Universidade de Aveiro
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FÁBIO ALEXANDRE GOMES DA SILVA

COMO A ANSIEDADE MODULA A NOSSA NATUREZA PREDITIVA: PERCECIONANDO O NOSSO AMBIENTE SOCIAL SOB AMEAÇA

HOW ANXIETY DRIVES OUR PREDICTIVE NATURE: PREDICTING OUR SOCIAL ENVIRONMENT WHEN UNDER THREAT

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Psicologia, realizada sob a orientação científica da Doutora Sandra Cristina de Oliveira Soares, Professora Auxiliar com Agregação do Departamento de Educação e Psicologia da Universidade de Aveiro e da Doutora Marta Isabel Garrido, Professora Associada na Melbourne School of Psychological Sciences na Universidade de Melbourne.

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I dedicate this work to my parents, for countless reasons that surpass enumeration.

o júri

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palavras-chave

Ansiedade; Perceção Visual; Expectativas; Vieses percetivos; Ameaça; Visualização de Pontos-Luz;

resumo

A ansiedade tem um papel crucial na forma como lidamos com ambientes ameaçadores. De entre os seus vários efeitos, a ansiedade torna-nos mais sensíveis a mudanças sensoriais no nosso ambiente. Embora isso contribua para a deteção mais rápida de possíveis ameaças, também pode gerar algumas consequências indesejadas. Essas consequências estão especificamente ligadas à forma como percecionamos o mundo, combinando informações sensoriais e expectativas, o que também pode acarretar vieses percetivos. Pensa-se que a ansiedade enfatiza a entrada sensorial, ao mesmo tempo que reduz a relevância das expectativas na perceção. Como as expectativas desempenham um papel vital em certos cenários, como situações sociais, aqui investigamos como a ansiedade pode afetar a perceção de comportamentos sociais. No primeiro estudo, começamos por avaliar como diferentes métodos de indução de ansiedade interferem sobre como julgamos a direção de figuras humanas (ambíguas) a caminhar. Independentemente do paradigma usado para induzir ansiedade, nenhuma mudança na nossa preferência para vermos movimentos de aproximação foi observada. O segundo estudo simulou uma interação entre um agente e um potencial segundo agente, que, se presente, estaria sob uma máscara de ruído. Enquanto sob ameaça de choque, os participantes foram solicitados a identificar a presença deste último agente, considerando a ação comunicativa ou individual apresentada pelo primeiro agente. A presença de ameaça não afetou a sensibilidade ou o critério (viés), nem a medida em que as ações comunicativas reduziram este último parâmetro. O terceiro estudo descreveu uma interação potencialmente agressiva entre dois agentes, ao lado de um observador (face) que exibiria uma reação de medo ou neutra face à interação. Desta vez, os participantes tiveram de identificar a presença de gestos agressivos, tanto em condições seguras como sob ameaça de choque. Apesar de não haver aumento na medida de sensibilidade, observámos um aumento na *drift rate* em direção ao limiar percetivo correto, sugerindo uma maior sensibilidade percetiva sob ameaça. A ameaça de choque não interagiu com o efeito advindo do tipo de expressão apresentada pelo observador. Por fim, o último estudo investigou gestos ameaçadores, medindo tanto a nossa sensibilidade quanto o nosso critério na identificação destes gestos, durante ameaça de choque. A associação entre a fonte de ansiedade (choques elétricos) e agressão também foi manipulada. Verificamos que a ameaça de choque aumentou a sensibilidade percetiva, levando a uma melhor capacidade geral de identificar agressão. A associação entre possibilidade de choque e agentes agressores não teve influência sobre este último efeito. No geral, os resultados parecem sugerir que os estados de ansiedade levam a adaptações benéficas sobre a perceção visual, conforme medido pelo processamento sensorial-percetivo melhorado (i.e., sensibilidade percetiva) em relação à ameaça em ambientes sociais. É importante salientar que este efeito parece não acarretar outras alterações percetuais, na forma de vieses para ameaça ou capacidade reduzida de usar expectativas contextuais.

keywords Anxiety; Visual Perception; Expectations; Perceptual Biases; Threat; Point-light displays

abstract

Anxiety contributes a great deal to how we properly deal with threatening environments. Among its many effects, anxiety makes us more sensitized to sensory changes in our environment. Although this contributes to the quicker detection of potential threat sources, it might also generate some unwanted consequences. These consequences are specifically tied to how we perceive the world by combining both sensory input and expectations, which may also entail perceptual biases. Anxiety is thought to emphasize sensory input, whilst reducing the relevance of expectations on perception. Since expectations play a vital role in certain scenarios, such as social situations, here we investigated how anxiety might affect the perception of social behaviors. In the first study, we began by assessing how different anxiety-induction methods interfered with how we judged motion-ambiguous walkers. Regardless of the paradigm used to induce anxiety, no change in our bias to see approaching motion was observed. The second study simulated an interaction between one agent and a potential second agent, which if present would be masked under a noise mask. Whilst under threat of shock, participants were asked to identify the presence of this last agent, considering the communicative or individual action displayed by the first agent. The presence of threat did not affect sensitivity or criterion (bias), nor the extent to which communicative actions reduced this latter parameter. Our third study depicted a potentially aggressive interaction between two agents, alongside an observer (face) who would display either a fearful or neutral reaction to the social interaction. This time participants had to judge the interaction, identifying the presence of aggressive gestures, whilst under threat and safe conditions. Despite no increase in the sensitivity measure, we observed an increase in drift rate towards the correct perceptual threshold, suggesting a greater perceptual sensitivity whilst under threat. Threat of shock did not interact with the effect associated with the type of expression shown by the observer. Lastly, our fourth study delved over threatening gestures, measuring both our sensitivity and criterion in identifying aggression, whilst under threat of shock. The association between the source of anxiety (electric shocks) and aggression was also manipulated. We saw that threat of shock increased one’s perceptual sensitivity, leading to an overall better ability to identify aggression. The association between possibility of shock and aggressive agents bared no influence over this latter effect. Overall, the results seem to suggest that states of anxiety carry beneficial adaptations over visual perception, as measured by the enhanced sensory-perceptual processing (i.e., perceptual sensitivity) towards threat in social settings. Importantly, this appears not to entail other perceptual changes, in the form of threat bias or reduced ability to use contextual cues.

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LIST OF ABBREVIATIONS

ACC	Anterior Cingulate Cortex
AD	Anxiety Disorder
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
BF	Bayes Factor
BIC	Bayesian Information Criterion
BNST	Bed Nucleus of the Stria Terminalis
DDM	Drift Diffusion Modelling
EEG	Electroencephalography
ERP	Event-Related Potential
FTV	Facing-the-Viewer Bias
GAD	Generalized Anxiety Disorder
LSAS	Liebowitz Social Anxiety Scale
LSF	Low Spatial Frequency
MMN	Mismatch Negativity
PD	Panic Disorder
PFC	Pre-Frontal Cortex
PLD	Point-Light Display
PLW	Point-Light Walker
ROI	Region of Interest
RT	Response Time
SDT	Signal Detection Theory
STAI	State-Trait Anxiety Inventory
STICSA	State–Trait Inventory for Cognitive and Somatic Anxiety
vMMN	Visual Mismatch Negativity

CHAPTER I

Introduction and Literature Review

Introduction

Anxiety stands as arguably one of the most extensively studied and experienced emotional states – even inspiring famous poems (Auden, 2011) and symphonies[1]. Likewise, its importance and pervasiveness on todays' society cannot be overstated (Baxter et al., 2013; Castaldelli-Maia & Bhugra, 2022; Steel et al., 2014). Albeit its definition – and its subsequent interlacing with fear – vary from author to author, anxiety is seen as a sustained state of apprehension, being a consequence of unpredictability in the face of a possible threat. It stands as a natural adaptive emotional reaction – on par with fear (Öhman, 2008) – but does, quite often, evolve into its pathological form. This latter maladaptive type is reflected in prolonged and unnecessary states of anxiety, which can severely affect one's life. In its adaptive form, however, anxiety serves as an early warning system, preparing oneself to deal with the possibility of threat by, among many other things, promoting early threat detection (Robinson, Vytal, et al., 2013). In this chapter, I begin by providing a brief overview of the literature surrounding anxiety. To further discuss its impact upon our visual perception, I dedicate the following topic to the mechanisms and influences behind visual perception. Lastly, I connect both topics, expanding on the effects of anxiety over the perception of our world, with a particular emphasis on social perception and threat detection. The final topic will briefly summarize the goals of this project, outlining the studies performed and remaining structure of this thesis.

