoff-Bulman, 1992; McGregor et al., 2010; Piaget, 2000; van den Bos, 2001)

Contributions of the present study

Two reasons might explain why we were able to demonstrate a link between arousal and compensatory behavior. First, recent developments in eye tracker technology have made this technology exceptionally non-invasive. No electrodes are placed on the skin and nor is the participant severely restrained, as is the case with the majority of physiological assessment tools. Consequently, an eye tracker is less likely to evoke arousal that can interfere with proposed arousal process underlying threat compensation reactions. Additionally, the non-invasive attribute of modern eye trackers make it less likely for participants to attribute any felt arousal to the recording device, which would remove the impetus for a compensation re-

sponse. Second, we used a full within subjects design in which we repeatedly presented participants with a meaning violation (unexpected correct answers) and an opportunity to compensate. This repeated design has the benefit of increased power, as well as a temporal benefit in that there is no significant delay between the meaning violation and the opportunity to compensate. Although research has shown that a short delay can promote a compensatory response in the form of affirmation (e.g., Burke et al., 2010) a relatively long delay can interfere with the need to compensate, as alternative compensatory responses might already take place (e.g., trivialization).

Aside from providing evidence for the role of arousal in responding to meaning violations, the present study also informs research on the hindsight bias phenomenon. As mentioned in the Introduction of this chapter, several processes have been proposed to explain the hindsight bias (Hawkins & Hastie, 1990). Most of the processes involve cognitive processes, such as memory processes and anchoring-and-adjustment processes. However, a motivational account has also been proposed. Ego-enhancing and sense-making motives are positively related to the display of a hindsight bias (Campbell & Tesser, 1983; Fischhoff, 1975; Musch, 2003). Our current integration of the hindsight bias in the MMM, and the supporting data from the present study, offers further evidence that a motivational account can underly the hindsight bias phenomenon.

Limitations and future research

In the present study we used a memory design to measure hindsight bias and found a large variation in displayed hindsight bias between participants. This could be due to the type of hindsight bias design we employed. In the memory design participants provide an answer twice, once before seeing the correct answer or outcome and once after. On the second measure participants are asked to recall their first answer. Importantly, this memory-based design, although effective in demonstrating a hindsight bias, might be relatively less effective in evoking a hindsight bias than other hindsight bias designs such as the hypothetical design (e.g., Campbell & Tesser, 1983; Fischhoff, 1975; Pennington, 1981; Powell, 1988; Wood, 1978, experiment 2), in which participants are asked to respond as if they had not been told the correct answer. After all, a memory task is about recalling a previously reported answer; and when the time-lag is not substantial, people can with relative ease recall their answer. For this reason, the memory design can be improved upon by extending the retention interval between the pre-answer response and post-answer response (e.g., Fischhoff, Beyth, Kahneman, Tversky, & Slovic, 1975; Hell, Gigerenzer, Gauggel, Mall, & Müller, 1988; Pennington, 1981).

In future studies one could have participants first come into the lab for the first part of the experiment (initial answers) and later for the second part (correct answer feedback and post-feedback answers). This would likely increase the likelihood of observing hindsight bias and would constitute a more powerful design.

In our current work we discussed the first and second line of evidence for the role of arousal in compensatory behavior following meaning violations. However, there is also a third line of evidence (Townsend et al., 2013). Aside from meaning violations inducing physiological arousal, and physiological arousal motivating compensatory behavior, compensatory behavior should also reduce the physiological arousal. Elliot and Devine (1994) provided evidence for this third link with a cognitive dissonance paradigm. They found that making a counterattitudinal argument caused psychological discomfort, assessed by a self-report measure of affect, and that the discomfort was reduced following attitude change. This study offers support for the third link, but research on this specific link is scarce. In fact, we are not aware of any studies demonstrating this link using physiological measurements of arousal. There is empirical work showing that reflecting on meaningful values (e.g., religion) prior to a meaning violation serves as a buffer and reduces the aversive arousal following the meaning violation. However, it would be more persuasive if the entire link of meaning violation to aversive arousal to compensatory behavior to reduced aversive arousal can be demonstrated in a single experiment. Using the present study's design, it might be possible demonstrate the entire causal link by having participants again see the correct answers. We predict that instead of the positive relationship between pupil size and hindsight bias found in the present study, a negative relationship between hindsight bias and pupil size should be found.

5.2 Conclusion

We found that the magnitude of hindsight bias was positively related to the size of pupil change in response to seeing the expected and unexpected correct answer to a set of questions. This finding is consistent with the MMM and other threat compensation theories that postulate a role of aversive psychophysiological arousal in producing compensatory behavior following meaning violations. The findings also provide further support for a motivational account of hindsight bias.

Chapter 6

The Social Pain of Cyberball

Decreased Pupillary Reactivity to Exclusion Cues

Based on Sleegers, W.W.A., Proulx, T., & van Beest, I. (2017c). The social pain of Cyberball: Decreased pupillary reactivity to exclusion cues. *Journal of Experimental Social Psychology*, *69*, 187-200. doi:10.1016/j.jesp.2016.08.004

Abstract

A heavily investigated topic in the ostracism literature is the manner in which being ostracized impacts immediate psychophysiological reactivity. Despite the prevalence of this research, it is still unclear which psychological mechanism underlies the immediate reaction to cues of ostracism. According to the social-physical pain overlap theory, cues to ostracism induce a social pain response akin to physical pain due to shared neurological substrates between social and physical pain. Alternatively, it is possible that the immediate reaction to ostracism reflects a conflict detection mechanism responding to a violation of the expectation that one should be socially included. In the present studies, we used pupillometry to distinguish the immediate reaction to ostracism in terms of it primarily representing a pain-oriented response or a conflict-detection response. We continuously measured the pupillary reaction during games of Cyberball, which contained social inclusion events (a ball thrown to the participant) and exclusion events (a ball thrown to another player). We find that participants show a diminished pupillary reaction to cues of exclusion but not to cues of inclusion, consistent with the social-physical pain overlap theory.

Keywords: ostracism; social pain; conflict; pupillometry; physiology

Humans face a variety of existential concerns. One of these concerns is reflected in our ubiquitous need to belong to a group (Baumeister & Leary, 1995). Research has consistently demonstrated that people are greatly affected by the loss of acceptance within a group. Indeed, research on ostracism—i.e., being ignored and excluded—has shown that being socially excluded affects one's sense of belonging and also causes a decrease in self-esteem, control, and meaning in life (Williams & Sommer, 1997). This socially painful experience results in the display of various behaviors aimed at restoring social standing, such as pro-social, or even aggressive behavior (for reviews, see Hartgerink, van Beest, Wicherts, & Williams, 2015; Williams, 2009; Williams & Nida, 2011). Taken together, these studies demonstrate the varied impact of ostracism experiences.

Importantly, the psychological impact of ostracism is measured well after the experience of exclusion. In the case of behavioral studies, this delay serves the research question as it addresses the downstream psychological consequence of the experience of ostracism. In contrast, many self-report studies are focused on people's subjective experience while being ostracized, which brings the validity of retrospective self-assessments into question. This shortcoming has likely—in part—motivated studies assessing the online physiological response to the experience of ostracism. Unlike most self-report based studies, the use of psychophysiological and neuroaffective measures allows for an investigation of the immediate and continuous reaction to ostracism.

Immediate reactions to ostracism: social pain or conflict

One of the most heavily investigated topics in the ostracism literature is how exclusion impacts neural activity. Dozens of studies have been performed in which participants are ostracized while their brain activity was concurrently measured using fMRI technology (for a review, see Cacioppo et al., 2013; Eisenberger, 2012). Many of these studies point towards the involvement of the anterior cingulate cortex (ACC), the anterior insula, and the prefrontal cortex—areas that have been linked to the experience and regulation of emotional distress. Although it is clear from these studies that certain brain areas are active during ostracism, their function remains somewhat ambiguous (Rotge et al., 2015).

Ostracism as social pain

Eisenberger (2015) argues that the involvement of the ACC relates to the experience of social pain, that is, the painful feelings that follow from social rejection, exclusion, or loss. Eisenberger (2012) also cites a substantial portion of

fMRI studies that show correlations between activity in this region and self-report measures of emotional distress, showing that there is a relationship between the ACC and the experience of social pain, ultimately postulating that this experience of social pain relies on the same neural underpinnings that are involved in the experience of physical pain. This idea stems from Panksepp (1998), who proposed that as animals evolved to become more social, they co-opted the same physiological systems used for physical events to monitor social events (i.e., rejection/ostracism), and is now known as the social-physical pain overlap theory (Eisenberger, 2012).

The social-physical pain overlap theory is also supported by other findings in the literature on ostracism. For instance, research has shown that acetaminophen reduces the emotional experience of social pain (Dewall et al., 2010; Vangelisti, Pennebaker, Brody, & Guinn, 2014) and being socially excluded reduces pain sensitivity, both in terms of higher pain thresholds and higher tolerance (DeWall & Baumeister, 2006). It also has been found that physical pain, like social pain, can threaten basic need satisfaction. Riva, Wirth, and Williams (2011) had participants submerge their hands in cold water or be socially excluded and found that both types of pain produced feelings of being excluded. This also negatively affected their sense of self-esteem, control, and a meaningful existence. Moreover, in spite of the impact of social pain on need satisfaction, it is not always found that being ostracized impacts subsequent mood (DeWall & Baumeister, 2006). In fact, when an effect on mood is found, an absolute interpretation of the results in terms of scale midpoint frequently indicates a neutral state of mind, rather than one of emotional distress (Twenge, Catanese, & Baumeister, 2003). This potentially counterintuitive finding has now been interpreted as one consistent with a numbing reaction caused by the body releasing opioids in response to social pain (for an overview of this idea, see MacDonald & Leary, 2005; but also see Gerber & Wheeler, 2009). This conception is consistent with the previously mentioned brain-imaging studies showing that the brain's response to physical pain and social pain involves common underlying neural circuitry.

Ostracism as cognitive conflict

Others, however, do not interpret the functions of the ACC is the same manner, and consequently, do not view ACC activation as primarily indicative of pain, social or otherwise. For example, brain activation in the dorsal ACC could also be understood in terms of its function as a conflict monitor (Botvinick et al., 2001; Botvinick, Cohen, & Carter, 2004; Bush et al., 2000). Conflicts in information processes, resulting from events such as task errors (i.e., providing an incorrect

response during a judgment task), incompatible response tendencies, and trivial expectancy violations (e.g., perceptual anomalies, oddball events) trigger activation in the ACC. Unlike pain, these conflicts in information processing are not experienced as aversive to the extent that social pain is experienced, but rather serve as a benign and frequent signal of any change in the environment, which activates an attentional orienting response (Sokolov, Spinks, Näätänen, & Lyytinen, 2002; Vinogradova, 2001, but see Hajcak & Foti, 2008).

Some researchers have suggested that a conflict detection mechanism could play a role in being ostracized because being ostracized is often unexpected, and therefore constitutes a violation of expectations (e.g., Bolling et al., 2011; Kawamoto, Nittono, & Ura, 2013; Kawamoto et al., 2012). These expectations can result from prior events, such as one's personal history of being included or excluded, or from our ubiquitous need to belong (Baumeister & Leary, 1995), which motivates us to follow the unwritten rule to err on the side of including others in everyday events. Additionally, research has shown that we tend to hold unrealistically positive self-illusions (Taylor & Brown, 1988), which makes the prospect of being excluded subjectively unlikely. For these reasons, we can expect that expectations play a role in the ostracism experience.

In sum, prior research provides evidence that ostracism may evoke two kinds of psychological responses: a pain-based reaction that results from the shared neural circuitry between physical pain and social pain, and a conflict-based reaction that results from a violation of expectations. It is likely that both of these reactions play a role in the response to ostracism, yet it remains unclear whether these processes differ in their temporal dominance. In the current research we investigate which of these possible reactions takes precedence in the immediate response to cues of being ostracized, using an emerging tool in the ostracism literature—pupillometry.

Pupillometry

Pupillary reactivity (i.e., changes in pupil size) can serve as an index of neuroffective arousal. This relationship between pupil size and arousal stems from its association with the locus coeruleus-norepinephrine system (LC-NE). The LC-NE system is believed to play an important role in the regulation of engagement or withdrawal from a task by regulating the release of NE through projections from the LC in the forebrain (Aston-Jones & Cohen, 2005). Research has shown that pupil size correlates with LC activity in monkeys (Joshi et al., 2016; Rajkowski et al., 1993; Varazzani et al., 2015 as cited in Gilzenrat et al., 2010) as well as in humans (Gilzenrat et al., 2010; Murphy et al., 2014), and work by Beatty and

colleagues has demonstrated that pupil reactivity is consistent with LC responses to task-events (Beatty, 1982; Jackson, 1982; Richer & Beatty, 1987). The link between pupil size and the LC-NE system allows researchers to infer a broad range of both cognitive processes (e.g., stimulus identification, working memory maintenance) and emotional processes (e.g., stimulus valence) from the extent of pupil dilation. To illustrate, Bradley et al. (2008) have shown that the pupil dilates more in response to both positively and negatively valenced pictures, compared to neutral pictures. This response co-varies with skin conductance, thereby demonstrating that the sympathetic nervous system can modulate pupillary reactivity.

Importantly, other research has provided evidence that pupil size can also be used to differentially infer cognitive processes such as conflict detection and emotional processes such as pain. For example, the pupil dilates in response to task error and incongruent trials during the Stroop task (Brown et al., 1999; Critchley et al., 2005; Laeng et al., 2011). Similarly, the pupil also responds to violations of expectations (Preuschoff et al., 2011; Proulx, Sleegers, & Tritt, 2017; Raisig et al., 2012, 2010; Sleegers et al., 2015). Sleegers et al. (2015) have shown, for example, that repeated presentations of reverse-colored playing cards (e.g., black Two of Hearts) lead to a sustained and consistent increase in pupil dilation across dozens of trials. In terms of pupillary response to pain, several studies report a change in pupil size correlated with noxious stimulation and self-reported pain (Chapman et al., 1999; Ellermeier & Westphal, 1995; Höfle et al., 2008). The pupil dilates in response to pain stimulation, and importantly, appears to diminish when the subjective experience of pain is lessened, for example, through hypnosis (Walter et al., 2006) or opioids (Connelly et al., 2014). Based on these findings, it seems that pupillary reactivity can serve as an index for physiological arousal in a broad array of cognitive and emotional processes that are likely to play a role during social exclusion.

Pupillometry and social exclusion

Pupillometry is an emerging tool in studies on ostracism, and several studies have used pupillometry in combination with social feedback paradigm (e.g., Silk et al., 2012; Vanderhasselt et al., 2015). In a social feedback paradigm, participants look at photos of other people, who either accept or reject them for a certain task or provide feedback on the desirability or likability of the participant. These studies show that negative social feedback elicits an increase in pupil dilation, thereby demonstrating the involvement of cognitive and/or emotional processes. Importantly, these studies have not linked pupil reactivity to conflict detection and pain processes, specifically.

Although social feedback paradigms involve a painful social event, this paradigm differs in various respects from another commonly used social exclusion manipulation: Cyberball (Williams, Cheung, & Choi, 2000). Cyberball is a ball tossing game in which three or more people toss a ball amongst each other. In a belonging game, participants receive an equal amount of ball tosses as the other players. In an ostracism game, participants receive substantially fewer ball tosses from the other players, often after having received a few ball tosses at the start of the session. This ostracism game consequently comprises a prolonged exclusion event, with the same players in a constant context, in which the presence of exclusion is not immediately noticeable. We believe this paradigm has several benefits over social feedback paradigms. First, Cyberball is a prolonged ostracism event in which several players socially exclude the participant. In contrast with other social exclusion paradigms, Cyberball is a holistic ostracism experience that unfolds over time. This temporal component enables researchers to look at the consequences of being ostracized over time, without intervening factors such as the setting, the people involved, and stimuli presented to the participant, as these remain constant. This allows for a more reliable assessment of a potential numbing response in response to the pain of being excluded. It also allows certain predictions to be made, such as the absence of a numbing response at the start of the Cyberball game. Second, the Cyberball paradigm allows us to investigate people's concrete expectations (e.g., the number of ball tosses they expect), thereby enabling us to investigate the role of expectations in ostracism. The Cyberball paradigm thus enables us to investigate what kind of immediate reaction predominates upon receiving a cue that one is being ostracized.

6.1 Hypotheses

As we have noted, it is unclear what kind of reaction predominates in response to cues of ostracism. A first hypothesis is that the immediate reaction to cues of ostracism primarily reflects social pain, based on the social-physical pain overlap theory of ostracism. If it is indeed the case that the social pain activated by cues of ostracism uses the same neural circuitry as those involved in physical pain, we could observe a numbing response due to the release of endorphins that diminish experiences of pain (MacDonald & Leary, 2005). Given that the pupil can be used both as a proxy for sympathetic nervous system arousal in response to pain (Chapman et al., 1999; Ellermeier & Westphal, 1995), and opioid impact on this response (Connelly et al., 2014), we can predict a decrease in pupil diameter in response to ostracism cues. Additionally, we can predict that this effect

increases over time. As more endorphins are released throughout the course of being excluded, more numbing should take place.

Alternatively, it could be the case that the online reaction primarily reflects a conflict detection process. Ostracism events consist of an initial detection of being ostracized and the subsequent regulation of the emotional distress caused by the ostracism event. Pupillary reactivity can reflect this detection of ostracism in Cyberball due to a probable violation of the expectation that one should be equivalently receiving ball tosses. If the initial response to cues of ostracism is indeed primarily a violation of expectations, we should see an increase in pupil dilation in response to these cues. This is based on the research showing the pupil unilaterally dilates following cognitive conflict induced by a variety of expectancy violations, such as task error and perceptual discrepancies (e.g., Brown et al., 1999; Critchley et al., 2005; Preuschoff et al., 2011; Raisig et al., 2012, 2010; Sleegers et al., 2015). Since it takes some time to realize one is being excluded during a game of Cyberball, we can additionally predict that this increase in pupil dilation appears gradually, once it is clear that each ball toss not received is indeed a signal of being ostracized.

In summary, our investigation of the immediate response to social exclusion could reveal two distinct and divergent outcomes. Either participants show a gradual decrease in pupil size (Hypothesis 1) based on the notion that a growing awareness of being ostracized is painful, which evokes a physiological numbing response consistent with the social-physical pain overlap theory, or a gradual increase in pupil size (Hypothesis 2), based on the notion that the immediate reaction is a detection of conflict—the result of a violation of the expectation that one should be included.

6.2 Study 1

We set out to investigate the immediate reaction to cues of ostracism using pupillometry and the Cyberball paradigm. We looked for evidence to support Hypothesis 1 (gradually diminished pupil diameter in an ostracism game) or Hypothesis 2 (gradually heightened pupil diameter in an ostracism game). In this first study, all participants started with a game of Cyberball in which they were equally included (belonging game), after which they played another game in which they were generally excluded (ostracism game).