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[1] Leonard Bernstein - Symphony No. 2 "The Age of Anxiety"

Anxiety

> Anxiety is an inescapable human experience and one by which we define our environment and ourselves. As meaning-seeking and meaning-creating creatures, we look to explain our subjective experience, including our sense of danger and vulnerability. Anxiety compels reason for our feelings and demands a response.

(Glick & Roose, 2010, p. 50)

Feelings of anxiety run rampant in today's society. Backing such statement, is the fact that anxiety disorders (ADs) place sixth in the rankings of disorders who most contribute to global disability, with its prevalence, worldwide, being estimated (as of 2015) to be around 3.6% - corresponding to about 264 million people (World Health Organization, 2017). Indeed, recent studies have highlighted ADs as the most prevalent mental disorder (Castaldelli-Maia & Bhugra, 2022). Its lifetime prevalence (occurrence of the disease at some point in life) is estimated to sit (as of 2014) at a worrisome 11.3% to 14.7% (Steel et al., 2014). These estimates have only been inflated given the COVID-19 pandemic experienced in these past years (Racine et al., 2021; Santomauro et al., 2021; Shah et al., 2021). The economic burden of anxiety is also clear, with estimates (as of 2012) putting it at around 74.4 billion euros – which for comparison was bellow annual costs for strokes (Olesen et al., 2012). Additionally, aside from affecting cultures (Good & Kleinman, 1985) and sexes (Altemus et al., 2014) differently, ADs have not only the youngest age of onset but also the higher tendencies to become a chronic (lifetime) condition of any other mood disorder (Wittchen, 2002). Importantly, ADs have become one of the most "popular" comorbidities, being investigated in respect to many diseases (e.g., irritable bowel syndrome), professions (e.g., medical personnel; Quek et al., 2019), sports (Correia & Rosado, 2019), among others. One could go on about anxiety's ripples on society, but it should be clear by this point just how serious and widespread such maladaptive evolution of this emotional state is. Nevertheless, functional (normative) anxiety states, that are temporary and infrequent in nature, seem often overlooked in the scientific literature, with their respective side-effects on one's life not extensively documented. Before addressing this in more detail, I will firstly present a brief introduction into anxiety itself.

What is anxiety?

The first attempts to describe anxiety within a psychological theory – with the original concept of anxiety originating in the Classic Greek Period (Hothersall, 2004, p. 249) – can be traced back to Freud's work (around 1924), where he regards anxiety as an unpleasant state and something that can be felt. This would include symptoms such as nervousness and apprehension, as well as physiological symptoms like heart palpitations and trouble breathing. Initially attributed to repressed libido, he would later reformulate his views, dividing anxiety into internal (neurotic) or external (objective) anxiety. Whilst the latter was synonymous with fear, the former (neurotic) anxiety described typical states of apprehension and physiological arousal, that Freud would later attribute to repressed dangerous sources/events (Spielberger, 1966, pp. 9–10).

Since then many authors tried to conceptualize anxiety (e.g., May, 1950; Mowrer, 1950; Sullivan, 1953) and later developed their respective theories on the matter. These can roughly be grouped into psychoanalytic (already introduced above; Freud, 1936), behavioral, physiological, and cognitive theories. In a succinct outline, behavioral theory (sometimes also referred to as learning theory), postulates that anxiety is a mediator between potential threats and adaptive responses. Put simply, much like fear responses can be learned and associated to certain dangerous stimuli, anxiety responses are built when facing more vague and unpredictable threats (Mowrer, 1939). Other theories, such as the physiological or neurophysiological theories relate anxiety to its fingerprint on the behavioral nervous system (e.g., J. A. Gray & McNaughton, 2003) and the activity/balance of certain neurotransmitters in the brain, such as serotonin and norepinephrine (e.g., Salzman et al., 1993). The last two theories briefly described here come from Eysenck (1987) and Öhman (2004). The former mostly described the cognitive basis underlying the different traits (high and low) of anxiety. The latter views anxiety in light of the fear module theory, separating individuals with high and low proneness to anxiety based on the sensitivity of their respective fear module – i.e., the circuit implicated in fear responses. In more recent years, more theories and models, adopting more cognitive or neurobiological standpoints, have emerged, proposing explanatory views on how anxiety is evoked and how it can develop into a pathological state (e.g., J. A. Gray & McNaughton, 2003; Grupe & Nitschke, 2013; Mineka & Zinbarg, 2006). Irrespectively, although each author highlights some specific mechanisms and origins for anxiety, they are far from mutually exclusive, sharing many important features between them, such as the importance of its cognitive characteristics and its distinction from fear (Strongman, 1995).

Importantly, along the way, the ambiguity of this concept was markedly improved with the introduction (division) of anxiety as a state and a trait by Cattell and Scheier (Cattell & Scheier, 1958). Trait anxiety reflects an individuals' own predisposition (i.e., a personality trait) for elevated anxiety feelings and how easy such responses are evoked (Endler & Kocovski, 2001). One of the first investigations that aimed at differentiating these two personality poles, came from Malmo (1957) who showed that patients who had "pathological anxiety" (similar to what is referred today as high trait anxiety) displayed high arousal patterns in several physiological measures, regardless of the environment (stressful or not). However, the study and development of this concept owes a great deal to Charles Spielberger (Spielberger, 1966, pp. 16–19) who also introduced the famous State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983). Later research has shown that not only is trait anxiety relatively stable over time (Usala & Hertzog, 1991), its often associated with the development of ADs and other mental disorders (Gottschalk & Domschke, 2017). More recent times have also seen the introduction of anxiety sensitivity, which, even if partially overlapping with trait anxiety, reflects instead one's fear of anxiety symptoms (oftentimes known as "fear of anxiety"; Taylor et al., 1991).

In its state form, anxiety is best conceptualized as a "future-oriented cognitive-affective-somatic state" (Chua et al., 1999), that is felt as "a sense of uncontrollability focused on possible future threat, danger, or other upcoming, potentially negative events" (Barlow et al., 1996). More concisely, it is viewed as a "unique and coherent cognitive-affective structure within our defensive motivational system" (Barlow, 2004). By increasing the activity of the sympathetic nervous system (Hoehn-Saric & McLeod, 1988) this state prompts the mobilization of defensive responses (see below), preparing oneself to deal with potentially threatening events. This functional state also promotes/prepares sensory processing to quickly detect any threat, enabling a rapid implementation of appropriate defensive responses, as I will describe in more detail below (Baas et al., 2006; Grillon et al., 1991; Robinson et al., 2012). Importantly, this state involves both conscious feelings of anxiety (felt as, for instance, unease and apprehension) and physiological and behavioral defensive responses – albeit in some cases these two facets are not always seen together (see LeDoux & Pine, 2016 for a discussion on this topic).

Anxiety shares many similarities and even overlaps with fear, with feelings and responses of fear (e.g., panic attacks) being a major part – alongside anxious feelings and avoidance behaviors – of ADs (American Psychiatric Association, 2022). Despite sharing many features with fear, states of anxiety have since been distinguished from fear based mostly on uncertainty. Albeit not entirely convergent, it is generally assumed that whilst fear represents a short response toward an imminent and present threat, anxiety on the other hand is a more sustained response toward uncertain or unpredictable (but anticipated) dangers (Lang et al., 2000; LeDoux & Pine, 2016). This distinction is further supported by neurophysiological studies showing that the neural substrates and circuitry underlying each state (fear and anxiety) are, indeed, partially overlapping, but have, nonetheless, their significant differences (see Apps & Strata, 2015; Tovote et al., 2015).

Aside from explaining anxiety and differentiating this state from a fear response, researchers have always been interested in properly measuring anxiety, a task far from easy given the overlapping symptoms with fear (as shown above; see also Öhman, 2008) and depression (Caci et al., 2003; Endler et al., 1992). The first measure of anxiety came from Spielberg (1983) who introduced the STAI, a 20-item self-report inventory, that has since then been translated in over 30 languages, being used widely throughout the scientific literature, standing as the *de facto* anxiety measure (Spielberger, 1984). Later a new anxiety measure with 21 items was introduced called the State–Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Barros et al., 2022; Ree et al., 2008) that further divided/separated anxiety into cognitive and somatic symptoms. It further improved on STAI's capacity to distinguish depression from anxiety (a known pitfall; Knowles & Olatunji, 2020), providing a more "clean" anxiety measure (Grös et al., 2007). Although these are, arguably, the most famous and widely used inventories, other inventories/questionnaires and scales have also been developed (e.g. Beck Anxiety Inventory; Steer & Beck, 1997) as well as other scales targeted at specific variants of anxiety (Liebowitz Social Anxiety Scale; LSAS; Liebowitz, 1987) and ADs (Generalized Anxiety Disorder questionnaire; N. Williams, 2014). Notably, these assessment tools have been valuable in helping the identification and characterization of high trait (dispositional) anxiety as well as ADs.

High trait and pathological anxiety

Although anxiety may be, arguably, less important (vital) in todays' modern society, this state was an indispensable asset for our ancestors, who, in the face of more commonly occurring unsafe environments, developed this state as a safety mechanism. Its propagation through our evolution is assumed to be carried from the basic principle that false positives are better than false negatives, since the latter may likely mean harm or death, and the former usually just results in some "discomfort" (Hofmann et al., 2002). Albeit useful long ago, it has, in today's society, morphed into a state that emerges in other contexts that involve other sources of threat to oneself, and less related to the possibility of physical threats (e.g., fear of making a fool out of oneself). The (often) maladaptive transposition of this state into these new scenarios, has given anxiety "a new purpose". This has supported this state's pervasiveness in today's modern societies, as opposed to its expected reduction, given that we are, in general, safer now than a few thousand years ago (Pinker, 2011). Thus, as stated in Beck and colleagues (1985, p. 4), "[…] the cost of survival of the lineage may be a lifetime of discomfort".

As described above, one personality trait that aids in the occurrence/prevalence of such feelings, is elevated trait anxiety. High trait anxiety is characterized by a hyper-responsiveness to stress, leading to frequent feelings of anxiety. Although non-pathological, such elevated anxiety trait can often contribute, or at least be associated, with the development of anxiety and depressive disorders (Gottschalk & Domschke, 2017; Hettema, 2008; Kendler et al., 2004; Weger & Sandi, 2018). These ADs happen when states of anxiety become reoccurring and interfere significantly in one's life, leading to their pathological label. Although generalized anxiety disorder (GAD) can be seen as the prototypical disorder, the anxiety disorder spectrum encompasses many more disorders – which may vary depending on which criteria/manual one chooses to follow (Grillon, 2008). For instance, according to the Diagnostic and Statistical Manual of Mental Disorders (American Psychiatric Association, 2022), other ADs include specific phobias, panic disorders, social anxiety disorders, among others. Similarly, the International Statistical Classification of

Diseases and Related Health Problems (World Health Organization, 2019) also specifies a vast list of different variants of ADs, that broadly overlap with those described in the manual presented above.

This broad spectrum of ADs, with their respective phenotypic manifestations, is also reflected in the heterogeneity of neuroimaging findings regarding pathological anxiety. One core feature among the different types of ADs is related to the overactivation of the amygdala and insula (Etkin & Wager, 2007; Schmidt et al., 2018). This finding is perfectly aligned with the idea that the amygdala is implicated in the detection of biologically salient cues (Öhman, 2005) and is implicated in aversive conditioning (Davis, 1992; Kapp et al., 1992). The amygdala's hyperactivity found in ADs (and in individuals with elevated trait anxiety) appears to be a direct consequence of a reduced capacity of other areas, such as the ventrolateral and ventromedial pre-frontal cortex (PFC; Bishop, Duncan, Brett, et al., 2004; Brühl et al., 2014; Greening & Mitchell, 2015; M. J. Kim & Whalen, 2009; Monk et al., 2008) and the fusiform gyrus (Pujol et al., 2009) to down-regulate this activation. This exaggerated amygdala activity is specially seen in clinical anxiety subjects during threat processing (Etkin & Wager, 2007). Additionally, the anterior cingulate cortex (ACC) also seems implicated in high-trait anxiety, with reduced connectivity between the ACC and the lateral PFC (Comte et al., 2015), but increased ACC connectivity to the amygdala (Greening & Mitchell, 2015), associated with higher levels of trait anxiety. Moreover, the insula also plays an important role when individuals are anticipating possible aversive stimuli. This is shown in Simmons et al. (2006), where anxiety prone individuals (i.e., with elevated trait anxiety) showed an exaggerated (compared to non-anxiety prone subjects) insula activity during threat anticipation contexts (see also M. B. Stein et al., 2007).

Another brain region implicated in ADs and in elevated trait anxiety is the bed nucleus of the stria terminalis (BNST), a structure considered part of the extended amygdala, and that, together with the latter, is deeply integrated in threat processing (Somerville et al., 2010; Yassa et al., 2012). In fact, the classical startle response attributed to fear states seems to be dependent on an intact BNST (Lang et al., 2000; Lee & Davis, 1997). Importantly, the BNST appears to have a more specific role in monitoring for the presence of threat in uncertain contexts, be it a psychological or physical type of threat (Mobbs et al., 2010; Somerville et al., 2010). As put by Ledoux and Pine (2016), "The BNST has thus come to be for anxiety what the amygdala is for fear […]". Indeed, some reviews suggest that, compared to the amygdala, the BNST plays an even bigger important role in regulating sustained fear responses (anxiety), with subsequent lesions in this region implicating attenuated anxiety states in contexts of unpredictable threats (Knight & Depue, 2019; Lebow & Chen, 2016; Walker et al., 2003). Contrarily, overactivation and more sustained responses of the BNST appears to be present in ADs and in individuals with elevated trait anxiety (e.g., Brinkmann, Buff, Feldker, et al., 2017; Brinkmann, Buff, Neumeister, et al., 2017; Brinkmann et al., 2018; Buff et al., 2017; Yassa et al., 2012).

These core/shared features among ADs (e.g., overactivation of the amygdala) algo give rise to some general facets that are common across all ADs, such as aberrant and excessive states of apprehension and hypervigilance when under unpredictable environments and excessive biases towards threat-signaling cues (Bar-Haim et al., 2007; Craske et al., 2009; Grupe & Nitschke, 2013). People diagnosed with GAD also display exaggerated physiological (e.g., elevated startle responses) and subjective (e.g., intolerance of uncertainty) emotional responses in the face of unpredictable contexts (Dugas et al., 2005; Ray et al., 2009). Deficits in areas related to working memory and attention are also reported to be found in this population (Vytal et al., 2016; Yang et al., 2015; but see Najmi et al., 2015; Leonard & Abramovitch, 2019). Furthermore, high trait anxiety is also associated with several cognitive changes. For instance, these individuals tend to give biased assessments of the risk associated with unpredictable events (Butler & Mathews, 1987; Craske & Pontillo, 2001; Mitte, 2007), and have a quicker engagement towards threat cues (Koster et al., 2006). Safety learning mechanisms (fear extinction) are also impoverished in anxious-prone individuals (Rauch et al., 2006; Waters et al., 2009). Additionally, high trait anxiety is also associated with a poorer performance in learning tasks (Thoresen et al., 2016) and increased difficulty in filtering irrelevant information (Bishop, 2009; Derryberry & Reed, 2002; Gaspar & McDonald, 2018). All of the aforementioned effects can be overwhelmingly impactful on one's life, thus gathering a vast amount of literature around them in an attempt to gain a better understanding of their ramifications.