6.2.1 Method

Participants and design

Thirty-nine participants participated in this study (6 males; 32 females; 1 unknown). The average age was 19.44 (min: 18; max: 25). Participants were rewarded with course credits or €8. The design was a 2 (Cyberball game: belonging/ostracized) within-subjects design, in which participants were first included and then excluded. We report all data exclusions, all manipulations, and all measures in the study.

Since no prior studies have been conducted using pupil dilation as an outcome measure in the Cyberball paradigm, we are unsure about the anticipated effect size of the main effect of interest (i.e., the effect of ostracism on pupil dilation). Hence, we conducted a power analysis, using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), assuming a small to medium effect size. With a repeated measures design and default settings, this resulted in a required sample size of 10 to 32 participants. This sample size is consistent with prior work using pupil dilation as the measure of interest (e.g., Bradley et al., 2008; Preuschoff et al., 2011).

Procedure

Participants were welcomed into the lab and seated in a cubicle. On-screen instructions informed the participant that they were going to participate in several visualization tasks and that their eyes were going to be measured using an eye tracker. They were also informed they could experience feelings common in everyday life, that their participation was voluntary, and that at any moment they could stop the experiment.

After giving their consent, the test leader made sure the participant was seated about half a meter from the eye tracker display (Tobii T60) and the eye tracker was calibrated using the built-in calibration procedure in Tobii's Extensions for E-Prime 2.0. Hereafter, participants played the first Cyberball game.

After the Cyberball game, two filler tasks followed, in counterbalanced order. These tasks included a painting preference task and a snowy pictures task (for more information on these tasks, see section 8.3 in the Supplemental Materials). Afterwards, participants contacted the test leader who asked them to take a short break before contacting the test leader again to start the second part of the experiment.

The second part was identical to the first part, again starting with the Cyberball task, followed by the painting preference task and snowy pictures task. Differ-

ent than the first part, after the filler tasks, participants were also presented with a fundamental needs questionnaire that was followed by demographic questions and checks. These were administered on average about 5 min after the Cyberball game. They were then debriefed and thanked for their participation.

Materials

The experiment was designed and administered in E-prime 2.

Cyberball game. Cyberball was presented as a mental visualization game—a common instruction in the Cyberball paradigm. Participants were asked to take a minute and to imagine actually playing a ball tossing game with other people. This was followed by questions about the scene they imagined, such as the color of the ball and where the game takes place. Importantly, we also asked how many ball tosses the participant expected to receive. During these questions information about the game was displayed on the screen. This information included the number of players (3) and the number of total ball tosses (90). After this, the game 'connected' to the other players, at which point the participant saw two avatars with common male and female names representing the other players, named Maarten (left player) and Anne (right player) in the inclusion condition and named Lotte (left player) and Thomas (right player) in the exclusion condition. Note that in each game we used common male and female names and that we also changed the order in which the gender was associated to the position of the left or right avatar (also see Figure 6.1).

Cyberball event. A Cyberball event was defined as a ball toss, which consists of three components: a baseline period (500 ms), the ball toss animation (900 ms), and the period during which the computer or participant decides whom to toss the ball to (a varying period). The start of the ball toss animation was denoted at the start of an event (t = 0). To assure a reliable assessment of pupil size, we extended the standard duration of the Cyberball game to 90 ball tosses in total. Before each ball toss there was a randomly varying period during which the computer (900 to 4300 ms) or participant (determined by participant) considered whom to toss the ball to. This was followed by an animation of the ball being tossed to the selected player. Each ball toss was either to the player (an inclusion event) or not (an exclusion event). During the first game, the participant was equally included (belonging game), thus receiving a total of 30 out of 90 ball tosses during the entire game. In the second game, the player was generally excluded and received only 10 out of the 90 ball tosses (ostracism game). Note that in

both the belonging game and the exclusion game, participants experienced both inclusion and exclusion events. This allowed us to directly compare exclusion events across both a belonging and ostracism game. And, also to directly compare inclusion events across both a belonging and ostracism game.

Ball tosses were randomly determined and could take place throughout the game, thereby assuring that the participant remained involved in the task and also remained unsure about what to expect for each given ball toss. The participant could click on another player's avatar to toss the ball to that player.

We also added a visual frame around the players (see Figure 6.1). This extra object can divert the participant's attention from the game and allowed us to investigate where people may divert their attention to during the Cyberball game.

Pupillometry. Pupil data was collected using a Tobii T60 eye tracker (Tobii, Stockholm, Sweden). The Tobii T60 is integrated in a 17″ TFT monitor and records at a rate of 60 Hz. Each measurement has a validity indication that ranges from 0 (the system is certain that all data belongs to the particular eye) to 4 (gaze data is missing or incorrect). Only recordings with a validity score of 0 were used.

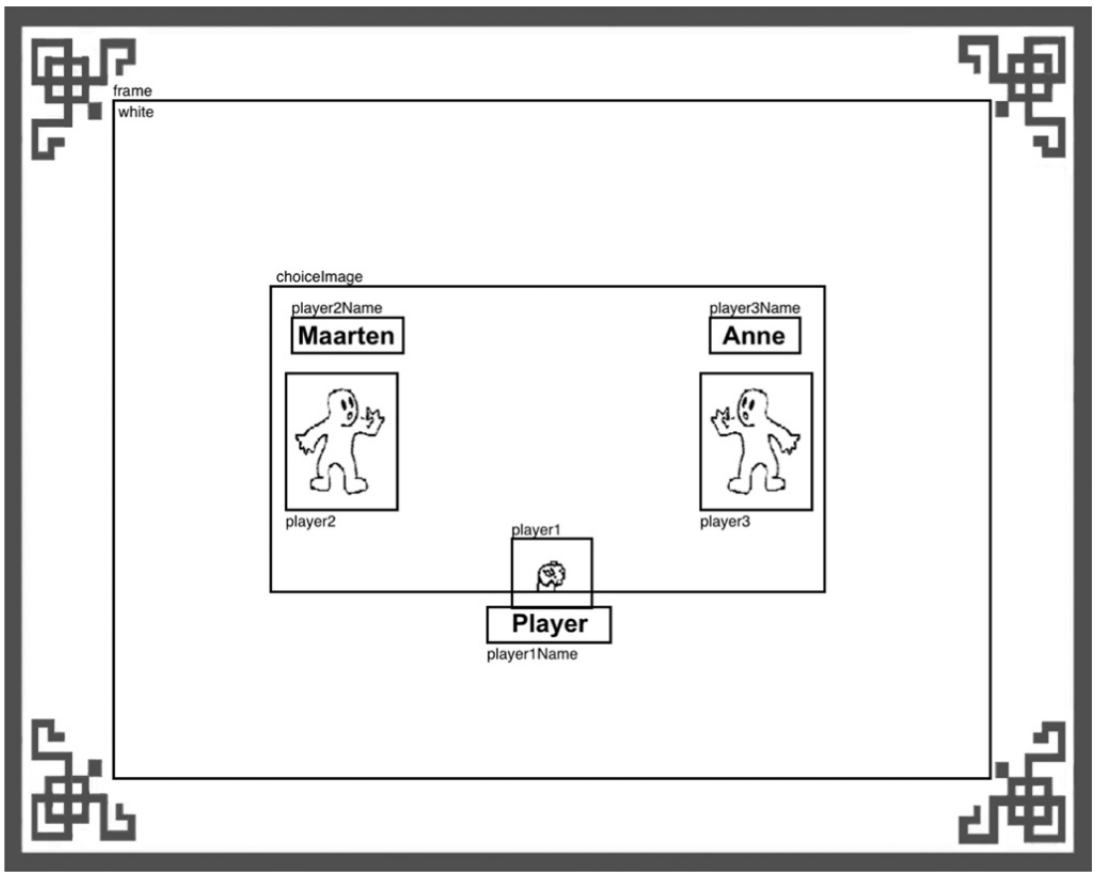

Figure 6.1: A depiction of the Cyberball game with its various objects that served as regions of interest.

Pupil size from each eye were averaged together to create a single pupil size score and filtered with a modified repeated median filter (outer width: 25, inner width 15) using the 'robfilter' package (Fried et al., 2014) in R (R Core Team, 2016). Because the Cyberball task is a black and white task with a continuous sequence of events (i.e., no discrete presentations of stimuli) no light reflex period was present. Missing data (e.g., blinks) were corrected with linear interpolation using the 'zoo' package (Zeileis & Grothendieck, 2005). Hereafter, the pupil size was controlled for baseline differences by subtracting the average pupil size during a 500 ms pre-event (Beatty & Lucero-Wagoner, 2000) period from the subsequent pupil measurements. Events with more than 25% missing data were removed (6.75%), resulting in an average of 84.26 usable trials in the inclusion game and 83.54 in the exclusion game. Additionally, we also used the pupil data to investigate what people looked at on the screen by defining regions of interest (e.g., the players, their names, the area in which the game took place; see Figure 6.1). This allowed us to rule out alternative explanations such as participants looking away from the screen and becoming more disinterested in the game as a function of being ostracized or included.

Fundamental needs and mood. The fundamental needs and mood questionnaire consisted of 16 items that measured the participant's need for belonging, self-esteem, meaningfulness, control ($\alpha = .84$), and mood ($\alpha = .87$) after the Cyberball game (van Beest, Williams, & van Dijk, 2011). Example are: "During the game I had the sense that I belonged", "I had the feeling that I had control over the game", and "I felt tense during the game". The questions were answered on a 7-point Likert scale, ranging from 1 ('Completely disagree') to 7 ('Completely agree') and presented in a fixed order.

Checks and demographics. Before both the belonging and ostracism games we asked participants how many ball tosses they expected to receive (0-90). This question allowed us to assess our assumption that all participants would expect to receive an equal number of ball tosses prior to playing the game, and exclude outliers who did not expect to receive a fair number of ball tosses. After all, if participants expect to receive no ball tosses prior an ostracism game then expectations are not violated when this happens. Alternatively, if participants expect an equal number of ball tosses prior to a belonging game expectation are not violated when this happens.

At the end of the experiment, we also assessed age, gender, whether participants had participated in a Cyberball task before (yes/no), whether they realized

the other players were not real (yes/no), and what they thought the research questions were (open ended).

6.2.2 Results

Expectations

Before playing the first Cyberball game (belonging), participants reported expecting to receive an average of 31.46 (SD = 16.54) ball tosses, compared to an average of 29.77 (SD = 12.72) ball tosses before playing the second Cyberball game (ostracism). This later average does not differ significantly from expecting an equal number of ball tosses (30 ball tosses, $t(38) = 0.11$, $p = .910$), 95% CI [25.65, 33.89], $d = 0.02$, nor from the average expected number of ball tosses before the belonging Cyberball game, $t(38) = 0.98$, $p = .335$, 95% CI [-1.81, 5.20], $g_{av} = 0.11$. A total of four participants expected to receive only a few ball tosses (20 or fewer) and were removed from the data analysis, leaving 35 participants.

Gaze durations

We calculated what percentage of time the participants spent looking at each region of interest (ROI) during each of the two Cyberball games and compared these percentages for each ROI with paired t-tests. The findings are displayed in Table 6.1. To see whether participants did not look away from the Cyberball events, we looked at the time spent in the ROIs surrounding the players. During the ostracism Cyberball game, participants looked significantly more at the white area between the frame and the players and marginally significantly more at the frame surrounding the screen. These results point at participants looking more at the fringes of the screen. Notably, there was no significant difference in the amount of missing data, indicating that participants did not look away from the screen during the ostracism experience compared to the belonging experience to any significant extent.

Pupillometry

Exclusion events. To test our main hypotheses, we first looked at the events during which the participant did not receive the ball. In the belonging Cyberball game, these events do not necessarily represent an ostracism cue, as not receiving the ball is part of tossing a ball to each player equally. However, in the ostracism Cyberball game, where these events are more frequent, these events do represent an ostracism cue because they show one is not being included to the same extent

as the other player. On these events we performed a repeated measures GLM analysis with Cyberball game (belonging/ostracism) and event period (0 to 2000 s, in 100 ms bins) as within-subject factors, with the average pupil size as the dependent variable (see Figure 6.2). This revealed a significant main effect of the Cyberball game, $F(1, 34) = 14.29$, $p = .001$, $\mu_p{}^2 = 0.296$. There was a smaller pupil size increase upon not receiving a ball in an ostracism Cyberball game ($M = 0.026$ mm, $SE = 0.005$, 95% CI [0.017, 0.036]) compared to not receiving a ball in a belonging game ($M = 0.046$ mm, $SE = 0.007$, 95% CI [0.032, 0.060]). There was also a main effect of the event period, $F(20, 15) = 13.35$, $p < 0.001$, $\mu_p{}^2 = 0.947$. Pupil size increased after a ball was tossed to another player, and decreased after about 600 ms. There was no significant interaction effect, $F(20, 15) = 1.13$, $p = .412$, $\mu_p{}^2 = 0.601$.

Inclusion events. We repeated the same analysis for the events that did have the participant as the recipient of a ball toss. The total duration of each event was shorter due to the fact that participants more quickly tossed a ball to another player upon receiving it than the other players were programmed to do, leading to an event period of 0 to 1600 ms. A GLM with Cyberball game (belonging/ostracism) and event period (0 to 1600) did not yield a main effect of the Cyberball game, $F(1, 34) = 0.002$, $\mu_p{}^2 < 0.001$. It did reveal an effect of event period, $F(16, 19) = 14.94$, $p < 0.001$, $\mu_p{}^2 = 0.926$, and a significant interaction effect, $F(16, 19) = 4.24$, $p = .002$, $\mu_p{}^2 = 0.781$, see Figure 6.3. In both the ostracism

Table 6.1: Percentage of time spent looking at each region of interest, during a belonging or ostracism Cyberball game in Study 1.

ROI	**Inclusion**		**Exclusion**		***t***(34)	***p***
	M	*SD*	*M*	*SD*		
Frame	0.31	0.60	1.83	5.02	1.782	.084
Player 1	7.07	3.48	4.97	2.97	-0.235	.815
Player 1 name	0.38	0.38	1.03	0.78	-3.432	.002
Player 2	29.00	5.42	30.66	6.69	4.722	<.001
Player 2 name	0.60	0.66	0.95	1.19	1.902	.066
Player 3	30.38	7.41	28.38	7.79	2.921	.006
Player 3 name	0.63	1.01	0.97	1.58	-1.887	.068
White area	0.47	0.79	1.08	1.64	2.575	.015
Playing field	21.18	5.44	20.42	6.65	2.702	.011
Missing data	9.98	8.75	9.71	5.55	-0.748	.459

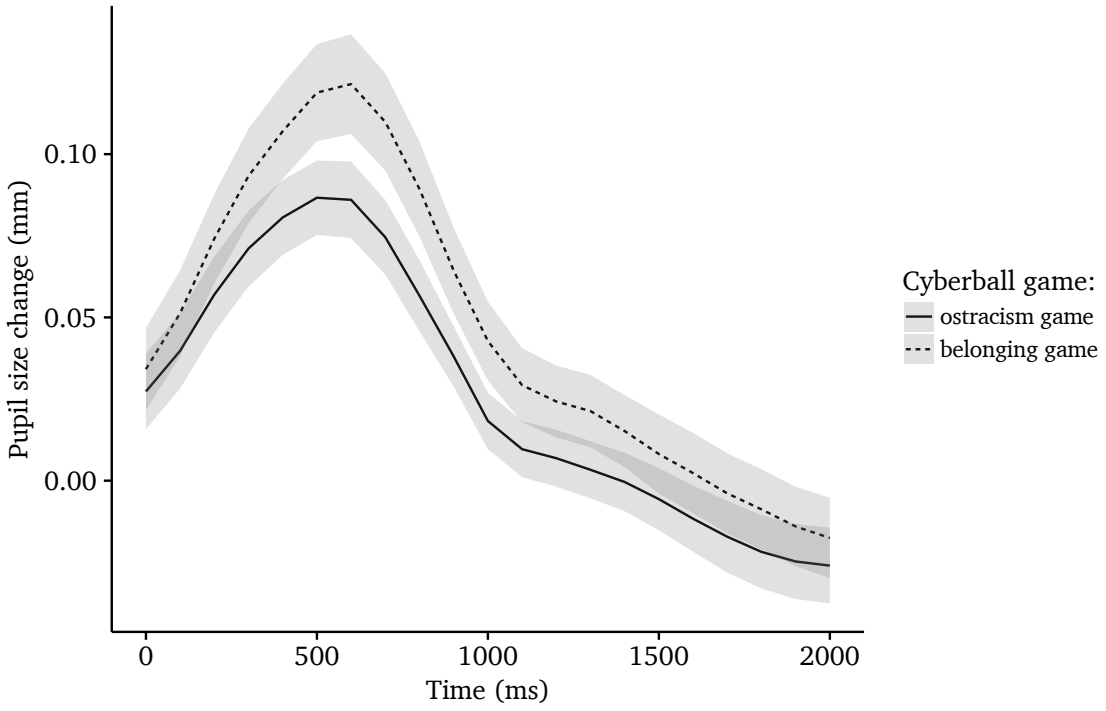

Figure 6.2: Change in pupil size during exclusion events in two games of Cyberball—first a belonging game, followed by an ostracism game (Study 1).

and belonging Cyberball games, the pupil size increased rapidly upon seeing the ball being tossed to the participant, but slowly decreased soon after when playing a belonging game, while it remained somewhat level in an ostracism game.

Effect across the duration of a Cyberball game. Above we analyzed the overall pupillary change in response to both inclusion and exclusion events (i.e., across all ball tosses). We anticipated that it might take participants some moments to realize that they are being excluded, so the decrease in pupil size should be more pronounced as a function of the time that has passed playing the Cyberball game. Additionally, this should not be the case in the belonging game. Hence, we performed two planned comparisons. We combined the average pupil change into three event bins of 30 events each and conducted a two 3 (Cyberball period: event 1 to 30/event 31 to 60/event 61 to 90) repeated-measures analyses). This revealed an effect of event bin during the ostracism game, $F(2, 68) = 9.50$, $p < 0.001$, $\mu_p{}^2 = 0.218$, but not during the belonging game, $F(2, 66) = 0.72$, $p = .491$, $\mu_p{}^2 = 0.021$.[1] Additionally, we conducted three separate *t*-tests to compare

[1]We also performed a 2 (Cyberball condition: belonging/ostracism) × 3 (Cyberball period: event 1 to 30/event 31 to 60/event 61 to 90) repeated-measures GLM to test for a possible interaction effect. This revealed a main effect of ostracism, $F(1, 33) = 12.80$, $p = .001$, $\mu_p{}^2 = 0.279$ and of event bin, $F(2, 66) = 5.60$, $p = .006$, $\mu_p{}^2 = 0.145$, but not a significant interaction, $F(2, 32) = 1.57$, $p = .223$, $\mu_p{}^2 = 0.089$.