Functional anxiety

Notwithstanding its negative effects when viewed as a sustained and dysfunctional state, normative/functional states of anxiety, as experienced when individuals experience elevated state anxiety in fitting scenarios and for short durations, can evoke beneficial and adaptive effects. Although the literature concerning states of anxiety (as experienced when one is anticipating potential threats) is limited, a few studies have probed this area of research using a myriad of different methods. Some methods used to induce anxiety rely upon anxiety-eliciting videos, such as videos depicting home invasions or threat of falling (e.g., Giannakakis et al., 2017). Others simply use imagery, where participants are asked to imagine personal or imaginary anxiety-eliciting situations (e.g., Heenan & Troje, 2014). Other methods, such as social (speech) stressors, induce general feelings of anxiety in anticipation of a future stressful event, such as giving a public speech (e.g., Wieser et al., 2010). Lastly, some methods induce anxiety in a more sustained manner. These include, for instance, the threat of scream (Beaurenaut et al., 2020) and the threat of shock (e.g., Grillon et al., 2004) paradigms, with the latter being the most commonly used. Both paradigms take advantage of the unpredictability of the aversive event used, with the former paradigm using loud screaming sounds and the latter using mild electric shocks. Specially in what concerns the latter paradigm (threat of shock), this provides a well validated (Schmitz & Grillon, 2012) and efficient way to induce anticipatory (threat-induced) anxiety. Here, the possibility of random, but merely sporadic, electric shocks results in elevated feelings of anxiety as well as physiological markers of anxious states (Grillon et al., 2004).

Albeit good ways to additionally provide insights into pathological anxiety states, it is worth noting that, at least from a neurobiological standpoint, anxiety induced by the methods discussed above more aptly mimics states of potentially impending danger and less so of ADs (Chavanne & Robinson, 2021). Nonetheless, as expected, normative states of anxiety share many of the brain regions and circuits implicated in ADs and in elevated trait anxiety (but see Saviola et al., 2020), implicating predominantly the amygdala (Bishop, Duncan, & Lawrence, 2004; Herrmann et al., 2016; Torrisi et al., 2018; Vytal et al., 2014) and the BNST (Grupe & Nitschke, 2013; Lang et al., 2000; Ueda et al., 2021; Walker & Davis, 2008). However, in these cases, the neutral circuitry of anxiety appears to be preserved, leading to expected (properly regulated) activation of these areas (Cannistraro & Rauch, 2003). Here, the PFC connectivity with the amygdala appears to function adequately, with the PFC signaling to the amygdala that fear/anxious responses are no longer required when such is in fact the case (M. J. Kim, Loucks, et al., 2011). In other words, a proper communication between PFC and amygdala activity appears to be a mandatory requirement for functional anxiety responses observed in healthy individuals, with impairments in such a connection being implicated in higher disposition towards anxiety and even ADs (Bishop, 2009; M. J. Kim, Gee, et al., 2011; M. J. Kim & Whalen, 2009). The same level of connectivity between BNST and the PFC (as well as the amygdala) seems crucial to a proper autonomic and neuroendocrine control in the context of potential threats (Klumpers et al., 2017). Lastly, and as mentioned before, the ACC and insula, by also initiating and maintaining inputs that modulate prefrontal and limbic structures, are also of critical importance in maintaining healthy anxiety responses (Carlson et al., 2011; Holzschneider & Mulert, 2011; Straube et al., 2009). It is worth noting that the abovementioned regions and circuits implicated in anxiety, concern the physiological, behavioral and cognitive features that define anxiety, and not necessarily the mental state (conscious feelings) associated with anxiety (see LeDoux & Pine, 2016 for a discussion on this topic).

Aside from underpinning the neural pattern of an anxiety response, researchers were also able to isolate the physiological consequences of such states. These range from increased heart rate (Hodges & Spielberger, 1966), startle response (Grillon et al., 1991), skin-conductance (Kopacz II & Smith, 1971), respiratory frequency (Masaoka & Homma, 2001), among others. All of these responses are associated with heightened activity in the autonomic nervous system and are involved in creating a preparedness state to deal with threat (Jansen et al., 1995; Schirmer &

Escoffier, 2010). The insights gained from these studies also depict just how vastly anxiety affects cognitive processes. For instance, memory components that concern temporary information storage and manipulation, such as verbal and spatial short-term memory and even overall working memory, seem disrupted under threat of shock (Shackman et al., 2006; Vytal et al., 2012, 2013). This seems to be dependent on how anxiety states share the same resources used by working memory, particularly those involved in spatial working memory (Cornwell et al., 2008; Vytal et al., 2013). Findings concerning long-term memory, however, seem to point in the opposite direction, with threat of shock leading to an improved long-term memory (Weymar et al., 2013; but see Bolton & Robinson, 2017). Specifically, this is thought to be associated with the emotional arousal and corresponding physiological responses evoked by this state and the evident connection between the hippocampus and the amygdala (Cahill et al., 2003; Roozendaal et al., 2006, 2009). Nonetheless, the evidence amounted so far presents a mixed picture and a high dependency on the type of memory (e.g., episodic, spatial) being explored (see Robinson, Vytal, et al., 2013). Decision making is also another cognitive process affected by states of anxiety, with participants evidencing a shift towards more safe (i.e., less risk-prone) decisions, when under anxiety in an attempt to reduce harm (Clark et al., 2012; Starcke & Brand, 2012).

Attention is perhaps the most thoroughly studied cognitive function within normative anxiety, showing a slightly different picture compared to that of ADs. Instead, some aspects of anxiety, such as inhibitory control, appear to be improved under anxiety (Robinson, Krimsky, et al., 2013) – albeit this can be still interpreted to reflect reduced attentional control (see Grillon et al., 2016). Overall, however, studies have amounted some evidence showing reduced interference from distractors during anxiety (K. Hu et al., 2012) and even improved goal-directed attentional control (A. J. Kim et al., 2020; but see A. J. Kim & Anderson, 2020). As mentioned before, one relevant and vastly documented effect of anxiety is a state of increased vigilance (hypervigilance) and overall alertness. Alongside sensory-perceptual changes (discussed in a chapter below), this state reflects a tendency to a sustained vigilance state, actively searching for sensory changes in our environment (Eysenck, 2013, Chapter 3; Kastner-Dorn et al., 2018). Importantly, this heightened attention seems particularly targeted (biased) towards stimuli signaling any sort of danger (i.e., threat related; Robinson, Vytal, et al., 2013). Indeed, while removing attention from fearful faces or presenting these under high-attentional load conditions results in a reduced amygdala activation, such decrease in amygdala activation is not observed when one is under anxiety (Bishop, Duncan, & Lawrence, 2004; Cornwell et al., 2011). However, studies relating threat biases and states of anxiety in healthy populations are considerably scarcer compared to threat biases in dispositional or ADs, with many also implying interactions with dispositional anxiety (Edwards et al., 2006, 2010; Miller & Patrick, 2000) and even yielding contradicting findings (see Bar-Haim et al., 2007). In fact, some studies evidence attentional biases away from threat in healthy individuals exposed to threat of shock (Shechner et al., 2012). Furthermore, most studies employed visual search paradigms or used distractors in their tasks, assessing attention and vigilance as a function of task performance, with very little studies using any sort of gaze measures. The very few that assessed this, showed that under threat participants exhibit a reduced fixation stability (Laretzaki et al., 2011), have lower sampling rates when exploring target areas (i.e., less saccades and dwell times; Stankovic et al., 2014) and have enhanced gaze capture by physically salient, but not reward-associated, stimuli (A. J. Kim & Anderson, 2020).

A perhaps even more important ramification of anxiety on healthy individuals, and an extension of the previous paragraph, concerns its impact on visual mechanisms, from processing to perception. Before continuing with an in-depth exploration of these effects, it is first important to briefly address how we build our visual world and what sort of influences might affect this process.

Influences on visual perception

> What is said to be perceived is in fact inferred.
>
> (Bartlett, 1932, p. 83)

> The human mind *uncontrollably* creates meaning from stimuli. This is a fact, a process you cannot escape, an activity that goes on in spite of your will or even desire.
>
> (Bloomer, 1990, p. 9)

Visual perception is a broad and complex topic. It is broad in the sense of incorporating the whole process that gives rise to vision: from sensory reception (light reaching the eyes) to the conscious perception of what we are seeing. To reach this last phase, sensory input is processed through multiple layers of complexity, first extracting simple features (e.g., color, motion) and then being grouped and organized into more complex (meaningful) percepts (Bloomer, 1990, Chapter 1). Importantly, the image we create of our visual environment is not a true representation of itself. In reality, what we see is far different from an exact replica of the sensations we receive. Instead, many factors contribute to what we see. From expectations, to motivations, these all play a part in shaping (biasing) our perception of the world. Although their influence has been considered mostly negligible up until the 21st century, the idea that top-down influences (i.e., higher level cognitive processes, such as expectations) carry a significant weight over our vision of the world, has been steadily solidifying in the literature (Bar & Bubic, 2013). But just how pervasive and influential are top-down influences over visual perception?

Expectations and perceptual biases

Given the amount of information reaching our eyes, the whole process of visual perception can be demanding. In addition, the prospect of a clear and unambiguous view is often not met, and we are instead faced with noisy or ambiguous visual information. To overcome this, one tactic employed by our brains is to constantly predict the causes of sensory input that are reaching it. As well summarized by Bruner and Goodman (1947, p. 35), we live "in a world of more or less ambiguously organized sensory stimulation.". This allows for a more efficient information processing as well as more robust inferences over degraded information.

The idea that the brain tries to predict (i.e., anticipate) the causes of sensory-input is by no means new, dating back to, at least, the 1860s (Helmholtz, 1867, see 2013 for a recent reprint). Such notion, however, took some time to gain traction, with the knowledge of how such mechanism is implemented in the brain also eluding researchers. Past decades, however, saw a renewed interest on this matter, leading to perception being viewed as a highly active process, with the brain trying constantly to hypothesize the meaning/causes behind sensory input. Frameworks as to its implementation have also emerged, with one of the most prominent being predictive coding (Huang & Rao, 2011; Rao & Ballard, 1999). This framework views vision as a hierarchical processing mechanism, with sensory input being compared with an internal model of the world, often referred to as expectations or priors, at each processing stage. The difference/disparity between such comparison (i.e., between sensory input and expectations) is labeled as prediction error and is propagated up the visual stream and used to update our internal models. Perception thus works by minimizing the difference between predicted (internal models) and observed causes (sensory input; Huang & Rao, 2011; Rao & Ballard, 1999). Importantly, most theories behind visual perception share the core idea of the brain as a anticipatory machine, trying to, most efficiently, articulate expectations (priors) with sensory data (likelihood), with the overall goal of minimizing the discrepancy between these two factors (de Lange et al., 2018).

An indirect marker of this mechanism in action can be glimpsed using electroencephalography (EEG) or magnetoencephalography (Rauss et al., 2011). For instance, by exposing participants to sets of repeated auditory stimuli, certain neural activity markers regarding that processing will be dampened. The exact explanation behind this weaker response towards expected (repeated) stimuli remains up for debate (see de Lange et al., 2018). Importantly, however, a break in this pattern, with, for example, a deviant stimulus (e.g., with a different pitch), will create a negative deflection in the EEG activity – an assumed reflection of prediction error – in what is referred to as mismatch negativity, or simply MMN (see below for a more thorough explanation; Garrido et al., 2009; Stefanics et al., 2014). In sum, we actively predict our visual environment, creating expectations on what we are seeing that are combined with incoming sensory input. Mismatching information between the two is constantly used to update our model of the world, refining future expectations (de Lange et al., 2018). Crucially, a proper management of how these two components, expectations and sensory input, are integrated proves critical towards a proper and efficient perception of the world (see below the pathological consequences of this disruption).

The influence of expectations can be felt mostly at times where sensory input is ambiguous or noisy, with prior expectations biasing your perception in an attempt to disambiguate incoming information. A basic example is seen when participants associate a specific one dot color with a direction and another color with an opposite direction. After then presenting them with ambiguous moving dots, participants rely heavily on their color to infer their perceived dominant direction (Sterzer et al., 2008; see also Aitken et al., 2020). Indeed, the weight of expectations can be so impactful in certain scenarios, as to make us see illusory stimuli that are expected to be present (Aru et al., 2018; Chalk et al., 2010), being a major mechanism behind hallucinations (Pajani et al., 2015; Powers et al., 2017). Logically, when sensory input is clear and reliable such influences are less weighed on perception (Rossel et al., 2023). In these circumstances our visual system still uses expectations for efficiency purposes, such as being faster and more accurate in detecting expected stimuli (Bar, 2004; Pinto et al., 2015; T. Stein & Peelen, 2015; Wyart et al., 2012).

Nonetheless, and as already mentioned, adequately managing the weight given to expectations is of critical importance. On the one hand, overweighing expectations might excessively bias one's perception, misinterpreting the presence of a signal (i.e., expected stimuli), or in other words, creating the abovementioned illusory and even hallucinatory percepts. On the other hand, an underrepresentation of expectations might hamper complex signal recognition, leading to a slower interpretation of complex stimuli and a reduced ability to extract meaning. Indeed, the ability to manage expectations and sensory input has even been proposed to account for deficits found in some psychiatric disorders. Specifically, autism has been linked to hypo-active priors, resulting in a subsequent over reliance on sensory input, explaining hampered social abilities and overstimulation (Lawson et al., 2014; Pellicano & Burr, 2012; von der Lühe et al., 2016). Conversely, psychotic disorders, such as schizophrenia, are suggested to instead exhibit hyper-active priors, with delusions and hallucinations as a possible result (Griffin & Fletcher, 2017; Horga et al., 2014; Kafadar et al., 2020; but see Stuke et al., 2018).

In building our expectations, we exploit statistical regularities found throughout our lives, to then anticipate incoming information. The source of these regularities can be varied, ranging from simple but persistent environmental associations to more flexible (i.e., contextual) regularities. Simpler associations, also known as structural expectations, usually reflect long-term relations gathered from our environment, afforded by repeated experience, and have since been integrated as a default expectation (Hardstone et al., 2021; Seriès & Seitz, 2013). These are found, for instance, in how we use the knowledge of light being usually above to derive the shape of objects in our environment (Sun & Perona, 1998) – also easily incorporating new light sources (from different directions) into this process (Gerardin et al., 2010). Many more regularities have since been found, showing that, given their frequency, we have built in (default) prior expectations to account for them. This is the case with, for instance, cardinally oriented lines (i.e., horizontal or vertical; Girshick et al., 2011), perceiving convexity in objects (Goldreich & Peterson, 2012), and perceiving other's gaze as directed towards us (Mareschal et al., 2013). Such long-term associations are even suggested to be able to tune our sensory cortex (alter its cortical response properties) to account for these regularities more easily (Cloherty et al., 2016).

We can also develop (learn) and use new and more malleable (short-term) regularities that aid perception – also known as contextual expectations. Such expectations can even alter our default (structural) expectations, updating our current internal models as to what to anticipate (W. J. Adams et al., 2004; Sotiropoulos et al., 2011). Following the example of the colored dots given above, contextual expectations are often introduced through cues found in our sensory environments. This is often seen by biased perceptions of ambiguous stimuli according to contextual cues presented alongside them. Indeed, this phenomenon is easily seen in our daily lives, when we try to perceive degraded stimulus (e.g., far away or partially obscured by objects) and use context to infer what it is (simply known as scene and object interaction; Brandman & Peelen, 2017). A clear example is shown by Bar (2004), where a blurred object can just as easily be perceived as a hairdryer or a drill depending on its surrounding context. Or, for instance, how we are more likely to perceive a second person in difficult viewing conditions when another participating element performs a communicative gesture as opposed to an individual one (more about this below; Manera, Del Giudice, et al., 2011; Manera et al., 2013).

It is easy to see how expectations play a vital role in shaping perception, by facilitating how stimuli are processed based on external cues (e.g., context) and accommodating environmental regularities. However, other top-down influences, including goals/motivations and emotional states also weigh in, creating perceptual biases that act upon sensory information (Otten et al., 2017). These biases are systematic tendencies or preferences based on our motivations and emotions that affect how we process and perceive our visual world, either by shaping saliency of some stimuli (via attention) or directly altering our perception. Although we may believe ourselves impervious, these perceptual biases are commonplace, distorting (or, more aptly, shifting) our perception, leading to certain favored interpretations.