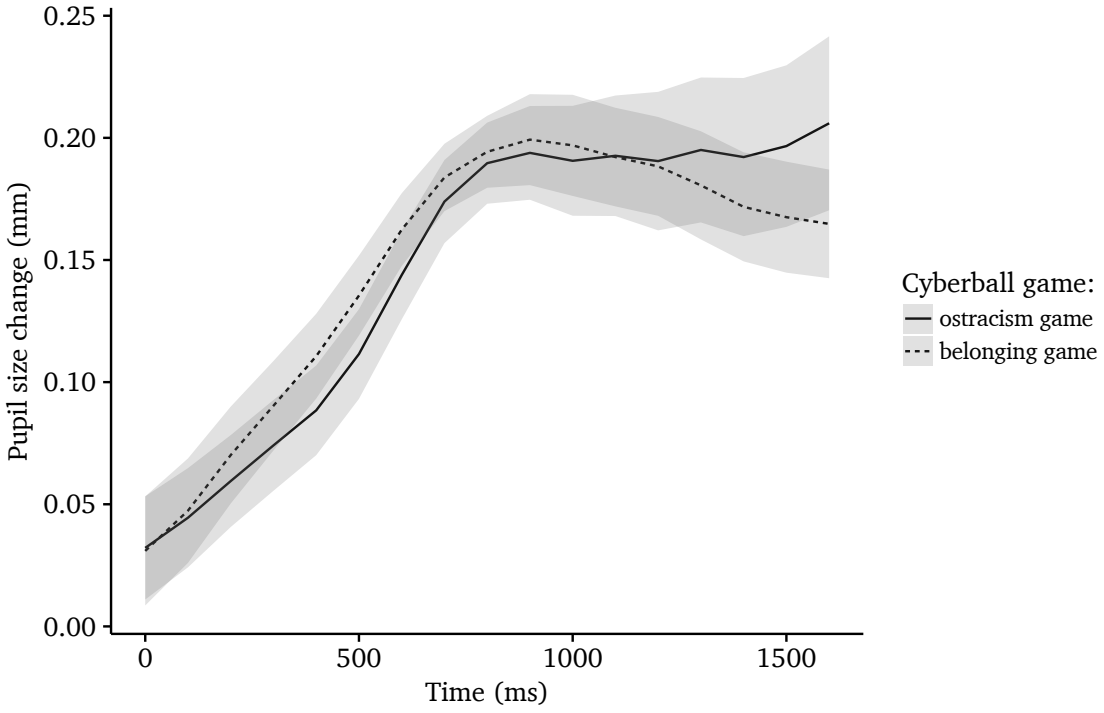

Figure 6.3: Change in pupil size during inclusion events in two games of Cyberball—first a belonging game, followed by an ostracism game (Study 1).

the average pupil size change in response to exclusion events between the two Cyberball games, per event bin. During the first 30 ball tosses, there was no statistically significant difference between the belonging game and the ostracism game, $t(34) = 1.50$, $p = .151$. In the later two bins (events 31 to 60 and events 61 to 90), the difference was statistically significant, $t(34) = 3.48$, $p = .001$ and $t(33) = 2.29$, $p = .028$, respectively. These results are consistent with Hypothesis 1; we see that after the first bin there is a substantial decrease in average pupil size in response to an exclusion event during the ostracism Cyberball game ($M_{\text{event 1 to 30}} = 0.088$ mm, $SD_{\text{event 1 to 30}} = 0.040$; $M_{\text{event 31 to 60}} = 0.060$ mm, $SD_{\text{event 31 to 60}} = 0.036$, $M_{\text{event 61 to 90}} = 0.049$ mm, $SD_{\text{event 61 to 90}} = 0.013$), while it remains constant during the belonging Cyberball game ($M_{\text{event 1 to 30}} = 0.096$ mm, $SD_{\text{event 1 to 30}} = 0.047$; $M_{\text{event 31 to 60}} = 0.081$ mm, $SD_{\text{event 31 to 60}} = 0.051$; $M_{\text{event 61 to 90}} = 0.085$ mm, $SD_{\text{event 61 to 90}} = 0.059$).

Fundamental needs

To test whether the ostracism manipulation induced self-reported threat to needs and decrease in mood, *t*-tests were performed between the average scores of the fundamentals needs subscales and the mid-point of the response-scale (4). Results show that all but mood differed from the mid-point (see Table 6.2) in a

manner consistent with feeling ostracized.

Checks

Six participants (15.4%, 1 missing) reported having experience with the Cyberball paradigm[2] and 19 participants (47.5%, 2 missing) did not believe the participants they were playing with were real participants.

Table 6.2: Difference average fundamental needs scale and subscales from midpoint and descriptives from Study 1.

Scale	**Statistics**		
	$t(34)$	p	M (SD)
Belonging	-14.05	<.001	1.91 (0.88)
Control	-11.28	<.001	1.97 (1.06)
Self esteem	-2.01	.052	3.41 (1.72)
Meaning	-4.18	<.001	3.11 (1.27)
Mood	0.26	.798	4.05 (1.31)
All combined	-3.07	.004	3.44 (1.08)

6.2.3 Discussion

We found that participants showed a gradually decreased pupillary reaction to exclusion events in a game of Cyberball in which they were generally ostracized (ostracism game), but not when they were equally included (belonging game). For inclusion events, no such difference in pupillary dilation was observed relative to either version of the game. Additionally, we found that mood was not affected by being excluded. These findings are in support of Hypothesis 1. That is, the results are consistent with a numbed reaction towards exclusion events that fits with the social-physical pain overlap theory. The findings do not support Hypothesis 2, or a conflict-based reaction due to a violation of the expectation that one should be equally included.

6.3 Study 2

In Study 2 we continued to test the two hypotheses by including a manipulation to further disentangle our two competing hypotheses. For this purpose,

[2]Excluding these participants did not substantially impact the results (e.g., the effect of ostracism on pupil size during exclusion events remained, $F(1, 27) = 8.66$, $p = .007$).

we selected value affirmation. Recent research has shown that beliefs, such as religious convictions, can serve as a buffer and mute neurophysiological activity in response to expectancy violations (Inzlicht et al., 2009; Inzlicht & Tullett, 2010; Sleegers et al., 2015). For example, Inzlicht and Tullett (2010) primed participants with their religious affiliation before performing a Stroop task and subsequently found decreased activity in the ACC as measured by error related negativity (ERN), compared to those who were not primed. Similarly, Sleegers et al. (2015) found that participants who strongly affirmed their moral beliefs decreased pupillary dilation in response to reverse-colored playing cards. These findings indicate that the affirmation of values can mute the physiological response to cognitive conflicts following from expectancy violations such as task error and perceptual anomalies. In contrast, studies have shown that self-affirmation has no buffer effect on the negative effects of ostracism (Dingwall, 2011; Howell & Shepperd, 2017; and see Williams, 2009). Consequently, if the pupillary reactivity in response to cues of ostracism similarly reflects a conflict detection process, then we should expect a muted pupillary response as a function of value affirmation, which would support the hypothesis that pupillary reactivity following ostracism cues reflects an underlying conflict detection mechanism. Alternatively, if we fail to find an effect of value affirmation and again find a decreased pupillary reactivity in response to ostracism cues, this would constitute a further lack of support for a conflict detection hypothesis.

We also changed the design of Study 2 to address some methodological trade-offs present in Study 1. In Study 1, participants always played the belonging game first, and the ostracism game second. To address potential ordering effects, we changed this order in Study 2 by having participants first play the ostracism game first and then the belonging game. Moreover, in order to better track the self-reported effects of our ostracism manipulation, we administered the fundamental needs and mood questionnaire twice, after each game, together with an additional questionnaire that measures anxiety caused by a state of uncertainty. This was added to gain more insight into the self-reported consequences of the ostracism experience. Previous research has shown that anxiety is an important construct related to how people cope with uncertainty arousing experiences (e.g., McGregor et al., 2013), with uncertainty likely to play a role in ostracism as there is often an initial an element of uncertainty. We can therefore expect that being ostracized causes an increase in anxious uncertainty. The fundamental needs and mood scale does not include any items related to felt anxious uncertainty, so we extended our design by adding a questionnaire specifically designed to measure this possibility.

6.3.1 Method

Participants and design

Seventy-one participants participated in this study (14 males; 56 females; 1 unknown). The average age was 19.57 (min: 17; max: 24). Participants were rewarded with course credits. The design was a 2 (Cyberball game: belonging/ostracism) x 2 (values prime: present/absent) mixed design with ostracism as a within-subjects factor and the prime as a between-subjects factor. Participants were excluded in the first game and equally included in the second game. A power analysis on a between subjects test for the effect of the values prime on pupil dilation revealed a required sample size ranging between 34 (medium effect) and 122 (small effect).

Procedure

The procedure was identical to the first study, except that half the participants were primed with a questionnaire on various controversial topics immediately prior to the first Cyberball game, which allowed them to affirm their values. This questionnaire was framed as being part of a different experiment. After filling in this questionnaire, participants contacted the test leader and the procedure identical to Study 1 would commence.

Materials

The same material was used as in Study 1, except for some key differences noted below.

Pupillometry. Pupil data was prepared identical to that in Study 2. Events with more than 25% missing data were removed (3.17%), resulting in an average of 86.34 usable trials in the inclusion game and 87.90 in the exclusion game.

Values prime. To buffer the potential negative impact of ostracism, half of the participants were presented with a values prime before the start of the experiment. To this end, participants indicated to what extent they agreed or disagreed with various controversial topics (e.g., gay rights, nuclear energy, multiculturalism; see Sleegers et al., 2015).

Anxious uncertainty. Anxious uncertainty was measured after each Cyberball game, after the administration of the fundamental needs (after exclusion: α = .71, after inclusion: α = .78) and mood questionnaire (after exclusion: α = .88,

after inclusion: $\alpha = .66$). Participants were asked to what extent they felt certain emotions related to anxious uncertainty (e.g., conflicting, concerned, nervous) on the same 7 point Likert scale (after exclusion: $\alpha = .87$, after inclusion: $\alpha = .81$), following McGregor, Zanna, Holmes, and Spencer (2001) and McGregor et al. (2010).

Checks and demographics. We again assessed how many ball tosses participants expected to obtain prior to playing both Cyberball games and used this to exclude outliers. We also assessed age, gender, and experience with similar tasks. This time, we did not assess whether participants realized that the other players were fake. We feared that presentation biases likely motivated many participants to indicate that that they were not fooled, regardless of what they believed over the course of the experiment.

6.3.2 Results

Expectations

Before playing the ostracism Cyberball game, participants reported expecting to receive an average of 29.48 ($SD = 7.16$) ball tosses. This average does not differ significantly from expecting an equal number of ball tosses (30 ball tosses, $t(65) = 0.584$, $p = .561$, 95% CI [27.72, 31.25], $d = 0.07$). This time, however, expectations did change between conditions. Before the belonging Cyberball game, participants expected on average 24.54 ($SD = 10.4$) ball tosses. This was a significant change from the expectations before the ostracism Cyberball game, $t(63) = 3.389$, $p < .001$, 95% CI [-8.16, -2.62], $g_{av} = 0.55$, as well as significantly different from expecting an equal number of ball tosses (30), $t(66) = 4.30$, $p < .001$, 95% CI [22.00, 27.07], $d = 0.48$. There were also nine participants who already expected to be excluded at the start of the experiment (expected to receive 20 ball tosses or less). They were subsequently removed from data analysis, leaving 63 participants.

Values prime

To investigate the effect of the values prime buffering the impact of ostracism cues on pupillary reactivity, and find support for Hypothesis 2, we looked at whether the presence or absence of the values prime impacted the average pupil change during exclusion events in the ostracism Cyberball game. The average pupil change in the values prime condition was 0.024 ($SE = 0.005$, 95% CI [0.014, 0.034]) while the average pupil change in the no values prime condition

was 0.021 (SE = 0.005, 95% CI [0.011, 0.031]). A GLM-repeated measures with the values prime as a between-subjects factor and event period (0 to 2000, in 100 ms bins) as within-subject factor revealed an effect of event period, $F(20, 36)$ = 18.70, $p < 0.001$, $\mu_p{}^2 = 0.912$, but no main effect of the prime, $F(1, 55) = 0.23$, $p = .634$, $\mu_p{}^2 = 0.004$, nor a significant interaction with event period, $F(20, 36)$ = 1.50, $p = .348$, $\mu_p{}^2 = 0.390$. Hence, the values prime did not seem to have an impact on the average pupil change.

Additionally, all pupil analyses from the next sections were performed with the presence or absence of the prime as a between-subjects factor. These analyses also failed to reveal a main effect or show any interactions between the prime and the variables of interest (all Fs < 1). As a result, both the prime condition and the no prime conditions were collapsed to increase the sample size and therefore achieve higher power.

Gaze durations

We again looked at whether participants maintained their attention throughout the Cyberball games by recording where they looked at during each game (see Table 6.3). We found a difference in the amount of missing data between conditions, $t(56)$ = -1.97, $p = .054$, in that there was more missing data during the belonging condition than during the ostracism condition. Participants also spent more time looking at the frame in the ostracism condition compared to the belonging condition, $t(56) = 2.82$, $p = .007$. Taken together, these results point at

Table 6.3: Percentage of time spent looking at each region of interest, during a belonging or ostracism Cyberball game in Study 2.

ROI	**Inclusion**		**Exclusion**		$t(56)$	p
	M	*SD*	*M*	*SD*		
Frame	0.32	0.43	0.72	0.98	2.82	.007
Player 1	6.59	3.38	5.72	3.70	-1.77	.082
Player 1 name	0.55	1.74	0.57	0.74	0.072	.943
Player 2	28.80	6.86	27.53	7.31	-1.31	0.197
Player 2 name	0.83	1.55	0.93	1.17	0.46	.648
Player 3	30.70	5.00	32.24	6.41	2.06	.044
Player 3 name	0.74	1.31	0.71	0.60	-0.14	.889
White area	0.87	3.25	0.98	1.95	0.50	.618
Playing field	21.81	6.24	23.09	8.71	1.21	.229
Missing data	8.77	5.40	7.51	3.23	-1.97	.054

some disengagement of participants during the belonging game, while participants remained attentive during the ostracism game.

Pupillometry

Exclusion events. Identical to Study 1, we investigated pupillary reactivity during events in which the ball was not thrown to the participant. A repeated measures GLM analysis was performed with Cyberball game (ostracism/belonging) and event period (0 to 2000 s, in 100 ms bins) as within-subject factors, with average pupil change as the dependent variable. This did not reveal a main effect of the Cyberball game, $F(1, 56) = 0.932$, $p = .338$, $\mu_p{}^2 = 0.016$. It did reveal an effect of event period, $F(20, 37) = 19.32$, $p < 0.001$, $\mu_p{}^2 = 0.913$, and an interaction effect between the Cyberball game and event period, $F(20, 37) = 1.92$, $p = .042$, $\mu_p{}^2 = 0.510$.

Visual inspection (see Figure 6.4) showed that the pupil size change in the ostracism game is smaller than in the belonging game at the start of a ball toss, but reverses after about 700 ms. In fact, a separate analysis on the initial event period reveals a significant difference, $F(1, 56) = 4.02$, $p = .05$, $\mu_p{}^2 = 0.067$. Pupillary reactivity to a ball toss of which participants were not the receiver was smaller in an ostracism game ($M = 0.063$ mm, $SE = 0.003$, 95% CI [0.056, 0.070])

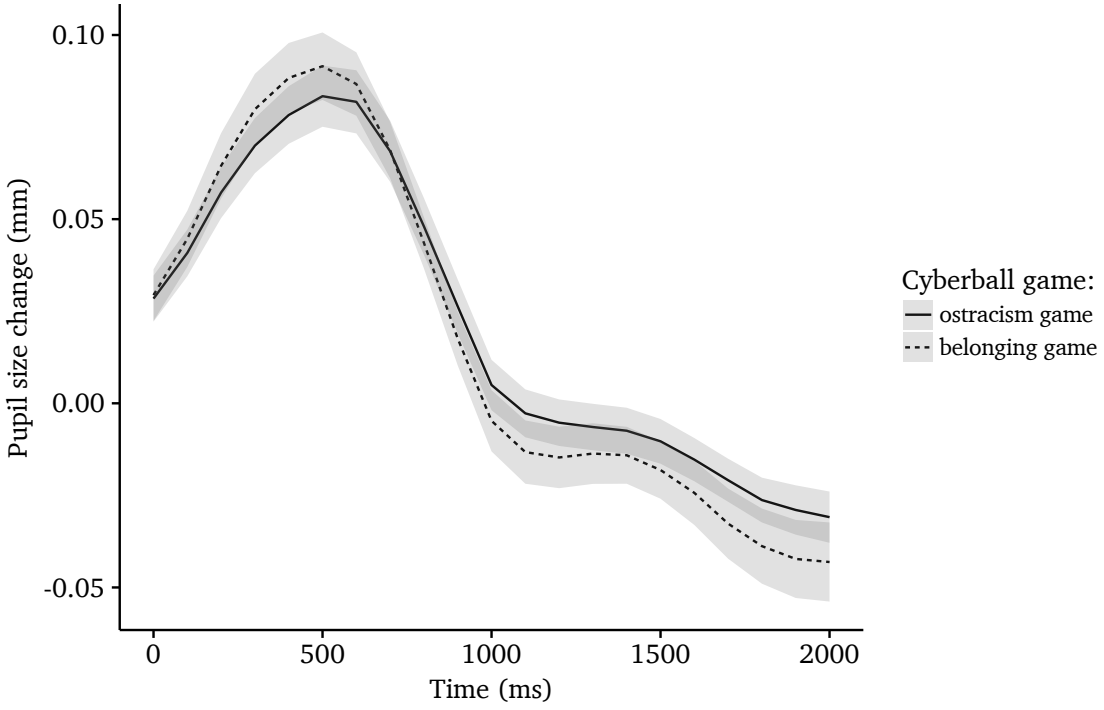

Figure 6.4: Change in pupil size during exclusion events in two games of Cyberball—first an ostracism game, followed by a belonging game (Study 2).