Starting with motivations, these cognitive goals weigh in and facilitate the perception of what we desire to see – giving support to the famous expression of "we see what we want to see" (Balcetis & Dunning, 2006). This type of bias is often referred (but not solely) in the psychological literature as *wishful thinking* or *wishful seeing* (Balcetis & Dunning, 2006), and reflects our biological and psychological desires/drives. There are plenty of examples that can attest as to how impactful this bias can be. For instance, hungry participants tend to detect food-related words more quickly (Radel & Clément-Guillotin, 2012), and thirsty individuals tend to perceive transparency to a greater extent (Changizi & Hall, 2001). Even basic reward associations can reflect this bias. For example, when letters (as opposed to numbers) are associated with rewards, people tend to see them more easily in ambiguous drawings of letters and numbers compared to the latter (Balcetis et al., 2012; see Cole & Balcetis, 2021 for more examples).

Likewise, emotional states – possibly through their associated motivational drives (Balcetis, 2016; Zadra & Clore, 2011) – shape our perception of the world in a significant way, albeit in a, perhaps, less straightforward manner. Firstly, many influences of emotion over perception are done so indirectly via attentional biases. This is seen in studies showing how under fear or anxious states people have an increased biased attention towards threat-signaling stimuli (an effect also present in control individuals to a lesser extent; Öhman, Flykt, et al., 2001), such as words or pictures (MacLeod & Mathews, 1988; Sheppes et al., 2013). Likewise, positive moods appear to shift attention towards positively-valued stimuli (M. W. Becker & Leinenger, 2011; Tamir & Robinson, 2007). Despite this indirect route, emotional states can and do bias perception in a more direct fashion. For instance, the steepness of a hill, a famous example of a perceptual bias (Proffitt et al., 2001), is seen as more inclined when a sad mood is induced in participants, as opposed to a positive (happy) mood (Riener et al., 2011). These two moods also lead to differences in the perceptual approach adopted by the individual (also involving attention) in terms of narrow (local) versus global view of images. During positive moods, participants adopt a more global view (forest), as opposed to the more local view (tree) during negative states (Gasper & Clore, 2002) – although this effect was modulated by type of view is most available (Huntsinger et al., 2010) and motivation to approach (Gable & Harmon-Jones, 2008). Fear also influences how a slant is perceived, with participants at a bigger risk of falling, or with greater fear of height, judging hills as steeper compared to those in safer conditions or with less fear of heights (Stefanucci et al., 2008; Stefanucci & Proffitt, 2009; Teachman et al., 2008).

Lastly, it is worth noting that biases can also have bottom-up (exogenous) trajectories. In these cases, the stimuli itself is the source of the bias, automatically boosting their processing and orienting one's attentional focus towards itself, or altering perceptual mechanisms, affecting its, and incoming stimuli's, processing (D. M. Beck & Kastner, 2009). For instance, stimuli with bigger contrast differences compared to their respective background grab attention more easily (Andersen et al., 2012). Sudden motion, is another simple example of a bottom-up driven bias (Abrams & Christ, 2003). A more complex and important example regards threat biases, which were already mentioned above as a consequence of fear and anxiety. These stimuli benefit from inherent physical properties which boost their physical salience, driving a faster attention capture, in what is often termed as threat-superiority effect (B. A. Anderson & Britton, 2019; Bannerman et al., 2009). One paradigmatic example concerns the quicker detection of threatening animals, such as snakes and spiders, compared to neutral ones, such as birds (Gomes et al., 2017; Öhman, Flykt, et al., 2001). Anger and fearful faces, both expressions signaling potential dangers, seem also to bias one's attention, invoking rapid gaze orientation towards such expressions (Öhman, Lundqvist, et al., 2001; Pinkham et al., 2010; but see D. V. Becker et al., 2011). Indeed, these phenomena are thought to be rooted in basic features (e.g., geometric shapes) that automatically signal high value in these stimuli (Larson et al., 2007, 2009). In addition, processing these emotionally laden stimuli also implements perceptual biases over upcoming stimuli. For instance, even without awareness of the stimuli, exposure to fearful faces can activate the amygdala (Morris et al., 1998; Vuilleumier et al., 2001). In turn, the amygdala, via connections to the visual cortex, can boost sensory processing, leading to an increased perceptual processing of threat-related stimuli (Vuilleumier, 2005). Not only this, but other visual shifts that prioritize threat processing, such as the prioritization of low spatial frequencies (LSFs) which carry rough/coarse visual features of a stimuli (see below for an explanation; Mermillod et al., 2010), are also observed when participants are exposed to fearful faces (e.g., Bocanegra et al., 2012; X. Hu et al., 2023; Nicol et al., 2013; Phelps et al., 2006).

Taken together, the expectations and other sources of perceptual biases discussed above play a role in almost every aspect of perception, particularly when perceiving ambiguous or noisy stimuli (Bruner & Goodman, 1947). However, one area where such influence seems highly marked appears to be the perception of social stimuli, such as faces or people (whole bodies). Thus, before continuing to how anxiety is involved in the perceptual mechanisms discussed so far, it is important to first briefly discuss the link between social perception and top-down influences.

Social perception and top-down influences

As a highly gregarious species, social interactions, involving either cooperation or competition, are a common occurrence in our daily lives. Within these interactions, meanings and intents are embedded in them, that offer vital cues in deciphering one's intention and potential responses. Thus, a vital component for social interactions is the capacity to rapidly interpret other's actions and retrieve their intentions based on several different social cues. Indeed, the highly specialized mechanisms for social perception – a cornerstone of social cognition (Fiske & Taylor, 2013, Chapter 1) – we possess and their associated efficiency, be it towards faces or bodies, is a clear indicator of the importance vision plays in social behaviors (Martin & Macrae, 2010). For instance, we can simply by the quickest of glances extract information about the age, sex, gender and even emotional state of a person (Bruce & Young, 1986). Nonetheless, when presented briefly, or displaying ambiguous expressions, we are prone to employ biases in categorizing these faces. For instance, when rapidly judged, facial expressions of surprise tend to be interpreted as more negative expressions (Neta & Tong, 2016). Moreover, a general bias towards anger attribution is seen in faces expressing minimal expressions of anger or even neutral expressions (Shasteen et al., 2015). These biases can also be brought about by the use of that face's immediate history (prior) to bias their interpretation in the direction of the expected facial expression (Jellema et al., 2011). Even the attribution of certain positive or negative connotations to certain people, as emerging in the cases of gossip, leads negatively associated faces to dominate the perceptual field when competing to reach visual awareness (E. C. Anderson et al., 2011). In fact, our own emotional state can also interfere with the processing of dynamic expressions, resulting in faces congruent with our own emotional state to persist longer when transitioning between emotional states compared to incongruent expressions (Niedenthal et al., 2000). As a last example, contextual cues (negative versus positive) can also help to disambiguate ambiguous facial expressions, such as surprise (frequently confused with fear; Roy-Charland et al., 2014). Namely, negative cues, but not positive cues, led to amygdala activations similar to those seen in fear following surprise expressions (H. Kim et al., 2004). Thus, it seems clear that, in the face of ambiguity, biases, taking several different forms (as discussed in the previous topic) permeate how we perceive and judge faces.

However, most of the effects concerning visual perception explored over social stimuli are isolated to facial expressions (and most often static ones). Whilst the value of faces in transmitting emotions and intentions about others cannot be questioned, body posture and movements carry also an incredible wealth of information, and its importance can rival that of faces (Pitcher & Ungerleider, 2021). To study how we extract information from dynamic bodies (and even dynamic faces in some cases), researchers have, for a long time now, relied heavily on point-light displays (PLDs) of human motion. This method was first introduced by Johansson (1973) and entails the representation of humans with dots/circles placed on the major joints, limbs and head. Since then, several databases have been developed that depict dynamic point-light displays of human agents performing different actions, with various meanings and emotional valences (e.g., Decatoire et al., 2019; Dekeyser et al., 2002; Okruszek & Chrustowicz, 2020). With this simple apparatus, researchers have been able to study basic and complex social perception, without the presence of unnecessary confounds (e.g., clothes, attractiveness). Indeed, researchers have shown, among many other examples, that these PLDs of humans are able to convey information regarding the identity of the actor (Loula et al., 2005), their gender (Pollick et al., 2005), actions being displayed (Alaerts et al., 2011; Dittrich, 1993) and emotional states (Alaerts et al., 2011; Atkinson et al., 2004; Vaskinn et al., 2016). Once more, this can attest to how specialized our brains are at extracting social cues, and also to the validity of this technique in carrying important, socially relevant, information.

These types of stimuli have been incredible useful in studying visual biases and expectations when interpreting ambiguous social displays of either solo or multiple agents. One relevant type of bias explored using PLDs concerns the perception of bistable motion, specifically regarding the identification of motion direction. Bistable motion is induced by presenting point-light displays of walking agents (often referred simply as point-light walkers [PLWs]) that can be viewed as having two veridical and anatomically plausible interpretations, either approaching (facing-the-viewer; FTV) or receding (facing away from the viewer; Schouten & Verfaillie, 2010). Using bistable PLWs, researchers have shown that we have an inherent bias towards perceiving approaching motion (i.e., FTV bias). This has first been shown by Vanrie and colleagues (2004), and has since then been replicated by multiple other studies (e.g., Schouten et al., 2010; Weech et al., 2014). Several factors have been advocated to be at play here. Some authors argue in favor of simple convexity biases, an heuristic developed from a frequent exposure to convex objects in our environment (Mamassian & Landy, 1998), as responsible for the FTV bias found in PLWs (Weech et al., 2014; Weech & Troje, 2013, 2018). Others suggest instead that biological/social relevance might be the main cause (e.g., Han et al., 2021; Heenan & Troje, 2014, 2015; Yiltiz & Chen, 2018; but see Peng et al., 2021). This latter view implies that FTV biases are based on fundamental social principles, preparing us for an impending social interaction or against potential threats. It follows that quickly determining if a person is facing us allows us to quickly implement appropriate responses and can thus be of potential value (Han et al., 2021). Although such response might, indeed, be something harmless, such as smile or hand wave, it might also be a quicky retreat or preparing oneself for a fight. As such, it can be argued that this inherent bias towards a "facing us" view of others, might be a safeguard against false negatives (Han et al., 2021). Supporting this, researchers have shown that the FTV bias can be subject to different factors, that either increase or decrease this propensity to perceive approaching motion. For instance, male PLWs tend to be associated with greater FTV biases – an effect suggested to be associated with males being, typically, more aggressive (Brooks et al., 2008; Schouten et al., 2010). Male participants have also been shown to have greater FTV biases than their female counterparts (Peng et al., 2021; Schouten et al., 2010). Greater social anxiety and weaker inhibitory abilities (Heenan & Troje, 2015; Yiltiz & Chen, 2018; but see Peng et al., 2021) also have been found to be associated with greater FTV biases. Additionally, feelings of guilt (Shen et al., 2018) and the mere the imminence of the social interaction (Han et al., 2021) also increase this bias. One last, but particularly relevant, example, concerns how anxiety reduction, either through progressive muscle relaxation or physical exercise, also seems to moderate FTV biases, reducing its effect (Heenan & Troje, 2014). Regardless, the exact nature of FTV biases remains debated, with the possibility that both convexity biases, as well as top-down factors, both contribute to the robustness of this effect in the general population.

Nonetheless, the usefulness of PLDs in studying social biases is not isolated to studying the perception of motion. As already hinted in the previous topic, the perception of other's actions and intentions is also highly dependent on predictions (Kilner et al., 2007). Indeed, PLDs have already been used to show that people can anticipate how actions will unfold and infer intentions from simple gestures, as well as how we show a remarkable ability to separate neutral from socially-relevant gestures (Becchio et al., 2012; Frith & Frith, 2006; Sapey-Triomphe et al., 2017). For example, we are able to discern competitive from cooperative intentions, as well as individualistic vs non-individualistic (eat or share an apple) actions, from simple motions (grasping for an object), from both PLDs and normal videos (Becchio et al., 2012; Manera, Becchio, Cavallo, et al., 2011; Sartori et al., 2011). In fact, simple information, like motion/activity of certain finger muscles appears to be enough for people to disambiguate these grasping actions and retrieve any intention-to-interact from people (Betti et al., 2022). Difficulties in such tasks, where using contextual information is required to properly infer the types of intentions presented (individual vs cooperative), have been reported in individuals with autistic disorders (Chambon et al., 2017) and even associated to healthy individuals with higher autistic traits (Bianco et al., 2020).

Manera and colleagues (2010) have also elaborated another particularly interesting paradigm, where they were also able to show, using PLDs of two agents, how expectations are crucial in anticipating incoming actions and the timing of those very same actions – a phenomenon they labeled as interpersonal predictive coding (Manera, Becchio, Schouten, et al., 2011; Manera, Del Giudice, et al., 2011; Manera et al., 2013). In this paradigm, the participant is simply asked to indicate how many agents (represented as PLDs) are present in a video. The catch, however, is that only one agent is clearly shown, and the other can be either present or absent, with its identification being hindered by noise and other visual disruption techniques. By varying the nature of the action of the first noise-free agent, either showing a communicative (e.g., "come here" gesture) or individual (e.g., "takes a sip of water") gesture/action, they provide participants with cues to identify the presence of the latter (degraded) agent. Indeed, they were able to demonstrate that when presented with communicative actions (as opposed to individual ones), participants exhibit a more lenient decision threshold, as measured by criterion (see below or in Stanislaw & Todorov, 1999), in deciding presence (i.e., are more biased towards signaling presence). Importantly, since then, several studies have come to replicate this effect (e.g., Okruszek et al., 2017; Zillekens et al., 2018) and even expanded on the neural correlates behind this process (Friedrich et al., 2023).

In sum, it is fair to say that both predictions and perceptual biases play a major role in defining our perceptual experience. Moreover, social perception appears not only susceptible to these influences, but also, given its ambiguity and complexity, highly reliant on both expectations and prone to biased interpretations. The next topic will tie both of these two initial chapters together, exploring specifically how states of anxiety may alter the weight given to expectations and simultaneously introduce its own biased perception, with a particular emphasis over social scenarios.

Linking anxiety and (social) visual perception

> "Worry often gives a small thing a big shadow."
>
> Swedish proverb

Among the many effects of anxiety, affecting how our visual perception of the world takes place remains highly unexplored. Indeed, most efforts seem to have been focused on attentional biases. Those that more directly approach perception when under anxiety, do so with more basic paradigms, providing limited insight into how such effects might carry over to our daily lives. Below I explore the state of research surrounding anxiety and visual perception, highlighting unexplored questions and paving the way to this thesis' objectives and inquiries.

Early sensory-perceptual processes under anxiety

The first topic in this chapter showed how states of unpredictable threat (i.e., anxiety-inducing) usually give rise to hypervigilance. Although characterized by increased sustained attention (i.e., a heightened environmental scanning), another component of this hypervigilance state is an enhanced early sensory-perceptual processing (Robinson, Vytal, et al., 2013; Weymar et al., 2014). Early sensory-perceptual processing, in relation to vision, refers to the early (most temporally immediate and basic) phases of sensory processing, involving the initial stages of detection and processing (Robinson, Vytal, et al., 2013). Enhancement of this mechanism is assumed to rely on the sensitization of sensory cortical systems and is thought, based on non-human research, to be moderated by the amygdala, specifically the basal nucleus of the amygdala, which projects towards early visual areas (Amaral et al., 2003; Davis & Whalen, 2001; Lojowska et al., 2018). Subsequently, these connections lower overall sensory thresholds, or in other words increase baseline visuocortical activity, providing a greater capture of sensory input (i.e., a heightened stimulus-driven process). This results in a quicker ability to detect and process sensory changes in our environment, leading specifically to an improved signal discrimination (perceptual sensitivity; de Voogd et al., 2022).

Increased sensory-perceptual processes can be measured via different methods. One such method is the sensitivity index (*d'*) from signal detection theory (SDT), which measures one's ability to accurately discriminate between signal and noise (see Stanislaw & Todorov, 1999). Another way, albeit more recent and thus less common, concerns drift diffusion modelling (DDMs; Ratcliff & McKoon, 2008) where both decisions and reaction times are considered in elaborating a decision model. Specifically, the drift rate parameter concerns how one quickly accumulates evidence towards a perceptual decision boundary, having the potential to show how much evidence one requires in reaching the correct decision threshold. The lesser evidence one requires (i.e., bigger drift rates) when facing a specific stimulus to reach to correct decision, the bigger one's perceptual sensitivity (Pirrone et al., 2017).