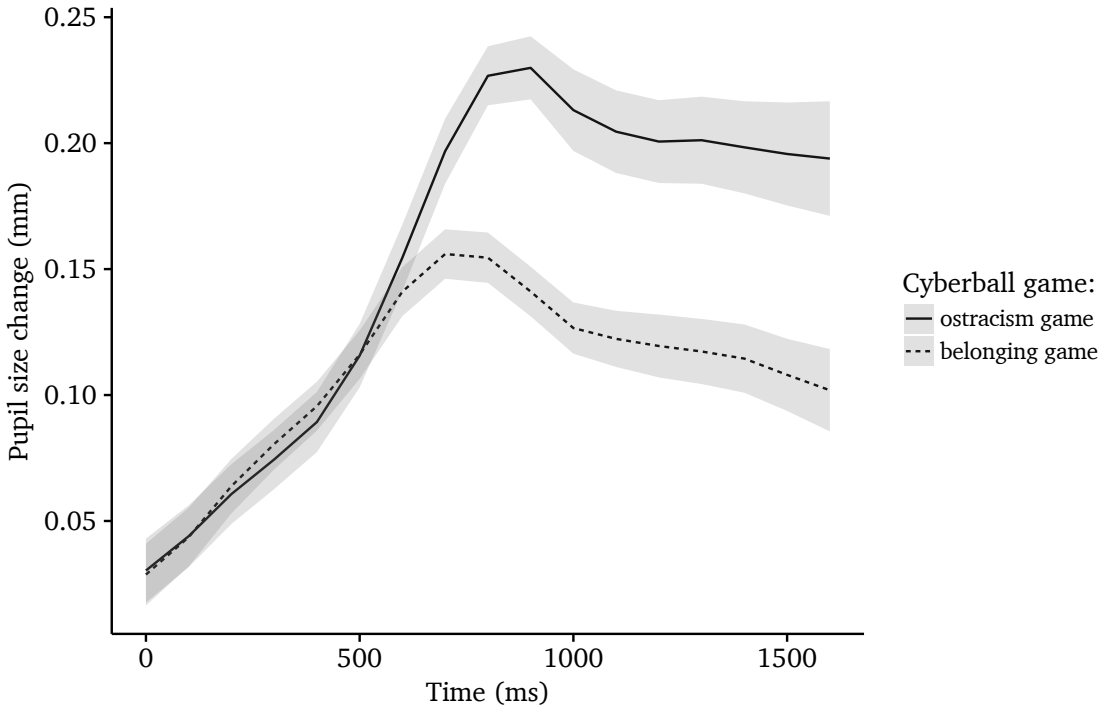

Figure 6.5: Change in pupil size during inclusion events in two games of Cyberball—first an ostracism game, followed by a belonging game (Study 2).

compared to a belonging game (M = 0.069 mm, SE = 0.004, 95% CI [0.062, 0.077]). After this moment, the pupil size in the ostracism game seems to remain larger than in the belonging game, and a separate analysis across this event period confirms a significant effect of the Cyberball game, $F(1, 56) = 4.00$, $p = .05$, $\mu_p^2 = 0.067$. The pupil change is now larger in the ostracism game condition (M = -0.014 mm, SE = 0.004, 95% CI [-0.022, -0.005]) than in the belonging game condition (M = -0.02 mm, SE = 0.006, 95% CI [-0.035, -0.012]).

Inclusion event. We again repeated the same analysis for events in which the participant received the ball: A repeated measures GLM analysis with Cyberball game (ostracism/belonging) and event period (0 to 1600 s, in 100 ms bins) as within-subject factors, with average pupil change as the dependent variable. This revealed a main effect of the Cyberball game, $F(1, 55) = 61.11$, $p < 0.01$, $\mu_p^2 = 0.526$, an effect of event period, $F(16, 40) = 44.55$, $p < 0.001$, $\mu_p^2 = 0.947$, as well as an interaction, $F(16, 40) = 11.05$, $p < 0.001$, $\mu_p^2 = 0.815$, see Figure 6.5. Pupil size increased quickly in the first second, but increased even more in the ostracism game, after which the pupil size slowly decreased in both conditions.

Effect across the duration of a Cyberball game. We again tested for an effect of time across the entire Cyberball game, as it might take participants some moments

Table 6.4: Difference in fundamental needs, its subscales and mood, and the anxiety questionnaire between the belonging and ostracism condition in Study 2.

Scale	**Statistics**		**Inclusion**	**Exclusion**
	$t(56)$	p	*M (SD)*	*M (SD)*
Belonging	27.20	<.001	6.10 (0.66)	1.98 (0.67)
Control	15.82	<.001	5.10 (1.00)	2.01 (0.91)
Self esteem	11.53	<.001	5.52 (0.76)	3.20 (1.23)
Meaning	10.98	<.001	5.82 (0.79)	4.29 (1.34)
Mood	11.54	<.001	5.82 (0.52)	4.29 (0.91)
Above combined	16.66	<.001	5.74 (0.48)	3.63 (0.74)
Anxious uncertainty	4.50	<.001	1.80 (0.57)	2.07 (0.72)

to realize they are being excluded. Given the findings that revealed a difference between being included and excluded in pupillary reactivity in the initial phase of an event (0-700 ms) and the later phase of an event, we specifically focused on this event period across the duration of a Cyberball game. Identical to Study 1, we performed two planned comparisons, which revealed an effect of event bin during both the ostracism game, $F(2, 112) = 36.39$, $p < 0.001$, $\mu_p{}^2 = 0.394$, and the belonging game, although the effect is smaller during the belonging game, $F(2, 112) = 9.71$, $p < 0.001$, $\mu_p{}^2 = 0.148$.[3] Separate paired t-tests reveal that there is no significant difference between the two Cyberball games in response to exclusion events during the first 30 ball tosses, $t(56) = 0.99$, $p = .326$. However, during the next 30 ball tosses this difference is significant, $t(56) = 2.13$, $p = .037$, but not during the last 30 ball tosses, $t(56) = 1.51$, $p = .137$. In summary, it appears that the average pupil size decreases both during the ostracism game and the belonging game, but this decrease was relatively faster in the ostracism game (ostracism: $M_{\text{event 1 to 30}} = 0.085$ mm, $SD_{\text{event 1 to 31}} = 0.038$; $M_{\text{event 31 to 60}} = 0.058$ mm, $SD_{\text{event 31 to 60}} = 0.027$; $M_{\text{event 61 to 90}} = 0.053$ mm, $SD_{\text{event 61 to 90}} = 0.028$; belonging: $M_{\text{event 1 to 31}} = 0.080$ mm, $SD_{\text{event 1 to 31}} = 0.036$; $M_{\text{event 31 to 60}} = 0.069$ mm, $SD_{\text{event 31 to 60}} = 0.036$; $M_{\text{event 61 to 90}} = 0.060$ mm, $SD_{\text{event 61 to 90}} = 0.037$).

Fundamental needs and mood. The fundamental needs and mood questionnaire was administered twice in this study, after each Cyberball game. Results showed that participants experienced an increase in their fundamental needs, as

[3] A 2 (Cyberball condition: belonging/ostracism) × 3 (Cyberball period: event 1 to 30/ event 31 to 60/event 61 to 90) repeated-measures GLM revealed no main effect of ostracism, $F(1, 56) = 1.94$, $p = .169$, $\mu_p{}^2 = 0.033$, a main effect of event bin, $F(2, 112) = 34.63$, $p < 0.001$, $\mu_p{}^2 = 0.382$, and an interaction effect, $F(2, 112) = 3.81$, $p = .025$, $\mu_p{}^2 = 0.064$.

well as elevated mood, after the belonging game compared to after the ostracism game (see Table 6.4). We also compared the average scores on each of the scales administered after the ostracism Cyberball game to the neutral mid-point (4) and found that all scores fell significantly below the mid-point, except for mood, which was found to be significantly greater than 4 (M = 4.29, SD = 0.91, $t(56)$ = 2.43, p = .018, 95% CI [0.052, 0.533], see Table 6.5).

Anxious uncertainty. We performed an identical analysis on the results of the anxious uncertainty scale, and found that participants expressed more anxious uncertainty after being excluded (M = 2.07, SD = 0.72) compared to being included (M = 1.80, SD = 0.57), $t(56)$ = 4.50, p < .001, 95% CI [0.15, 0.39]. These scores were significantly below the mid-point (exclusion: $t(56)$ = 20.30, p < 0.001; inclusion: $t(56)$ = 28.87, p < 0.001, 95% CI [-2.12, -1.74]).

Checks. Two participants (2.78%) reported having experience with the Cyberball paradigm.[4]

6.3.3 Comparison between Study 1 and 2

Given that we conducted two similar studies, we performed additional analyses in which the responses to the Cyberball game that participants played first (belonging in Study 1, ostracism in Study 2) can be compared between the two studies. This controls for any ordering effects caused by having just participated in a

[4]Excluding these participants did not substantially impact the results (e.g., the effect of ostracism on pupil size during exclusion events in the 0 to 600 ms period remained, $F(1, 54)$ = 4.28, p = .043).

Table 6.5: Difference from neutral mid-point (4) of fundamental needs, its subscales and mood, and the anxiety questionnaire administered after the ostracism Cyberball game in Study 2.

Scale	**Statistics**		**M (SD)**
	$t(56)$	p	
Belonging	22.58	<.001	1.98 (0.67)
Control	16.54	<.001	2.01 (0.91)
Self esteem	4.89	<.001	3.20 (1.23)
Meaning	3.21	.002	4.29 (1.34)
Mood	2.43	.018	4.29 (0.91)
All combined	3.71	<.001	3.63 (0.74)
Anxious uncertainty	20.30	<.001	2.07 (0.72)

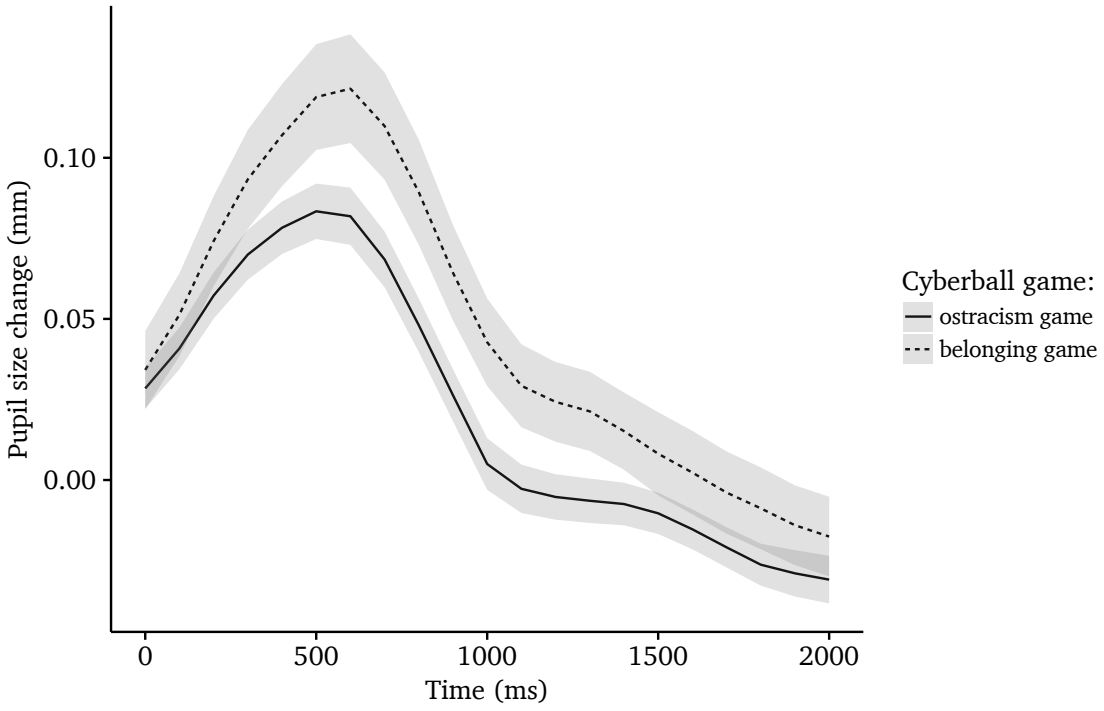

Figure 6.6: Change in pupil size during exclusion events in two games of Cyberball—the belonging Cyberball game from Study 1 vs. the ostracism Cyberball game from Study 2.

Cyberball game. This analysis was done by performing a repeated-measures GLM with the 100 ms time bins as repeated measure and study (belonging first/ostracism first) as between-subjects factor. This revealed a significant effect of study (i.e., ostracism), $F(1, 90) = 13.57$, $p < 0.001$, $\mu_p{}^2 = 0.131$, event period, $F(20, 71) = 25.92$, $p < 0.001$, $\mu_p{}^2 = 0.880$, and an interaction effect, $F(20, 71) = 1.86$, $p = .029$, $\mu_p{}^2 = 0.344$. Pupil size increased upon not receiving the ball, although in Study 2 (ostracism), this change in pupil size was consistently smaller ($M = 0.021$ mm, $SE = 0.004$, 95% CI [0.012, 0.029]) than in Study 1 (belonging; $M = 0.046$ mm, $SE = 0.005$, 95% CI [0.035, 0.057]), see Figure 6.6.[5]

6.3.4 Discussion

In Study 2 we again found that participants showed a gradually decreased pupillary reaction to exclusion events in an ostracism game of Cyberball compared to a belongingness game of cyberball. This lends additional support to the hypoth-

[5]We also repeated the analyses for the prime and no prime conditions separately and find largely consistent results in each condition, as well as some differences. Notably, separate analyses during the 0-700 ms and 700+ time period did not reveal significant effects of ostracism, potentially the result of a smaller effect of ostracism due to ordering effects and the loss of power. Importantly, the effect of ostracism remained in the between study comparison, in both the prime and no prime condition.

esis that a social-physical pain overlap mechanism underlies the pupillary response to cues of ostracism. We also did not find any moderating effects of primed values on pupillary reactivity, a null effect which failed to support the hypothesis that exclusion is primarily experienced as an expectancy violation.

Although we obtained a similar pattern of results between the two studies, the pattern was not identical. In Study 1 we found a decreasing average pupil size across the duration of an exclusion event. In Study 2 we found this trend to occur at the beginning of the event, during the period in which a ball is tossed to another player, but before it is clearly visible to where the ball is being tossed. Possibly, this different pattern of results may be caused by the order in which participants played the belonging or ostracism games. Research on ostracism has shown that threats to people belonging evoke a variety of emotional and motivational responses. One of these responses is an enhanced state of vigilance during which there is a stronger concern for preventing further losses of social connection (Molden, Lucas, Gardner, Dean, & Knowles, 2009). Possibly as a result of having just played the ostracism game, Study 2 participants became more wary and were specifically impacted by the uncertain period during which a ball was tossed. The higher average pupil size change after a ball was tossed in the subsequent belonging game could indicate a higher level of arousal, therefore reflecting this state of increased vigilance for social cues. Alternatively, but relatedly, it could have been the case that due to the initial acceptance in Study 1, an expectation of inclusion was established, which was violated in the subsequent ostracism game, thereby increasing the severity of the ostracism experience. Severity of ostracism has been related to numbing (Bernstein & Claypool, 2012), with more numbing when the ostracism experience is severe. This could also potentially explain the difference between Study 1 and Study 2.

6.4 General discussion

In two experiments we tested two possible hypotheses that link pupillary reactivity to the experience of ostracism. Based on prior theorizing, we argued that ostracism necessarily consists of an initial detection of the fact one is being ostracized, and emotion regulatory processes to deal with the distressing event that is the ostracism experience. We hypothesized that pupillary reactivity could reflect either a social-physical pain overlap process which would be reflected in decreased pupillary reactivity, or an conflict detection process which would be reflected in increased pupil dilation in response to exclusion events. In two studies we demonstrated that the pupil dilates to a lesser extent in response to exclusion

events in a game during which the participant is generally ostracized (ostracism game), compared to the same event during a game in which the participant is equally included (belonging game), thereby supporting the social-physical pain overlap theory of ostracism.

Social-physical pain overlap theory

Being ostracized is a painful experience akin to being physically hurt. Researchers in the field of ostracism have suggested that this analogy is more than just a metaphorical way of speaking. The experience of social pain seems to rely on some of the same neural underpinnings that are also involved in the experience of physical pain, as supported by neuroimaging studies (for an overview, see Cacioppo et al., 2013; Eisenberger, 2012), studies on pain sensitivity after a belonging threat (DeWall & Baumeister, 2006), and studies in which analgesics reduce the emotional experience of social pain (Dewall et al., 2010; Vangelisti et al., 2014). We have shown that this diminished response to ostracism might also be reflected in the pupil. The pupil can reflect a variety of cognitive and emotional processes, some of which are related to sympathetic nervous system arousal (Bradley et al., 2008) the experience of pain (Chapman et al., 1999; Ellermeier & Westphal, 1995; Höfle et al., 2008; Walter et al., 2006), and diminished pupillary dilation as a function of opioid impact on pain response (Connelly et al., 2014).

One alternative line of evidence for the social-physical pain overlap theory is that self-reports of experienced distress as a result of being ostracized often show no effects on mood, i.e., a numbing effect, whereby an absolute interpretation of the results in terms of its scale frequently indicates a neutral state of mind rather than one of emotional distress (Twenge et al., 2003). In both our studies, we find no significant impact of ostracism on mood in terms of a significant decrease towards the lower end of the response-scale. We do find differences in fundamental needs and anxious uncertainty depending on whether participants were included or excluded. These results lend some support to the social-physical pain overlap theory, although it is unclear why we observe only a numbing effect of ostracism on mood. It is possible that self-report responses can be affected by unrelated factors such as demand characteristics, making it harder to detect numbing effects that follow from the social-pain overlap theory. Or alternatively, it is possible that fundamental needs items do not tap into the affective component associated with a pain response. Instead, fundamental needs items tap more into a factual/affective response to being ostracized. For example, the item “I feel excluded” is likely to be immediately impacted upon noticing that one is being excluded, not just because one feels excluded but also simply because one is ex-

cluded. Immediately following the ostracism experience, the latter remains true, so even though a defensive numbing response took place, it remains true that one was excluded, making it likely that participants report feeling excluded, despite already coping with the experience due to the defensive numbing response. If this is indeed the case, our pupillometry findings further bolster the advantages of using physiological measures to investigate ostracism, which circumvent some of the limitations of self-report measures.

Alternative explanations

An alternative explanation for our findings is that pupil sizes decreases because the participants became bored. However, we do not believe that this is a viable alternative explanation, insofar as there was no evidence for general disengagement on the part of the participants during the ostracism games. First, we also did not observe any increases in missing data during the ostracism Cyberball game compared to the belonging Cyberball game. Second, the diminished pupillary response in the ostracism game was associated only with exclusion events, as we saw no decreased pupillary reactivity during events in which participants received a ball toss and only observed it during ostracism-specific events. If participants were generally disengaged, we would have predicted a decreased pupillary response to both exclusion and inclusion events in the ostracism game. Finally, we observed a similar pattern of results in two studies, despite reversing the order in which they were included or excluded. If the decreased pupillary reactivity was due to boredom, we should have observed the decreased pupillary reactivity in the belonging game in Study 2, as this was the second Cyberball game they played. Instead we observed more numbing during the ostracism game, which was presented first.

We hypothesized that exclusion events could initially cause an increase in pupillary reactivity, possibly reflecting a conflict detection mechanism (e.g., Brown et al., 1999; Preuschoff et al., 2011; Sleegers et al., 2015; Smallwood et al., 2011) based on the violation of the expectation that one will be equally included in social interactions. We did not find any discrete evidence of a conflict detection mechanism. However, we acknowledge the possibility that a violation of expectations process might still have occurred. For instance, it could still be the case that conflict detection plays a role, but that the numbing response that we observed overshadowed a conflict-based response. Possibly, and we concur that this remains an empirical question, the type of experience is likely to be of great importance in how people respond, even in terms of initial physiological reactions. It has already been demonstrated that the severity of the threat can impact the numbing

response, with more severe threats inducing a numbing response whereas less severe threats can cause increased sensitivity to threat (Bernstein & Claypool, 2012). Other potentially aversive experiences such as task error or trivial violations of expectations might noticeably elicit physiological changes consistent with a conflict response, but fail to elicit a more downstream coping response such as the numbing effect. Future research could be focused on comparing different types of aversive experiences and how they elicit unique physiological changes.

Additionally, it is possible that expectations are more likely to be quickly updated in a holistic experience such as Cyberball. That is, Cyberball can be seen as one social exclusion experience, rather than a sequence of social exclusion events. At the start of a Cyberball game, participants have the expectation that they will be included, as shown in the data of the questions we asked before each Cyberball game. Soon after, however, participants will likely update their expectations by realizing they are being excluded, thus coming to expect to not receive the ball. If the expectation of receiving the ball decreases over the course of the Cyberball game, this could potentially explain the decreased pupillary reactivity we observe within the exclusion condition. Regarding inclusion cues (i.e., receiving the ball) we should see the opposite pattern. Receiving the ball in the exclusion condition should be a violation of expectations, thus resulting in an increase in pupil size. We did not observe this effect in Study 1, although we did in Study 2, so more research appears to be warranted to both investigate this difference between the two studies, as well as this potential explanation.

Due to our interest in the physiological response to violation of expectations, we are performing a study in the lab that addresses these possibilities. In this study we improve upon our work in two ways. First, we include an overinclusion condition in which participants are disproportionally included, rather than excluded. That is, they receive more ball tosses than the other players in the game. The effects of being overincluded have been shown to be positive (Niedeggen, Sarauli, Cacciola, & Weschke, 2014) and are therefore unlikely to cause social pain, while it should have clear effects on expectations. The more frequent social inclusion cues in an overinclusion condition should have the same effect on pupil size as the social exclusion cues in an exclusion condition, thereby demonstrating an expectation process rather than social pain process. Second, an additional limitation in our studies is that it is difficult to compare inclusion and exclusion cues due to the confound that after an inclusion cue, a response from the participant is needed while this is not the case following an exclusion cue. This confound might interfere with pupil size due to increased arousal as a result of having to decide whom to toss the ball to. A solution to this problem might be to observe another person playing Cyberball, rather than playing oneself. A participant can be in-

structed to observe a specific person play Cyberball, who is then either included or excluded. This kind of vicarious exclusion has been shown to show similar results to that of personal exclusion (Wesselmann, Williams, & Hales, 2013) and might therefore prove to be a valuable improvement as it will allow a direct comparison between inclusion and exclusion cues. This could provide further insights into the underlying process of each kind of cue.

Limitations

A potential limitation arises from the fact that pupillary reactivity can be linked to a variety of cognitive and emotional processes. Although several studies have shown the size of the pupil to be related to the experience of physical pain (e.g., Chapman et al., 1999; Ellermeier & Westphal, 1995), we have not directly demonstrated such a relationship in the present studies. Future research could provide further support by manipulating the presence and absence of opioids such as acetaminophen before participants play the Cyberball game. If the decreased pupil dilation is indeed a result of a numbing response, then this might be enhanced under the influence of pain suppressing drugs such as acetaminophen.

Future directions

In our two studies we used pupillometry as a proxy for physiological arousal. Our findings contribute to the ostracism literature that so far has revealed a syndrome of sympathetic nervous system arousal findings. It has been shown that being ostracized can increase blood pressure (Stroud, Tanofsky-Kraff, Wilfley, & Salovey, 2000), cortisol levels (Blackhart, Eckel, & Tice, 2007), and skin conductance (Kelly, McDonald, & Rushby, 2012). It has also been demonstrated that being ostracized decrease one's skin temperature (IJzerman et al., 2012) and skin temperature in the face area (Paolini, Alparone, Cardone, van Beest, & Merla, 2016). We contribute to this literature by showing that also the pupil indicates the involvement of sympathetic nervous system arousal in the ostracism experience. It is possible to combine these measurement techniques, for example by combining pupillometry with other proxies for arousal such as the galvanic skin response (Bradley et al., 2008). To gain a more comprehensive insight into how people respond to ostracism events, future research could combine physiological measures to provide convergent evidence on the underlying defense mechanisms.

Pupillometry can also be used as a tool to bolster existing models of ostracism. Recent development in eye tracker technology have made eye tracking an affordable and easy-to-use tool. This tool is, as demonstrated by the present

research, applicable to the investigation of ostracism. Heretofore immediate responses to ostracism are measured using self-report measures such as the fundamental needs scale (e.g., van Beest et al., 2011) or a negative affect dial (Wesselmann, Wirth, Mroczek, & Williams, 2012) that is tuned during the ostracism experience. These measures rely on the ability of participants to accurately introspect their affective responses to being ostracized. Physiological measures such as pupillometry do not rely on this ability and also record more immediate responses to ostracism cues than self-report measures. The use of pupillometry could provide new insights for models that make specific predictions about immediate reactions to ostracism cues, such as William's need-threat model of ostracism, which makes the prediction that reflexive responses to ostracism are less likely to be moderated by external factors. The absence of an effect of our value affirmation could perhaps be seen as initial support for this prediction, although it must also be noted that the value affirmation test might be underpowered.

As mentioned in the Introduction of this chapter, Silk et al. (2012) have demonstrated an increase in pupil dilation following rejection. In the present paper, we demonstrated a decrease in pupil size in response to an ostracism cue. We believe a reason for this discrepancy is likely to be the paradigm of choice. A game of Cyberball is a single event in which the players remain constant throughout the game. The ostracism cues (i.e., not being on the receiving end of a ball toss) actually represent a single holistic ostracism experience. Following a realization that one is being excluded, defensive mechanisms such as a pain response can become active to cope with the experience. In contrast, the paradigm of Silk and colleagues consisted of receiving repeated rejections from multiple people. Importantly, Silk and colleagues randomized acceptance and rejection blocks, thus potentially interfering with a numbing response as acceptance blocks could alleviate the negative experience resulting from the rejection blocks. This, however, remains conjecture and the literature would benefit from a future investigation of this possibility.

6.5 Conclusion

Across two studies we demonstrated a decreased pupillary reaction to cues of ostracism in the Cyberball paradigm. This response was found to be consistent with a numbing response based off of the social-physical pain overlap theory rather than a conflict detection response.

Chapter 7

General Discussion

People seek meaning in understanding. This understanding is found in expectations. Through the adoption of an almost innumerable number of beliefs, people structure the experiences that allow them to expect specific relationships, whether it is color of playing cards, the behavior of people, or the unfolding of world events. People's beliefs are, however, imperfect. Many beliefs do not accurately reflect reality or are entirely mistaken. As a result, people regularly face violated expectations. The violation of expectations results in the loss of meaning and constitutes a negative experience. People are therefore motivated to prevent the loss of meaning, for example by interpreting events in a manner that it consistent with prior beliefs (i.e., assimilation) or to restore meaning after such loss has occurred, for example by changing one's beliefs (i.e., accommodation). A frequent alternative response is that following the loss of meaning in one domain, meaning in an unrelated domain is affirmed. This particular response to meaning violations is strong evidence for a domain general process underlying meaning maintenance. That is, rather than specific meaning violations (e.g., mortality salience, the loss of control) eliciting specific, related, compensatory behaviors (e.g., striving for symbolic immortality, restoring control), the loss of meaning in a general aversive state that can be resolved in a flexible manner. This idea is the foundation of the Meaning Maintenance Model (MMM).

The MMM is an integrative model that unites multiple theories in the threat compensation literature (e.g., Terror Management Theory; Burke et al., 2010; Greenberg et al., 1986, 1997a; Greenberg, Solomon, & Pyszczynski, 1997b; Rosenblatt et al., 1989, uncertainty management; McGregor et al., 2010; van den Bos, 2001; van den Bos & Lind, 2002, cognitive dissonance theory; Festinger, 1957; Harmon-Jones & Harmon-Jones, 2007) by seeing various threats to meaning as a violation of expectations, which result in common syndrome of aversive arousal. It is this state of aversive arousal that is the motivating force behind compensatory behavior. People are motivated to reduce the aversive arousal, which can be achieved either by resolving the source of the original meaning violations (i.e., assimilation and accommodation strategies) or by resolving the aversive arousal directly through palliative efforts such as affirming unrelated personal values (i.e., affirmation) or the construction of new meaning frameworks (abstraction, and assembly).

Many studies have shown that meaning violations induce a state of physiological arousal, but its relationship to compensatory behavior has yet to be directly demonstrated. So far, the causal role of arousal has been inferred indirectly by means of misattribution of arousal manipulations or through self-report assessments, rather than direct, physiological measures of arousal following a violation. In the current dissertation we provide further evidence for the role of arousal in

meaning making by reviewing the literature on this topic and empirical studies in which we applied pupillometry as a proxy for physiological arousal to provide further evidence for the role of arousal in response to meaning violations. Below we provide an overview of the main findings, a discussion on how these findings inform us on the role of arousal in meaning maintenance, and directions for future research.

7.1 Main findings

In Chapter 2 we reviewed the literature on the physiological substrates responsible for how people respond to threats. We discussed a variety of studies showing that upon detection of a threat, people initially respond with increased anxiety, vigilance, and avoidance—a set of reactions produced by the behavioral inhibition system (BIS). While the exact underlying neurological substrates of the BIS is still under debate, one of the likely contenders is the anterior cingulate cortex (ACC). This brain area has been shown to activate in response to errors, conflicts, and, particularly of interest, violations of expectations. Consistent with the MMM, the ACC is active in response to what we call meaning violations, such as the experience of cognitive dissonance, mortality salience, social exclusion, and the loss of control. These meaning violations not only activate neurological substrates such as the ACC, but also induce sympathetic nervous system arousal as measured by skin conductance and cardiovascular reactivity measures. Crucially, it has been demonstrated that the experience of BIS is an aversive experience, thus motivating subsequent behavior to reduce BIS activation. This is achieved by the behavioral activation system (BAS). The activation of the BIS or BAS can be detected using frontal asymmetry and recent research has shown that meaning violations indeed result in an increased approach motivation. We argue that it is this state that is responsible for the often observed meaning seeking strategies such as the affirmation of personally held values and ideals, consistent with the MMM.

Chapter 3, 4, and 5 each consist of studies relating arousal to compensation strategies. In Chapter 3 we used a different meaning violation and investigated a different meaning maintenance strategy. Specifically, we presented participants with feedback about commonly held but incorrect beliefs, i.e., misconceptions. In line with predictions of the MMM, a disconfirmation of one's beliefs should result in increased arousal. Indeed, we found that when participants were shown to be mistaken, their pupils dilated to a greater extent, indicating more arousal. This response was moderated by the commitment to their beliefs, with stronger effects of feedback as the commitment towards the belief increases. We also varied the

ambiguity of the feedback, thus giving participants an opportunity to interpret the feedback in such a way as to confirm their beliefs. This assimilation of the feedback occurred for positively framed feedback, with participants not making a distinction between wholly positive and partially positive feedback, as indicated by the absence of a difference in pupil size. When feedback was negative, participants' pupillary reaction differentiated between partly negative and wholly negative feedback, and both were associated with a larger pupil size reaction than to positive feedback. These findings demonstrate an arousal response in response to negative feedback, as well as a bias to confirm one's belief, but only when the feedback is positively framed.

In Chapter 4 we presented participants with perceptual anomalies and gave them an opportunity to affirm their moral values. We found that the perceptual anomalies—reverse colored playing cards—elicited a larger pupil size, indicating greater sympathetic nervous system arousal. Curiously, we did not find a relationship between this arousal response and affirmation. We did, however, find a moderating effect of extremism. Participants who give extreme answers to a variety of personal-value questions showed less pupillary reactivity and more affirmation. We will discuss these findings and how it relates to the role of arousal in meaning maintenance more generally.

In Chapter 5 we tested the entire process as outlined in the MMM. In the first part of the study we had participants answer a series of factual questions that varied in difficulty. In the second part of the study they were presented with the correct answers, during which we measured their pupil size. Immediately after seeing the correct answer to each question, they were asked what their initial answer was. Assuming participants would answer some of the questions correctly and some incorrectly, we could relate the physiological response for incorrect answers to their tendency to display a hindsight bias, that is, indicate that their initial answer was closer to the correct answer than it actually was. This hindsight bias was interpreted as an accommodative meaning maintenance response that allowed us to test whether the physiological arousal response, as measured through pupillometry, could predict the extent of this bias. Indeed, we found that pupil size could predict whether people would display the hindsight bias. This finding is consistent with one of the central tenets of the MMM: meaning violations result in aversive arousal that motivate subsequent compensatory behaviors to reduce this arousal.

In Chapter 6 we presented our work on the role of arousal in response to a common and important meaning violation—social exclusion. Social exclusion is a complex meaning violation in that it can be regarded as either a direct threat to people's need to belong or a violation of expectations due to the often present

norms of inclusion, causing one to be surprised upon being excluded. Consequently, some argue that social exclusion is predominantly a pain-evoking event while others see it as predominantly a violation of expectations. In two studies, we applied pupillometry to a common social exclusion paradigm—Cyberball—to test these two interpretations. The results were consistent with a pain-based response, as indicated by decreased pupillary reactivity following exclusion cues (i.e., not receiving the ball) but not following inclusion cues (i.e., receiving the ball). Participants appeared to numb to the pain caused by exclusion cues, resulting in decreased pupillary reactivity.

7.2 The role of arousal in meaning maintenance

One of the central questions of this dissertation is whether a physiological arousal response can be observed following meaning violations and whether this arousal is related to compensatory behaviors such as assimilation and accommodation efforts, or the affirmation of personal values; as described in the Meaning Maintenance Model (MMM). Each chapter, although independent and addressing more specific research questions, provides new findings on the topic of arousal in maintaining meaning; and together these studies offer new evidence that strengthens the idea of a role of arousal between meaning violations and the compensatory efforts they induce.

According to the MMM, meaning violations induce a state of aversive arousal that motivates compensatory behavior. Compensatory behavior can take various forms. For example, feedback can be assimilated into existing meaning frameworks, beliefs can be accommodated to fit feedback about those belief, and related or unrelated beliefs can be affirmed. In our review (Chapter 2) we found evidence for physiological substrates responsible for these compensatory behaviors. The system believed to be responsible for this is the behavioral activation system (BAS). The BAS responds to reward cues, non-punishment, and escape from punishment; it is thus aimed at resolving the issue that led to the activation of the BIS. Consequently, the activation of this system can counteract the aversive arousal associated with the activation of the BIS. This idea of the BAS underlying the compensatory behaviors following meaning violations is not new. For example, McGregor and colleagues have postulated that a common meaning violation, uncertainty, can induce reactive approach motivation (McGregor et al., 2010). In our review of the literature on threat compensation we discussed these theories and showed that findings in this literature are consistent with this view.

In our empirical work we attempted to demonstrate a link between physio-

logical arousal and compensatory behavior. In Chapter 3 we had participants answer a series of factual questions, indicating whether they believed each statement to be true or false. After each question, they received feedback. In Study 2, this feedback either confirmed or disconfirmed their belief and was either ambiguous or unambiguous. We found that when feedback confirmed people's belief, there was relatively less pupillary reactivity compared to disconfirming feedback. Interestingly, there was no difference in pupillary reactivity between ambiguous and unambiguous confirming feedback, while there was such a difference when feedback disconfirmed their beliefs. The absence of a difference between ambiguous and unambiguous confirming feedback appears to indicate a confirmation bias—ambiguous positive feedback was interpreted as unambiguously confirming their belief. In other words, they assimilated their feedback into their existing belief. This is an initial study demonstrating a link between physiology and compensatory behavior.

Of course, the most relevant test to demonstrate a link between physiological and compensatory behavior is by testing whether the amount of physiological arousal is correlated with the amount of compensatory behavior that follows. We tried to test this link in Chapter 4, in which we presented participants with perceptual anomalies, recorded their pupil size, and provided them with an opportunity to affirm moral values. Although we found that pupil size did indeed increase in response to anomalous cards, this was not associated with a stronger affirmation of values. This absence can perhaps be explained by the fact we used a between-subjects design with only one moment during which personal values could be affirmed. The affirmation opportunity was at the end of the experiment, after the perceptual anomaly task that lasted around half an hour. This long task period is required due to the necessity of repeated pupil size measures. Pupil data is noisy and repeated observations are necessary to obtain a reliable signal. As a result, the meaning violation task is of a relatively long duration. It could be that after the first moment that perceptual anomalies were introduced, participants already started to resolve any felt aversive arousal in different ways, so that by the time the affirmation opportunity was presented, there was no need to affirm anymore. This also explains we did not find any differences in affirmation between the two conditions.

A solution is to use a fully within-subjects design, in which meaning violations and compensatory behavior opportunity are repeatedly presented. This allows for multiple pupil size recordings, as well as providing participants immediately with an opportunity to reduce the arousal by performing a compensatory behavior. This is what we did in Chapter 5. To repeatedly present a meaning violation and a compensation behavior opportunity, we used a memory hindsight

bias paradigm. In this paradigm, participants are first presented with a series of questions that warrant a numerical response. Then, in a second part of the experiment, participants are presented with the correct answers to each question, and asked to again indicate what their initial answer was. Due to the hindsight bias, people are sometimes inclined to indicate an answer closer to the correct answer than their initial answer actually was. We interpreted this behavior as an accommodation response; by telling the experimenter (and yourself) that you actually were not as wrong as you actually were, any negativity felt due to being wrong is alleviated. Crucially, this design allows for a full within-subject design, as each correct answer and compensatory behavior opportunity can be presented repeatedly, so that reliable pupil measurements can be obtained. We recorded the pupil size in response to seeing the correct answer and knowing their initial answer, we could determine their pupillary reactivity to being mistaken. We regressed the average pupil size change in response to a surprising correct answer on the amount of hindsight bias, and demonstrated a positive relationship. The average size of the pupil in response to surprising correct answers was positively related to the amount of hindsight bias. Thus, with this study we provide direct evidence that arousal is linked to compensatory behavior, as postulated in the MMM.

7.3 Theoretical implications

In this dissertation we offer evidence for the MMM's tenet that meaning violations evoke physiological arousal and that this arousal is related to compensatory behavior. The evidence we presented not only supports this important claim of the MMM, but also has implications for other theories in the field. The role of arousal is an often theorized component in psychological theories, especially in the threat compensation literature where some kind of threat motivates subsequent behavior.

One such theory is cognitive dissonance theory. We have already mentioned the vital role of arousal in cognitive dissonance theory, whose extensive body of research contains much of the work explaining why the relationship between arousal and compensatory behavior can be difficult to reveal. However, it appears that the literature on cognitive dissonance theory stalled regarding the relevance of arousal in cognitive dissonance around the 1980s (Cooper et al., 1978; Croyle & Cooper, 1983; Elkin & Leippe, 1986). The role of arousal in cognitive dissonance has recently been picked up by its integration in the MMM. Cognitive dissonance arguably consists of a violation of expectations. In its most typical case, the realization that one performed behavior that is inconsistent with one's personal preference is unexpected. Additionally, research has shown that cognitive dissonance

can lead to compensatory behaviors that are also observed after non-cognitive dissonance related expectancy violations (Steele & Liu, 1983). From the integration of cognitive dissonance in the MMM it follows that our present work on the relevance of arousal both in response to meaning violations and in relationship with compensatory behavior offers further support for the relevance of arousal in cognitive dissonance theory as well. Similarly, additional theories that are integrated in the MMM such as those related to states of disequilibrium (Piaget, 2000), imbalance (Heider, 1958), uncertainty (van den Bos, 2001), anxiety (Janoff-Bulman, 1992), and anxious uncertainty (McGregor et al., 2010) too should see the presented work as providing evidence for the role of arousal in those states.

Our findings are also relevant for terror management theory (TMT). According to TMT, people experience a psychological conflict between having the desire to live and the realization that death is inevitable. This produces an aversive state described as the experience of terror. To reduce this negative experience, people embrace cultural values to attain symbolic immortality (Greenberg et al., 1986; Solomon, Greenberg, & Pyszczynski, 1991). The presence of terror seems to imply a state of aversive arousal, consisting of the experience of negative affect and heightened physiological arousal. These two components have been investigated, but consistent with many studies in which such a mediating role is expected, none was found (Arndt, Greenberg, & Harmon-Jones, 1996; Rosenblatt et al., 1989). This led to the conclusion that "terror management processes are ultimately concerned with implicit knowledge of death rather than with thoughts of mortality that have recently entered consciousness." (Greenberg et al., 1997b, p. 101). That is, rather than considering methodological limitations that prevented the discovery of a role of arousal, it was concluded that arousal does not play a role—the theory was adjusted to incorporate the unintuitive notion of implicit terror. Although we did not use mortality salience as one of our meaning violation manipulations, we believe it is premature to conclude that arousal plays no role in this process (also see Tritt, Inzlicht, & Harmon-Jones, 2012). Rather, methodological shortcomings might explain the null-effects (e.g., the use of between-subject designs that severely lack power, significant delays between manipulation and outcome measures, and possible misattribution of arousal). Consequently, there remains the possibility to unite a substantial number of threat-compensation theories and reduce the number of these conceptually distinct theories, as is attempted by the MMM.

The MMM is, however, but a first step in integrating threat-related theories in the compensation literature. New integrative efforts have already been made that further integrate the body of work on threat and threat compensation, resulting in the general process model of threat and defense by Jonas et al. (2014). This

model is in many ways similar to the MMM. Like the MMM, the process model is an integration of threat defense theories such as terror management theory, need for control theories, the unconscious vigilance model, the reactive approach motivation model, as well as the MMM. Also similar to the MMM, this model's central tenets are that discrepancies (similar to expectancy violations) activate basic neural processes related to anxiety, causing proximal and symptom-focused defense responses that result directly from anxious arousal and heightened attentional vigilance associated with anxious states. The main difference between this model and the MMM is the presence of more explicit acknowledgement of the BIS/BAS process underlying the response to meaning violations and particular categorizations of compensatory behavior. According to the model, dispositional and situational affordances determine whether compensatory behaviors result in the resolution of the original meaning violation or whether they are merely palliative, are concrete or abstract, or are personal or social in nature. Theoretical work on the MMM has not included the specific and explicit assertions of specific compensatory behaviors to the extent that the general process model of threat and defense has, but it is also not inconsistent with its additional claims. As a result, both theories are based on the same findings in the literature, and importantly, the results of this dissertation pertain to both the MMM, as well as the process model of threat and defense.

7.4 Limitations and future directions

7.4.1 Testing the idea of misattribution of arousal

Despite the often claimed role of arousal in psychological theories, both in the threat defense literature as well as other literatures, the relationship between arousal and outcome variables is seldom found. In our own work, we have also not always succeeded in showing a relationship between arousal evoked by a meaning violation and the compensatory behavior it should elicit (see Chapter 4). In Chapter 5 we suggest two possible reasons for seemingly sporadic evidence for the arousal-behavior link. One possible reason is that physiological measures such as pupillometry, skin conductance, cardiovascular reactivity, or skin temperature, require repeated trials to obtain reliable signals. Some of these measures may require fewer trials than others, but they share the methodological problem of a relative long measurement period. As a result, the effect of the manipulation, in our case the presentation of a meaning violation, can dissipate before the behavioral outcome measures are assessed, resulting in null effects.

A second possible reason is that physiological assessment tools can serve as attribution sources for felt arousal. These tools often involve placing electrodes on the skin or being placed in technological contraptions like an fMRI machine, which are likely to evoke aversive arousal. In one study, this notion even served as the basis of a cognitive dissonance manipulation (van Veen et al., 2009). Participants had to argue that the fMRI machine they were in was comfortable, rather than the more truthful perception that it is not. We argued that this is another reason why studies on the link between physiology and compensatory behavior might fail to detect such relationship. Arousal evoked by a meaning violation can be attributed to the device, rather than the meaning violation, and consequently there is no need to perform compensatory behavior. In fact, researchers have employed this very paradigm, the misattribution of arousal paradigm, to demonstrate the relevance of arousal in producing compensatory behavior.

To address these two possible limitations, we implemented a full within-subjects design and used eye tracker technology to assess the physiological arousal response. In Chapter 5 we conducted a study in which we repeatedly presented a meaning violation and repeatedly assessed compensatory behavior. This within-subjects design constitutes a more powerful design in which each necessary component (meaning violation, physiological response, and compensatory behavior) is repeatedly measured. This prevents dissipation effects from obscuring a relationship between these components of interest. Additionally, we used pupillometry to assess physiological arousal. A benefit of pupillometry over alternative physiological measures is that modern eye trackers are relatively non-invasive. Modern eye trackers resemble standard computer monitors that can measure pupil movements and size from a short distance, without the use of restraints. Participants can sit freely in front of the monitor, identical to that in standard laboratory experiments. Consequently, we believe that another reason we succeeded in showing a link between arousal and compensatory behavior is that participant did not ascribe their felt arousal to the eye tracker, but at their actual source: the meaning violation.

However, despite our argument that the long measurement period and arousal evoking properties of physiological tools can prevent the detection of an arousal-behavior link, we have not explicitly tested this explanation. Future studies can be performed to find evidence for our explanation. For example, to test our argument that the long measurement period of physiological arousal interferes with observing the arousal-behavior link, the duration of the period can be manipulated outside of a physiological assessment context. There is some evidence that a delay can interfere with compensatory behavior, at least in the case of cognitive dissonance (Crano & Messé, 1970), but other research has shown that a delay is beneficial to the revelation of a compensatory behavior response, at least in the

case of mortality salience (Burke et al., 2010). Hence, future studies can be conducted to both find support for our argued limitation of physiological assessment tools and the effect of a delay on producing compensatory behavior.

An alternative idea is to manipulate the arousal levels in the context of physiology studies by incorporating a delay before the crucial manipulation and dependent measures. This will give participants a chance to acclimate to the measurement device, thereby reducing the arousal produced by the device. Researchers regularly include a period at the start of physiological studies, but these are aimed at creating a baseline that subsequent measures can be compared to; not for participants to fully acclimate to the recording device. An alternative idea is to also explicitly ask participants how they feel with regard to the recording device. If they express any discomfort, efforts can be made to make them feel more comfortable. If they do not, then they will also be less likely to attribute any felt arousal to the recording device at a later point in the experiment.

If our explanation is correct, this will have important implications for any work on the topic of arousal and arousal-produced behavior, not just the literature on meaning and compensatory behavior. We thus hope that future work will be conducted to test our predictions; but we also hope that the mere realization of this possibility will create pause in designing physiology-based experiments and that perhaps efforts can be made to reduce the likelihood of misattribution of arousal effects.

7.4.2 Pupillometry: positive or negative arousal?

In our studies we used pupillometry to assess the physiological arousal following meaning violations. We tested the prediction of the MMM that meaning violations produce a state of aversive arousal, which then motivates compensatory behavior to reduce this arousal. We thus assume that the arousal we measured through means of pupillometry reflects aversive arousal, and not positively valenced arousal. However, the size of the pupil cannot distinguish between arousal produced by negative sources, such as fearful stimuli, pain, or the violation of expectations, and positive sources, such as smiling faces, erotic stimuli, and delicious foods. This has been demonstrated by multiple studies in which both positive, negative, and neutral pictures are presented to the participant, during which the size of the pupil is recorded (Bradley et al., 2008; Partala & Surakka, 2003; van Steenbergen et al., 2011). Both positive and negative pictures elicit greater pupil size, compared to neutral pictures. However, we are confident that we can infer the increased pupillary reactivity in our studies to reflect negative arousal, rather than positive arousal, for a variety of reasons. First, meaning violations are

negative stimuli. Meaning violations such as mortality salience and the loss of control are undoubtedly negative experiences. According to the MMM, part of why these meaning violations are experienced as aversive is because they violate expectations. The violation of expectations is also an aversive experience, as seen in studies demonstrated that making errors is aversive (Hajcak & Foti, 2008) as well as the experience of surprise (Noordewier & Breugelmans, 2013). If we accept the violation of expectations to constitute a negative experience, we must see it as likely that the arousal we observed in response to expectancy violations is negatively valenced. Second, we linked the size of pupil to compensatory behavior. This relationship is, of course, readily explained by the MMM, while alternative explanations seem less readily available. People are unlikely to misreport their first answer in the direction of the correct answer after experiencing positive affect. We are not aware of a plausible explanation for why people should be more inclined to adjust their answer towards the correct answer after experiencing positive affect. For these reasons we are hesitant to see pupil size, in the context of our studies, as reflecting positive arousal.

Despite our reluctance to accept that the pupil measures in our studies reflect positive arousal, we nevertheless believe it to be fruitful to conduct studies to demonstrate that meaning violations induce aversive arousal and that this can be achieved through means of eye tracker technology. One way in which this can be achieved is through an anti-saccade task (Hutton & Ettinger, 2006). In this task, participants are presented with a neutral target stimulus that appears either on the left or right side of a fixation cross. Before each trial participants are instructed to either focus on this target (pro-saccade) or away from the target (anti-saccade). Saccades are generally initiated more slowly and less reliably during anti-saccade trials than pro-saccade trials, likely due to the need for inhibiting the automatic tendency to look at novel stimuli (Olk & Kingstone, 2003). This task was used by van Steenbergen et al. (2011) to test whether arousal, whether it is positive or negative, results in attentional narrowing; that is, smaller latency differences between pro-saccade and anti-saccade trials in an anti-saccade task. They presented participants with positive, negative, and neutral pictures before each pro-saccade or anti-saccade trial and additionally they measured the pupil size during the presentation of the picture. They found that the pupil dilated in response to both positive and negative pictures, but only negative pictures produced attentional narrowing. Consequently, it therefore possible to distinguish between negatively valenced and positively valenced stimuli through means of an anti-saccade task. In fact, in our lab we are currently employing this method to test whether the meaning violations discussed in this dissertation not only produce arousal as shown in the studies here, but also show an attentional narrowing effect, which would be

further evidence that these events are indeed aversive.

7.4.3 Post-compensatory behavior arousal

In this dissertation, we presented work on the role of physiological arousal in maintaining meaning. We have shown that meaning violations cause an increase in arousal and we have also shown that this arousal is related to compensatory behavior. These findings support the MMM's tenet that meaning violations produce a state of aversive arousal and that compensatory behaviors are performed to reduce this aversive arousal. However, we did not test whether the arousal is in fact reduced after performing compensatory behavior. In Chapter 4 we found that participants who tend to give extreme answers showed a muted pupillary reactive compared to those who give more nuanced responses. This can be interpreted as some evidence for this view, as the presence of extreme answers can indicate a strong foundation of personal values, and thus meaning, that can serve as a buffer to the effect of expectancy violations in unrelated domains, such as perceptual anomalies. However, this was not a specific test of the idea that compensatory behavior reduces aversive arousal. In the general literature, research on this specific link is scarce. This is perhaps no surprise, given the challenge of linking arousal to compensatory behavior in the first place, but there is some work that seems to offer support for this idea. For example, Elliot and Devine (1994) provided evidence for this link with a cognitive dissonance paradigm. They found that making a counterattitudinal argument caused psychological discomfort, assessed by a self-report measure of affect, and that this produced attitude change. Crucially, they again assessed the discomfort following the attitude change and found that it was reduced. There is also additional work on potential buffering effects of compensatory behaviors. Affirmation of personal values, such as religious values, before a meaning violation can prevent compensatory behaviors such as worldview defense (Jonas & Fischer, 2006; McGregor, Haji, & Kang, 2008; Schmeichel & Martens, 2005). These buffering effects have also been observed on physiological measures. For example, writing about personal values or group, ideological, or religious commitment relieve cortisol reactions and ERN amplitude (Creswell et al., 2005; Inzlicht & Tullett, 2010). There is also the evidence that trait levels of religiosity are negatively related to the ERN (Inzlicht et al., 2009) similar to how we found that more extreme participants showed a reduced pupillary response.

However, it would be more persuasive if the entire link of meaning violation to aversive arousal to compensatory behavior to reduced aversive arousal can be demonstrated in a single study. In Chapter 5 we offered a potential study that could test this sequence of events. In our hindsight bias paradigm we could add

another phase in which the participants again see the correct answers. Participants that have demonstrated a hindsight bias and thus adjusted their answers closer to the correct answer should then display a lower level of arousal upon seeing the correct answer again. This relationship should not be visible among those who did not adjust their answer. In this study the entire process of meaning maintenance is tested, from meaning violation to arousal, from arousal to compensatory behavior, and compensatory behavior to reduced arousal. The literature would benefit greatly from these designs.

7.4.4 Individual differences

A final suggestion for future research involves the study of individual differences. On multiple occasions throughout this dissertation we have suggested that individual differences can affect how people respond to meaning violations, both in terms of their physiological response as well as compensatory behavior. In Chapter 2 we discussed various individual differences in responding to meaning violations, in that some people might be more likely to interpret a meaning violation as a threat or as a challenge, thereby prolonging BIS activation and delaying the activation of the BAS.

In Chapter 4 we found that participants who tend to give extreme answers on questions about personal values show a muted physiological response to perceptual anomalies, a finding consistent with other work on the buffering effects of personal values. This shows that certain people might be better equipped to deal with violations of expectations, at least when those violations appear to be unrelated to the source of their meaning.

In Chapter 5 we found individual differences in the tendency to display compensatory behavior in terms of hindsight bias. While some participants frequently adjusted their answers to be closer to the correct answer, others rarely did so. We observed that if we excluded the ones who did not change their answer frequently, the relationship between arousal and compensatory behavior strengthened. This seems to show that certain people are more likely to use particular compensatory behavior strategies than others; a finding we also discussed in our review of the literature. Differences in self-esteem, for example, have been shown to affect whether people engage in compensatory behavior after a loss of meaning. People with high levels of self-esteem do not show the typical defensive behavior seen in response to these violations (Pyszczynski et al., 2004), while those with low levels of self-esteem appear to be more cautious and inhibited following meaning violations (Cavallo et al., 2009; McGregor, Nash, & Inzlicht, 2009; Vohs & Heatherton, 2001). Similarly, those high in neuroticism are more likely to inter-

pret cues as a violation (e.g., Goldenberg et al., 1999) and respond with greater discomfort to certain meaning violations, like being made aware of their mortality (Arndt & Solomon, 2003). Also physiologically, they respond with increased severity to experiences that arouse uncertainty (Hirsh & Inzlicht, 2008). Based on these findings it is clear that personality differences and specific meaning sources are of great influence in how people respond to meaning violations. Future work could be conducted to further test these differences, and the studies reported in this dissertation can easily be extended by adding individual different measures to test for these effects.

7.4.5 The five A's of meaning maintenance

According to the MMM, there are five different strategies to maintain meaning: assimilation, accommodation, affirmation, abstraction, and assembly. In this dissertation we offer empirical work on the relationship between physiological arousal and the first three of these meaning maintenance strategies, in Chapters 3, 4, and 5. We focused on these three strategies as they are the most commonly investigated meaning maintenance strategies. A rich theoretical background exists for these strategies, found in such theories as Festinger's cognitive dissonance theory (Festinger, 1957), Piaget's schemata (Piaget, 2000), Janoff-Bullman's assumptive worlds (Janoff-Bulman, 1992), and numerous other theories (see Park, 2010). An investigation of the relationship between arousal and particularly these meaning maintenance strategies seemed most informative for understanding the meaning maintenance process.

Future work could address the relationship between physiological arousal and the two remaining strategies, abstraction and assembly. As mentioned in the first chapter, support for these two strategies is based on empirical evidence of an increased tendency for pattern detection following meaning violations (Proulx & Heine, 2009; Randles et al., 2011)—indicative of an abstraction strategy—and increased creativity following meaning violations (Maddux et al., 2010; Markman et al., 2007)—indicative of assembly. An example of how the relationship between arousal and one of these strategies could be demonstrated is by observing arousal levels following a meaning violation, followed by a creativity task that is either successfully or unsuccessfully completed. Following successful completion, arousal levels should diminish relative to the condition in which there is no creative satisfaction. This would also address the previous suggestion of investigating the third link in the arousal-compensatory behavior link (see the section on Post-compensatory Behavior Arousal).

Besides the five strategies postulated in the MMM, it is also argued there

might be a 6th strategy: avoidance (Hirsh, 2012). Using this strategy, one would respond to a meaning violation by avoiding, suppressing, or ignoring conflicting information. This particular strategy readily lends itself to an empirical test using eye tracker technology. In this dissertation we have used eye tracker technology to measure the size of the pupil, but eye tracker technology can also be used for gaze detection, arguably the more common use-case for this technology. To test the idea of avoidance following meaning violations, participants could be presented with meaning violations (e.g., inconsistent word-pairs, reverse colored playing cards, negative belief feedback), followed by a grid of pictures of which one picture contains a second meaning violation (e.g., an astronaut in a desert, a tree under water). An inconsistency might draw initial attention, but if an avoidance strategy is implemented, this would result in attention quickly being drawn away from the meaning violation.

Finally, the different strategies should also be compared to each other. The five (or six) strategies differ in numerous ways. Some of the strategies are directly related to resolving the source of the meaning violation (assimilation and accommodation) while others indirectly address the meaning violation. These appear to serve a mere palliative function to restore meaning. The strategies likely also differ in terms of their ease of implementation. For example, changing one's beliefs to resolve a violation of expectations is likely to be more effortful than interpreting a situation to be consistent with one's beliefs; similarly, creating a wholly new meaning framework (assembly) is also likely to be a more effortful response to lost meaning.

The present state of the literature does not offer any empirical work on when which strategy is preferred. In fact, most studies offer only one single compensation strategy option. This likely forces participants to use the provided strategy, leaving open the possibility that the participant actually preferred a different strategy. Given a set of options, participant may prefer to chose less effortful strategies or perhaps strategies that directly resolve the source of the meaning violation, rather than a mere palliative strategy (e.g., Shepherd, Kay, Landau, & Keefer, 2011). Relatedly, if the only compensatory behavior opportunity is one that does not appeal to the participant (e.g., offering an opportunity to affirm religious values when the participant holds atheist beliefs) compensatory behavior might not be observed. For these reasons it appears to be fruitful to create experimental designs in which not one but multiple meaning maintenance strategies are offered. This would also impact the relationship between meaning maintenance and arousal. It is possible that the severity of the arousal response can predict whether a specific, perhaps more effortful, strategy is preferred and some strategies might be more successful in restoring meaning for the individual, thereby

reducing the experienced arousal.

7.5 Practical application

The work presented in this dissertation was aimed to test specific predictions of the MMM and thus was driven by a motivation for basic research, rather than practical application. Our work is limited in that all studies were conducted in lab settings, with non-representative samples. Nevertheless, our work informs theory that shows strong potential for informing important questions in society. Some of the implications for society have already been made clear by others. Janof-Bullman's (1992) work on the double dose of anxiety shows that traumatic events such as natural disasters and personal tragedies should receive two types of attention: attention aimed at managing the initial threat, often to physical health, and attention to the loss of understanding. Terrible events often violate our expectations related to the working of the world or personal estimations of vulnerability. The discomfort associated with the realization that we are mistaken should be seen as an important reason for helping victims of these events to make sense of what happened.

An important implication of the MMM is that meaning is not just found in grand world views, but also in the most trivial of beliefs. Trivial expectancy violations like seeing reverse colored playing cards or being informed that the shortest distance between Russia and the United States is only 3.6 kilometers also induce a state of arousal, despite their seemingly innocent nature. The presence of a physiological response to these violations indicate that these violations are possibly experienced as aversive, and therefore motivates efforts to resolve that arousal. It is an indication of a motivation to maintain these views. This might explain why certain views that seem trivial remain prevalent in society. Misconceptions such as that switching among different types of alcohol is more likely to lead to drunkenness than sticking to one type of alcohol, that reliable trait inferences such as trustworthiness can be derived from a person's face, that lie detectors work, or that we use only 10% of our brain are believed by many. At first sight it might appear that a quick correction can change a person's belief; but the findings in this dissertation speak against that view. Even trivial violations induce a state of arousal that motivates people to perform defensive behaviors—which are not always aimed at correcting the source of the meaning violation.

The realization that meaning can be found in understanding should motivate us to strive towards developing accurate beliefs. Simply put, we can help people maintain meaning by helping people be wrong less frequently. As academics, we

should feel comfortable with this suggestion. We have a responsibility to inform the public about our scientific discoveries and assist them in developing accurate world views. This can be achieved by popularizing our scientific findings and by combating sources of misinformation, of which there are many. Various forms of media are riddled with false information that are likely for a large part responsible for the prevalence of incorrect beliefs. Even our textbooks, the foundation of education, contain long-known falsehoods (Ferguson, Brown, & Torres, 2016). Besides these sources of misinformation, we must also dissuade people from adopting unscientific values. Recent movements, as exemplified in the US politics of 2016, appear to move towards values of relativism; that there is no such thing as facts and that feelings are as valid as empirical data and logic. These attitudes have resulted in a spread of false information that are more likely to result in disconfirmation; and consequently a loss of meaning. It thus appears to be warranted that a greater emphasis on the adoption of reasonable beliefs is warranted.

Although we have focused on trivial beliefs and their invalidity, beliefs part of large world views are equally susceptible to being invalidated. Grand world views such as religious doctrines often contain scientific falsehoods, such as that we are at the center of the universe and that the Earth is 6000 years old. The inclusion of these beliefs is further evidence that people indeed seek meaning through understanding. It is unfortunate then, that these beliefs are often incorrect. To this day certain people have a difficult time accepting scientific discoveries because they are inconsistent with their expectations about what the world is like; that is, they experience a meaning violation. In fact, it is inevitable that meaning violations will continue to be experienced when belief systems are adopted that do not consist of accurate beliefs.

Religion excels, however, in providing meaning through means other than understanding. Religion particularly offers individuals feeling that their existence is of significance, importance, and value in the world; that is, a feeling that they matter. Religion also offers purpose, as many religious doctrines include specific ideals to live up to. Recently, certain attempts are being made to offer people a satisfying meaningful perspective without the inaccurate beliefs present in religious doctrines. For example, Sam Harris' book entitled "Waking Up" offers a guide to spirituality without religion. Endeavors such as these might enable people to live more satisfying meaningful lives, without the relatively larger risk of experiencing meaning violations due to inclusion of false beliefs. This movement also appears warranted, as more and more people identify themselves as spiritual but not religious (Funk & Smith, 2012). Movements such as these show us alternative meaning frameworks are possible that do not require inaccurate beliefs to be maintained. Consequently, these alternative meaning frameworks offer meaning

by providing a sense of mattering and purpose, together with a reduced chance of experiencing meaning violations due to a misunderstanding of the working of the world.

In summary, the MMM reveals that an important component of meaning is a sense of understanding. Meaning is lost when this understanding is violated. Hence, to prevent the loss of meaning, beliefs based on evidence must be adopted in order to minimize their risk of being violated. These beliefs are but one component of meaning, and attention must be paid not just to the adoption of correct beliefs, but also to developing a sense of purpose and mattering.

7.6 Conclusion

"All right," said Deep Thought. "The Answer to the Great Question ..."

"Yes ...!"

"Of Life, the Universe and Everything ..." said Deep Thought.

"Yes ...!"

"Is ..." said Deep Thought, and paused.

"Yes ...!"

"Is ..."

"Yes ...!!! ...?"

"Forty-two," said Deep Thought, with infinite majesty and calm.

— Douglas Adams*, The Hitchhiker's Guide to the Galaxy*

If we could have tracked the eyes of the Magratheans as they were told the answer to Life, the Universe, and Everything, we likely would have seen an increase in pupil size as their expectation of a meaningful and satisfying answer was violated by the number 42. They experienced a state of aversive arousal that motivated them perform compensatory behaviors, in their case the construction of a new super computer that will calculate the question, rather than the answer. In this dissertation we have produced several contributions, hopefully answers, to question in the literature on meaning. We have shown that meaning violations, even trivial ones, produce a physiological arousal as seen in the size of the pupil. We demonstrated that this arousal is linked to compensatory behavior, thereby finding support for crucial tenets of the MMM.

After the Magratheans discovered the answer to life, the universe, and everything, they set out to discover the ultimate question to life, the universe, and everything, so that they could understand the answer. They constructed the planet-sized computer named Earth to calculate this question. It is on this planet that we provided some answers to questions of meaning, but as is common in science, we raised more questions, too. We hope that these questions will motivate more research on the topic of meaning and continue the admirable integrative efforts that are developing in the field. And perhaps, at its conclusion, will result in the ultimate question.

Chapter 8

Supplemental Materials

8.1 Supplemental materials from Chapter 3

Table 8.1: Misconceptions used in Chapter 3, in Dutch (left) and English (right)

Misvatting	**Misconception**
1 paard levert 1 PK.	1 horse equals 1 HP.
Aan Napoleon danken wij al die rare achternamen.	Thanks to Napoleon we have those weird surnames.
Albert Einstein heeft in zijn schooltijd onvoldoendes gehaald voor wiskunde.	Albert Einstein was bad at math in school.
Alcohol zorgt voor het afsterven van hersencellen.	Alcohol kills brain cells.
Als je een aardworm in tweeën splijt kunnen beide helften doorleven.	When you split an earthworm in two, both part can still live.
Als je een bepaalde plek vaak scheert worden de haren daar harder en stugger.	If you shave frequently, the hairs will become harder and more rigid.
Apen verlossen elkaar van vlooien.	Apes rid each other of fleas.
Beren gaan in winterslaap.	Bears hibernate.
Bij een pas overleden persoon groeien de haren nog even door.	The hairs of a recently diseased person continue to grow for a short while.
Marco Polo bracht de spaghetti mee uit China.	Marco Polo brought spaghetti from China.
Bliksem gaat van boven naar beneden.	Lightning travels from top to bottom.
Dankzij goede administratie werden zoveel joden in Nederland opgepakt.	Thanks to the Dutch's excellent administration, many Jews were arrested in the Netherlands.
Botten zijn van kalk.	Bones are made of calcium.
Cleopatra was een Egyptische koningin.	Cleopatra was an Egyptian queen.
Columbus ontdekte Noord-Amerika.	Columbus discovered North America.
Concentratiekampen zijn door de Nazi's bedacht.	Concentration camps were invented by the Nazis.
Cowboys droegen revolvers.	Cowboys carried revolvers.
Boeddha was dik.	Buddha was fat.
De Big Ben is het uurwerk op het Londense parlementsgebouw.	The Big Ben is the clock tower on top of London's parliament building.
De boemerang is Australisch.	The boomerang is originally from Australia.

Table 8.1 – continued from previous page

Misvatting	**Misconception**
De bulten van een kameel zitten vol met water.	The back of camels is filled with water.
De evolutietheorie van Darwin is ontworpen om een verklaring te geven voor het ontstaan van leven op aarde.	Darwin's theory of evolution was designed to explain the origin of life on Earth.
De kern van de aarde is vloeibaar.	Earth's core is fluid.
Door vlees snel dicht te schroeien verliest het vlees minder vocht.	By cauterizing quickly, there is less loss of fluid.
Een gouden medaille bij de Olympische Spelen is van goud.	A golden Olympian medal is made of gold.
De Russische winter brak Napoleon op.	It was the Russian winter that caused Napoleon's defeat.
De Sahara ligt vol zand.	The Sahara Desert is mostly sand.
De zon komt op in het oosten.	The Sun rises in the East.
De zwarte weduwe doodt haar partner.	The Black Widow kills her partner.
Diamanten ontstaan vanuit steenkool.	Diamonds are created out of charcoal.
Dichtbij een TV of computerscherm zitten is slecht voor je ogen.	Sitting close to a TV or computer screen is bad for your eye sight.
Mensen gebruiken maar 10 procent van hun hersenen.	Humans only use 10% of their brain.
De maag rammelt van honger.	The stomach growls due to hunger.
Een harnas was zo zwaar dat ridders op hun paard gehesen moesten worden.	The armor of knights was so heavy that they had to be lifted onto their horses.
Een hond kwispelt omdat hij blij is.	A dog wags its tail because it's happy.
Newton kwam op zijn natuurwetten doordat een appel op zijn hoofd viel.	Newton discovered his laws of nature because an apple fell on his head.
Luther spijkerde zijn stellingen op de kerkdeur.	Luther nailed his theses to the church door.
Napoleon Bonaparte was klein.	Napoleon Bonaparte was short.
Een kapitein is verplicht als laatste het zinkende schip te verlaten.	It is mandatory for a captain to be the last person to leave a sinking ship.
Een zonnebloem draait met de zon mee.	A sunflower turns in the direction of sunlight.
Eskimo's wonen in iglo's.	Eskimo's live in igloos.

Table 8.1 – continued from previous page

Misvatting	**Misconception**
Frankenstein was een monster.	Frankenstein was a monster.
Gaius Julius Caesar was een keizer.	Gaius Julius Ceasar was an emperor.
Galilei vond de telescoop uit.	Galileo invented the telescope.
Galileo liet kogels van de toren van Pisa vallen.	Galileo dropped cannonballs from the tower of Pisa.
George Washington was de eerste president van de Verenigde Staten.	George Washington was the first president of the United States.
Haar kan in 1 nacht grijs worden door schrik of zorgen.	Hair can turn gray within 1 night due to fear or worry.
Henry Ford bedacht het principe van de massaproductie.	Henry Ford invented mass production.
Wanneer je in het vliegtuig het toilet gebruikt, word het afval direct tijdens de vlucht gedumpt.	When you use a toilet in an airplane, the waste is dumped mid-flight.
Vleermuizen zijn blind.	Bats are blind.
Suiker veroorzaakt hyperactiviteit bij kinderen.	Sugar causes hyperactivity in children.
Een meteoriet die de aarde bereikt is een hete vlammende vuurbal.	A meteorite that hits Earth is a hot flaming ball of fire.
In een gerecht waar een alcoholische drank in zit, zit ondanks het koken nog steeds alcohol.	A dish whose recipe contains alcohol maintains, despite boiling, still alcohol.
Een vomitorium was een ruimte waar Romeinen braakten.	A vomitorium is a place where Romans went to throw up.
Het hart zit links.	The heart is on the left side of the torso.
Het Kremlin staat in Moskou.	The Kremlin is located in Moscow.
Het is zo dat hoe hoger je gaat hoe kouder het word.	The greater the altitude, the lower the temperature.
Het kunnen oprollen van de tong is erfelijk.	The ability to roll your tongue is hereditary
Het verteren van ingeslikte kauwgom duurt 7 jaar.	It takes 7 years to digest a swallowed piece of gum.
Iemand moet 24 uur vermist zijn voor hij/zij als vermist kan worden gemeld bij de politie.	A person needs to be missing for 24 hours before it should be reported to the police.

Table 8.1 – continued from previous page

Misvatting	**Misconception**
Hitler was een atheïst.	Hitler was an atheist.
Hitler voorzag Duitsland van de Autobahn.	Hitler provided Germany with the Autobahn.
In de Middeleeuwen dachten mensen dat de aarde plat was.	In the Middle Ages, people thought the Earth was flat.
In de Middeleeuwen werden heksen vervolgd.	In the Middle Ages, witches were prosecuted.
Bij judo is de zwarte band het hoogst.	The black belt in Judo is the highest possible level.
Je moet een halfuur wachten met zwemmen nadat je hebt gegeten.	You need to wait half an hour after eating before swimming.
Je voelt het als iemand naar je staart.	You can feel it when someone is staring at you.
Kaapstad is de zuidpunt van Zuid-Afrika.	Cape Town is the most southern point of South-Africa.
Kapers zijn zeerovers.	Privateers are pirates.
Katten kunnen zien in het donker.	Cats can see in the dark.
Katten spinnen omdat ze tevreden zijn.	Cats purr because they are happy.
Koekoeksklokken komen uit Zwitserland.	Cuckoo clocks are from Switserland.
Kruisridders deden hun vrouw een kuisheidsgordels om.	Knights of the Cross put chastity belts on their women.
Levertraan komt van walvissen.	Codfish-oil comes from whales.
Lezen bij zwak licht is slecht voor je ogen.	Reading in the dark is bad for your eyes.
Een hondenmond bevat minder bacteriën dan een mensenmond.	A dog's mouth contains less bacteria than a human's mouth.
Longen zijn hol.	Lungs are hollow.
In het Colloseum werden Christenen voor de leeuwen gegooid.	In the Colosseum, Christians were fed to the lions.
De kuisheidsgordel stamt uit de Middeleeuwen.	The chastity belt originates from the Middle Ages.
Mensen hebben 5 zintuigen.	Humans have 5 senses.
Mollen zijn blind.	Moles are blind.
Mos groeit aan de noordkant van bomen.	Moss always grows on the North-side of trees.

Table 8.1 – continued from previous page

Misvatting	**Misconception**
Mozart's tweede naam was Amadeus.	Mozart's second name was Amadeus.
Muizen zijn gek op kaas.	Mice love cheese.
Een kameleon veranderd van kleur om op te gaan in zijn omgeving.	A chameleon changes its color to match its surroundings.
Nederland werd op 5 mei bevrijd.	The Netherlands was liberated on May 5th.
Een hond met een natte neus is altijd gezond.	A dog with a wet nose is always healthy.
Olifanten gaan naar een olifantengraf net voordat ze doodgaan.	Elephants travel to an elephant's grave before they die.
Rood vlees is bloederig.	Red meat is bloody.
Samenlevende vrouwen gaan op den duur tegelijk menstrueren.	The menstrual cycle of women that live together eventually synchronize.
Thomas Edison is de uitvinder van de gloeilamp.	Thomas Edison invented the light bulb.
Sperma komt uit de zaadballen.	Sperm is produced in the testicles.
Struisvogels steken hun kop in het zand als er gevaar nadert.	Ostriches stick their head in the sand when danger is near.
Sperma overleeft maar een paar dagen.	Sperm only survives a few days.
Scharrelkippen lopen vrij rond op het erf.	Free-range chicken get to roam free on the farm.
Van Gogh sneed zijn oor af.	Van Gogh cut off his own ear.
Vikingen droegen gehoornde helmen.	Vikings wore horned helmets.
Vitamine C beschermt ons tegen verkoudheid.	Vitamin C protects against the common cold.
Vleermuizen oriënteren zich met sonar.	Bats use sonar to orient themselves.
In de Middeleeuwen werden mensen gemiddeld 30 jaar oud.	In the Middle Ages, people had a life expectancy of 30 years.
Vrouwen hebben een G-plek.	Women have a G-spot.
Walvissen spuiten water.	Whales spout water out of their blowholes.
Het gehoor en de tastzin zijn bij blinden bijzonder goed ontwikkeld.	Blind people have an exceptionally well-developed sense of hearing and taste.
We knipperen om de ogen nat te houden.	We blink to keep our eyes wet.
Witte wijn komt van witte druiven.	White wine is made of white grapes.

Table 8.1 – continued from previous page

Misvatting	**Misconception**
Water in een afvoer draait onder de evenaar dezelfde kant op.	Water in a sink located below the Equator turns in the same direction.
Weinig nadenken kost even veel energie als diep nadenken.	Thinking less takes as much energy as thinking hard.

8.2 Supplemental materials from Chapter 5

Table 8.2: Questions used in Chapter 5, in Dutch (left) and English (right)

Vraag	Question	Answer
Hoeveel zintuigen heeft de mens?	How many senses does a human have?	20
Voor hoeveel procent bestaat het menselijk lichaam gemiddeld uit water?	What percentage of the human body consists of water?	60
Hoeveel procent van het brein gebruikt de mens?	What percentage of the brain do people use?	100
Hoeveel dagen kan een persoon blijven leven zonder eten?	How many days can a person stay alive without eating?	28
Hoeveel dagen kan een zaadcel (van een mens) blijven leven?	How many days can a sperm cell (of a human) survive?	7
Voor hoeveel procent bestaat het brein uit water?	What percentage of the brain consists of water?	75
Hoeveel procent van al het voedsel in Westerse landen belandt in de prullenbak?	What percentage of all food in Western countries ends up in the trash?	27
Hoeveel spinnen eet je gemiddeld per jaar in je slaap?	How many spiders do you eat in your sleep every year, on average?	0
Na hoeveel dagen zal je sterven als je geen slaap hebt gehad?	After how many days will you die if you do not sleep?	11
Hoeveel procent van al het water op aarde is zoet?	What percentage of all water on Earth is fresh water?	3
Hoeveel procent moet de hoeveelheid water in je lichaam dalen om dorst te krijgen?	By what percentage does the concentration of water in your body have to drop before you experience thirst?	1
Hoeveel spieren gebruikt een persoon terwijl hij praat?	How many muscles does a person use while talking?	78
Om de hoeveel weken wordt de huid van je lichaam vernieuwd?	How many weeks does it take for your skin to renew itself?	4
Hoeveel doden vallen er elk jaar door het slechte handschrift van doktoren?	How many people die every year due to the bad handwriting of doctors?	7000

Table 8.2 – continued from previous page

Vraag	**Question**	**Answer**
Wat is de kleinste afstand in kilometers waarin Rusland en Amerika van elkaar af liggen?	What is the shortest distance between Russia and the U.S. in kilometers	3.8
Hoeveel procent van het aantal botten in je lichaam bevindt zich in je voet?	What percentage of the amount of bones in your body is in your feet?	25
Hoeveel haren verliest een gemiddeld persoon per dag?	How many hairs does a person lose every day?	200
Hoeveel procent van de mensen die roken lukt het om in ëën keer te stoppen?	What percentage of people who quit smoking succeed on their first try?	3
Hoeveel procent van ons DNA komt overeen met een slak?	What percentage of DNA do we share with a snail?	70
Hoeveel gezichtsuitdrukkingen kan een hond maken?	How many expressions can a dog make with its face?	100
Hoeveel aardbevingen vinden er per jaar plaats?	How many earthquakes take place every year?	50.000
Hoelang leeft een huisvlieg in uren?	How many days does the life of the average housefly count?	72
Hoeveel baby's worden er per jaar wereldwijd aan de verkeerde ouders gegeven?	How many babies are given to the wrong parents every year worldwide?	84
Wat is de totale lengte van iemands bloedvatenstelsel in kilometers?	What is the total length of a persons vascular system in kilometers?	100.000
Hoeveel keer meer bacteriën dan cellen zijn er in je lichaam?	How many times does the human body contain more bacteria than cells?	10
Hoeveel verschillende soorten bacteriën leven er in je mond?	How many different kinds of bacteria live inside a human's mouth?	700
Hoeveel procent van de cellen van een boom is levend?	What percentage of the cells in a tree are alive?	1
Hoeveel verschillende talen worden er gesproken in Afrika?	How many different languages are spoken in Africa?	2000

Table 8.2 – continued from previous page

Vraag	Question	Answer
Hoeveel procent van alle massa van het zonnestelsel bestaat uit de zon?	What percentage of the total mass in our solar system consists of the Sun?	99.8
Hoeveel procent van de dieren op aarde heeft 6 poten?	What percentage of all animals on Earth has six legs?	80
Hoeveel uur besteedt de gemiddelde persoon in zijn of haar leven aan reclame kijken?	How many days does the average person spend watching advertisements in his or her life?	13.000
Hoeveel keer past de aarde in Jupiter?	How many times does the Earth fit into Jupiter?	1300
Wat is de langste tijd in uren tussen de geboorten van een tweeling?	What is the longest recorded interval in hours between the birth of twins?	3625
Vanaf hoeveel meter kunnen olifanten water ruiken?	From what distance in meters can an elephant smell water?	4800
Hoeveel uur slaapt een olifant gemiddeld per dag?	How many hours does an elephant sleep every day?	2
Hoeveel zwerfhonden leven er in New York?	How many stray dogs live in New York city?	1.000.000
Hoeveel traptreden telt de Eiffeltoren?	How many steps does the Eiffel Tower count to the top?	1665
Hoeveel stranden heeft Australië?	How many beaches does Australia have?	10.000
Hoeveel keer past Rusland qua oppervlak op Pluto?	How many times does the surface of Russia fit onto Pluto?	1
Hoeveel spinnen leven er gemiddeld per vierkante meter in groene gebieden?	How many spiders live on average per square meter in green areas?	130
Wat is de gemiddelde leeftijd waarop Nederlanders gaan trouwen?	At what age do people in the Netherlands get married?	30
Hoeveel sneetjes gaan er uit een gemiddeld brood?	How many slices of bread can you get out of a loaf of bread?	24
Wat is de gemiddelde fietssnelheid van Nederlanders in km/h?	What is the average biking speed of Dutch people in km/h?	18

Table 8.2 – continued from previous page

Vraag	**Question**	**Answer**
Wat is het gemiddeld aantal TV-toestellen per Nederlands huishouden?	What is the average number of TVs in the Netherlands per household?	1.7
Wat is de gemiddelde leeftijd van ontmaagding in Nederland?	At what age do people in the Netherlands first have sex?	16.7
Wat is de gemiddelde schoenmaat van de Nederlandse vrouw?	What is the average shoe size of a Dutch woman?	39
Hoeveel centimeter is de lengte van een A4'tje?	What is the length of an A4 paper?	29.70
Hoeveel graden Celsius is de gemiddelde temperatuur in Nederland in juli? (zowel dag als nacht)	What is the average temperature (in Celsius) of a day in July in the Netherlands?	17.9
Wat is de gemiddelde leeftijd waarop een vrouw haar eerste kind krijgt in Nederland?	At what age does a women get her first child in the Netherlands, on average?	29.4
Wat is de gemiddelde lengte van de Nederlands man in centimeters?	What is the average length of a Dutch man in centimeters?	184
Wat is de gemiddelde lengte van de Nederlands vrouw in centimeters?	What is the average length of a Dutch woman in centimeters?	170
Wat is de gemiddelde prijs van een glas fris op het terras in euro's?	What is the average price of a soda at a terrace in euros?	2.2
Hoeveel kinderen krijgen Nederlanders gemiddeld?	What is the average number of children per household in the Netherlands?	1.8
Hoeveel jaren oud is de wereld?	How old is the world?	4.000.000.000
Wat is de gemiddelde levensverwachting in Nederland?	What is the average life expectancy in the Netherlands?	80
Hoeveel procent alcohol bevat een standaard glas bier?	What is the alcohol percentage of a glass of beer?	5
Wat is het gemiddelde wandeltempo (km per uur) van een volwassen persoon?	What is the average walking speed of a person in kilometers per hour?	5

Table 8.2 – continued from previous page

Vraag	Question	Answer
Hoeveel tanden heeft een volwassen persoon?	How many teeth does a average adult have?	32
Hoe vaak klopt een gemiddeld mensenhart per minuut in rust?	How many times a minute does a human heart beat on average in rest?	70
Hoeveel mensen wonen er op de wereld?	What is the current population of the Earth?	7.000.000.000
Hoeveel flesjes zitten er in een standaard kratje bier?	How many bottles are in a crate of beer?	24
Hoeveel volt zit er in een Nederlands stopcontact?	What is the voltage of Dutch power outlets?	240
Hoeveel landen zitten er in de Europese Unie?	How many countries are in the European Union?	28
Vanaf welke leeftijd mogen mensen beginnen met werken in Nederland?	At what age are people allowed to work in the Netherlands?	15
Hoeveel dagen duurt de Kerstvakantie voor de basisschool?	How many days does the Christmas vacation last during primary school?	14
Hoeveel calorieën zitten er in drinkwater?	How many calories does drinking water contain?	0
Hoeveel jaar is men getrouwd bij een Gouden bruiloft?	After how many years of marriage is a gold wedding anniversary celebrated?	50
Hoeveel mensen wonen er in Nederland?	What is the current population of the Netherlands?	17.000.000
Vanaf welke leeftijd gaan Nederlandse kinderen naar de basisschool?	At what age do children in the Netherlands go to school?	4
Vanaf welke leeftijd mag men in Nederland op voor het rijbewijs?	At what age are people allowed to start learning how to drive in the Netherlands?	17
Hoeveel uur werkt iemand per week als deze persoon een fulltime baan heeft?	How many hours does a person work a week if he or she has a full-time job?	40
Wat is de Nederlandse pensioensleeftijd?	What is the Dutch age of retirement?	67

Table 8.2 – continued from previous page

Vraag	**Question**	**Answer**
Hoeveel basiskleuren zijn er?	How many primary colors are there?	3
Hoeveel poten heeft een normale spin?	How many legs does a spider have?	8
Wat is de gemiddelde lichaamstemperatuur van de mens in graden Celcius?	What is the average human body temperature in Celsius?	37
Voor hoeveel mensen is er plaats in een gemiddelde auto?	How many people fit in a standard car?	5
Uit hoeveel cijfers bestaat een mobiel telefoonnummer?	How many digits are in a mobile phone number?	10
Vanaf welke leeftijd word je in Nederland als volwassen beschouwd?	At what age are you considered an adult in the Netherlands?	18
Wat is de maximale snelheid (km per uur) dat in een auto gereden mag worden op de snelweg?	What is the maximum speed (in km/h) you may drive on the highway?	130
Hoeveel seconden zitten er in één uur?	How many seconds are in an hour?	3600

8.3 Supplemental materials from Chapter 6

In the studies described in Chapter 6 we additionally measured participants' need for structure by presenting people with works of art and a snowy pictures task after each Cyberball game. Some genres of art contain more structure (still life/representational art) and could thus be preferred after a loss of structure. The loss of structure can also increase a need to see structure in ambiguous stimuli, such as snowy pictures. We thus expected that participants would show an increased tendency to prefer structural art and see more patterns in the snowy pictures.

Study 1

Method

Art task. In the art task participants saw a painting (5000 ms), after which they had to indicate their preference for that work of art by answering three questions (e.g., "I think the work of art is beautiful"), on a 7-point Likert scale. Participants were presented with two times nine paintings (960 x 768 pixels), selected from three different categories: absurd, realistic, and abstract.

Snowy pictures task. The snowy pictures task from Whitson and Galinsky (2008) was used. Participants were presented with a single picture at the time, and could look at the picture for as long as they wished. After each picture they were asked what they saw in the picture.

Results

Art task. To investigate changes in painting preferences as a function of being ostracized, a repeated-measures GLM was performed with Cyberball game (included/excluded) and art type (abstract/realistic/absurd) as within subject factors. This revealed no main effect of the Cyberball game, $F(1, 33) = 0.60$, $p = .444$, $\mu_p{}^2 = .018$. The analysis did reveal a main effect of art type, $F(2, 32) = 14.16$, $p < .001$, $\mu_p{}^2 = .469$. Realistic art was liked the most ($M = 4.06$, $SD = 1.06$) followed by absurd art ($M = 3.65$, $SD = 0.97$), and abstract art was liked the least ($M = 2.83$, $SD = 1.21$). The predicted interaction was not found, $F(2, 33) = 0.25$, $p = .779$, $\mu_p{}^2 = .015$.

Snowy pictures task. To investigate the possible effects of ostracism on increased pattern detection, we performed a repeated measures GLM with Cyberball game (included/excluded) and snowy picture type (hidden pattern present/hidden pattern absent) as within subject factors. The dependent variable was the sum of detected patterns, where each picture counted as 1 if a pattern was detected, and 0 if no pattern was detected. This revealed only an effect of snowy picture type, $F(1, 34) = 65.61$, $p < .001$, $\mu_p{}^2 = .659$.

Participants detected more patterns if a pattern was actually present (M = 5.59, SD = 0.78) than when it was not (M = 3.44, SD = 1.89). No main effect was found for Cyberball game, $F(1, 34) = 0.44$, $p = .513$, $\mu_p{}^2 = .013$, nor an interaction effect, $F(1, 34) = 0.33$, $p = .571$, $\mu_p{}^2 = .01$.

An identical analysis was performed with the time spent looking at the snowy picture as the dependent variable. This revealed a main effect of the Cyberball game, $F(1, 34) = 12.22$, $p = .001$, $\mu_p{}^2 = .264$, and of the type of snowy picture (pattern absent or present), $F(1, 34) = 59.90$, $p < .001$, $\mu_p{}^2 = .638$. Participants spent less time looking for a pattern after being ostracized (M = 15.13, SD = 6.47) compared to being included (M = 18.46, SD = 7.70); and they spent more time looking for a pattern on pictures that did not contain a pattern (M = 20.96, SD = 8.68) compared to pictures that did contain a pattern (M = 12.63, SD = 5.49). No interaction was found, $F(1, 34) = 0.90$, $p = 350$, $\mu_p{}^2 = .026$.

Study 2

In Study 2 we did not include absurd art and instead only used representational art (structured) and abstract art (unstructured). We also added an anxious uncertainty scale in addition to the fundamental needs scale.

Method

We extended the two art genres with two additional paintings so that in total ten paintings of each art genre (representational and abstract) were presented to the participant. After each ostracism manipulation, five paintings of each genre were presented in a random fashion.

Results

Art task. We did not reveal an effect of the Cyberball game, $F(1, 55) = 0.51$, $p = .480$, $\mu_p{}^2 = .009$. The analysis did reveal the main effect of art type, $F(1, 55) = 23.93$, $p < .001$, $\mu_p{}^2 = .303$. Realistic art was liked more (M = 3.70, SD = 1.09) than abstract art (M = 2.74, SD = 1.04). Again, no interaction was not found, $F(1, 55) = 0.54$, $p = .464$, $\mu_p{}^2 = .010$.

Snowy pictures. We again looked the sum of detected patterns as a function of snowy picture type and Cyberball game. This again revealed only an effect of snowy picture type, $F(1, 56) = 119.29$, $p < .001$, $\mu_p{}^2 = .681$. Participants detected more patterns if a pattern was actually present (M = 5.44, SD = 0.80) than when it was not (M = 3.63, SD = 1.58). No main effect of Cyberball game was found, $F(1, 56) = 0.65$, $p = 424$, $\mu_p{}^2 = .011$, nor an interaction effect, $F(1, 56) = 0.52$, $p = .474$, $\mu_p{}^2 = .009$.

An identical analysis was performed with the time spent looking at the snowy picture as the dependent variable. This revealed a main effect of the Cyberball game, $F(1, 56) = 11.93$, $p = .001$, $\mu_p^2 = .176$, and of the type of snowy picture (pattern absent or present), $F(1, 56) = 39.73$, $p < .001$, $\mu_p^2 = .415$. Contrary to the results of Study 1, participants spent more time looking for a pattern after being ostracized ($M = 18.98$, $SD = 10.51$) compared to being included ($M = 14.91$, $SD = 8.61$). Consistent with the results of Study 1, they did spend more time looking for a pattern on pictures that did not contain a pattern ($M = 21.01$, $SD = 12.21$) compared to pictures that did contain a pattern ($M = 12.82$, $SD = 6.65$). No interaction was found, $F(1, 56) = 0.62$, $p = .434$, $\mu_p^2 = .011$.

Chapter 9

Summary

In this dissertation I present the work I have conducted together with my supervisors on the role of physiological arousal in the Meaning Maintenance Model (MMM). The MMM is an integrative model that incorporates multiple theoretical frameworks in the existential psychology literature to explain both what meaning is and how people respond to lost meaning. The central idea is that people adopt sets of beliefs that allow them to make sense of the world. Through the adoption of these beliefs, people structure their experiences and come to expect specific relationships, whether it is the color of objects, the behavior of people, or the unfolding of world events. According to the MMM, meaning is found in these expected relationships.

However, people's beliefs are imperfect, causing them to regularly face events that do not fit in their meaning frameworks. This violates their sense of meaning. Traumatic experiences, misconceptions, and perceptual anomalies are but a few of the types of events that constitute a meaning violation.

The loss of meaning results in a state of aversive psychophysiological arousal that motivates people to reduce this state of discomfort. The MMM describes various ways to do so. For example, people can reinterpret events in a manner that it consistent with prior beliefs or they can restore meaning by changing one's beliefs. Alternatively, they can respond to a loss of meaning in one domain by affirming meaning in an unrelated domain.

The main topic of this dissertation is the aversive state between a meaning violation and the response to that meaning violation: the experience of meaninglessness. According to the MMM, the experience of meaninglessness is a state of aversive psychophysiological arousal that motivates people to perform compensatory behavior to reduce the arousal. We investigated this process in two ways. We conducted a review of related literature and performed experimental studies to better understand the role of arousal in producing meaning restoration responses.

In our review of the literature we discussed possible physiological substrates responsible for how people respond to threats, including the threat of losing meaning. We discuss how threats initially activate the behavioral inhibition system (BIS), as seen in increased anxiety, vigilance, and avoidance following a threat, and how this is subsequently followed up by activation of the behavioral activation system (BAS). We argue that the BAS is responsible for the often observed meaning seeking strategies such as the affirmation of personally held values and ideals, consistent with the MMM.

In our experimental work we used pupillometry. Pupillometry is the technique of measuring the size and reactivity of the pupil. Although it is true that the human eye is for seeing, the pupil also displays small fluctuations that do not seem to serve any visual function. Instead, these small fluctuations reflect a state of physiological arousal. We used this technique to investigate whether arousal plays a role in how people maintain meaning.

We presented people with various meaning violations, such as false beliefs (i.e., misconceptions), social exclusion, and perceptual anomalies. In one study participants were given feedback about their misconceptions and we measured their pupillary reactivity in

response to this feedback. We found that when participants were shown to be mistaken, rather than correct, their pupil dilated to a greater extent. This response was moderated by the commitment to their beliefs, with stronger effects of feedback as the commitment towards the belief increases. In a second study we also varied the ambiguity of the feedback and observed a bias to confirm one's beliefs, as assessed through pupillometry, but only when the feedback was positively framed.

Then we presented participants with perceptual anomalies and gave them an opportunity to affirm their moral values. We found that the perceptual anomalies—reverse colored playing cards—elicited a larger pupil size, indicating greater arousal. We also found that participants who give extreme answers to a variety of personal-value questions showed less pupillary reactivity and more affirmation. Curiously, we did not find a relationship between the arousal response and the compensatory response.

In a next study we tested the entire process as outlined in the MMM. We used the hindsight bias to see whether people adapted their belief in response to belief-feedback and tested whether pupillary reactivity to the feedback could predict the extent of the hindsight bias. This is indeed what we found. This result is consistent with one of the central tenets of the MMM: meaning violations result in aversive arousal that motivate subsequent compensatory behaviors to reduce this arousal.

Finally, we presented our work on the role of arousal in response to social exclusion. Some argue that social exclusion is predominantly a pain-evoking event while others see it as predominantly a violation of expectations. In two studies, we applied pupillometry to a common social exclusion paradigm—Cyberball—to test these two interpretations. The results were consistent with a pain-based response, as indicated by decreased pupillary reactivity following exclusion cues.

Together these findings offer support for the MMM's tenet that arousal plays a significant role in the maintenance of meaning.

Chapter 10

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Chapter 11

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