Other, and more predominant ways, upon which this potentiation of early sensory-perceptual processes during anxiety has been studied is by measuring the brain's electric activity, specifically event-related potentials (ERPs), to certain stimuli/events. For instance, Shackman and colleagues (2011) showed that when processing innocuous stimuli, states of threat amplify early ERPs (e.g., N1) and attenuate latter ones (P3). Relevantly, amplification of the N1 is thought to be associated with hypervigilance and enhanced sensory intake (Davis & Whalen, 2001; Hopfinger et al., 2004; Shackman et al., 2011), whilst attenuation of P3 is thought to reflect disrupted post-perceptual processes, such as goal-directed responses (see Nieuwenhuis et al., 2005). Besides higher amplitudes of early ERPs, their respective latency also appears to be reduced (Laretzaki et al., 2010). Indeed, even earlier measures concerning sensory-processing, observed in the first milliseconds of stimulus presentation, are also enhanced during states of threat (Baas et al., 2006).

The findings discussed so far are also supported by studies investigating mismatch negativity during anxious states. Mismatch negativity (MMN) is a "negative component of the waveform obtained by subtracting the event-related response to the standard event from the response to the deviant event." (from Garrido et al., 2009, p. 453). When presented with a deviant (oddball) sensory stimulus during a sequence of repeated sensory events, one can elicit this negativity potential which peaks at around 100 to 250 ms (Garrido et al., 2009; Sams et al., 1985). Importantly, MMN can be regarded as an error detection mechanism, encapsulating the mismatching result between expected and actually experienced sensations (Garrido et al., 2009). This event is thus a direct marker of sensory-perceptual processes, where augmented MMN implies a bigger weight given to sensory changes (i.e., hypervigilance) in relation to expected/top-down predictions and vice-versa. For instance, attention directly improves the reliability of sensory-input, increasing the value of prediction errors (Feldman & Friston, 2010; Garrido et al., 2018). Consequently attending a stimulus is shown to result in an enhanced MMN, compared to when such stimulus is unattended (Smout et al., 2019). This increased MMN is also what is observed when participants are exposed to deviant sounds when under threat[2], compared to safe, conditions (Cornwell et al., 2007, 2017). Indeed, these effects appear to mimic, at least partially, those found in people with ADs, such as post-traumatic stress disorders (Ge et al., 2011; Morgan & Grillon, 1999) and panic disorder (Chang et al., 2015; but see Cheng et al., 2021 and Tang et al., 2013).

As mentioned, this increased sensory-driven perception seen during anxiety consequently leads to expectations having lesser weight in defining our perception, as seen by the reduced suppression of prediction errors when facing deviants (compared to safe conditions). As such, the use of expectations based on contextual cues might be more limited under these states (Cornwell et al., 2017; Sussman, Jin, et al., 2016). Specifically, under threat, one might be less capable of gathering or employing other sources of information, such as contextual cues, when inferring the meaning of a sensory cause. As mentioned in a previous chapter, such scenario may be particularly harmful in making sense of more complex stimuli. One such case concerns social environments, where multiple complex visual (and auditory) cues are presented, and must be used in interpreting the other's intent and potential future actions (Kilner et al., 2007). Despite this, no study has yet directly assessed to what extent expectations are adequately used when under states of anxiety. One study by Berggren and Derakshan (2013), did suggest that elevated trait anxiety was associated with impaired usage of expectations, as seen with a difficulty in expectancy learning. Indeed, individuals with high trait anxiety have been shown to have a harder time adjusting to statistical regularities, and adopting optimal strategies in uncertain environments compared to low trait anxiety individuals (Browning et al., 2015). Another study by Cañal-Bruland and colleagues (2010) showed that perceptual effects expected as a function of performance (see Wesp et al., 2004), in this case with an increased performance in dart-throwing leading to target boards appearing bigger, disappear during higher anxiety conditions. Regardless, one study found that anxiety settings benefit one's perceptual sensitivity in identifying simple stimuli, with the reliance on prior expectations (as measured by criterion) being the same across safe and threat of shock conditions (de Voogd et al., 2022). Nonetheless, this general topic remains scarcely studied, particularly in what concerns how such effects carry over to social perception, leaving many questions open for exploration.

Detection of threat under anxiety

Although threat-induced anxiety can generally enhance sensory perception, making us more aware of sensory perturbations (i.e., new or unexpected sensory input), it also selectively improves the processing of stimuli deemed intrinsically valuable. Indeed, it seems that the enhanced sensory-perceptual processes seem particularly directed towards threat-signaling

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[2] To avoid repetition, the use of "under threat" or related variations of this expression is used interchangeably throughout this manuscript and reflect states of threat-induced (anticipatory) anxiety.

stimuli in our environment, with, for instance, bigger MMN responses occurring for fearful faces as opposed to happy faces (Robinson, Overstreet, et al., 2013). This is reflected in a greater sensitivity to detect the presence of cues signaling threat in our environment amidst noise, as is the case with the detection of fearful expressions (Kavcıoğlu et al., 2019; Sussman, Szekely, et al., 2016).

Another mechanism that aids a greater sensitivity towards threat during anxiety concerns a prioritization of LSF bands of visual input (Baas et al., 2002; Lojowska et al., 2015, 2019). The LSF visual bands, as briefly mentioned in a previous topic, carry coarse/rough characteristics of the stimuli in question, being more quickly processed and aiding in faster, even if more error-prone ("quick and dirty"; LeDoux, 1994), perception. Crucially, it seems that these more coarse and basic features (e.g., shape) are a key-factor used to recognize potentially threatening stimuli (Gomes et al., 2018; McFadyen et al., 2018), which subsequently leads to their faster identification (Lojowska et al., 2019). Thus, prioritizing LSF under anxiety further leads to a greater sensitivity and quickness in detecting potential harmful stimuli.

Although maximizing threat detection, both increased sensitivity and visual shifts favoring low spatial frequencies of visual input seen during anxiety may come at the expense of an increase presence of false positives, most often evidenced as a threat bias. This increased bias results in an apparent lower criterion (i.e., lower decision threshold when signaling threat) that predisposes one to more often misinterpret ambiguous stimuli as threatening or overemphasize threat-related features therein (Sussman, Jin, et al., 2016). For instance, although more easily perceived as threatening (possibly a result from increased sensitivity), during potentially threatening situations people more often misinterpret ambiguous faces as threatening (Bublatzky et al., 2020; Flechsenhar et al., 2022; Kavcıoğlu et al., 2019; Neta et al., 2017). Thus, such maximization of threat detection thresholds, reduces overall specificity, resulting in a more indiscriminate response pattern by the amygdala when faced with ambiguous facial expressions (van Marle et al., 2009). This general tendency to perceive and interpret ambiguous stimuli as threatening (or more threat-like) is called "interpretation bias", and seems also to be a common feature across ADs (e.g., Hazlett-Stevens & Borkovec, 2004; J. C. Richards et al., 2001; Yoon & Zinbarg, 2008).

As highlighted across this topic, the consequences of anxious states over the perception of our social environment have been explored almost entirely using facial expressions. Whilst one cannot argue with the importance of facial cues in informing us about other's emotions and intentions, body actions and gestures remain overlooked, in spite of their similar wealth of communicative information. This opens up a vast area of research, that aims to assess how potential benefits from anxiety (e.g., increased sensitivity), might actually be a trade-off, evoking perceptual biases and difficulties in using contextual cues, when navigating through our social world. This is the exact area we seek to explore and will describe in the following topic.

Thesis's objectives and outline

In the previous sections, I introduced anxiety, providing a brief overview into its conception and its pathological and adaptive (functional) variants, highlighting the latter's physiological and cognitive effects. Before providing a more in-depth view on the effects of anxiety over visual perception, I described how perception is an anticipatory endeavor, and how these expectations, alongside other biases, permeate how we view the world, with a specific emphasis on social perception. I finally provided a more extended summary into how anxiety might alter perceptual mechanisms, shifting the weight in favor of a sensory-driven perception but possibly hindering the use of contextual cues. I also showed how this improved perceptual sensitivity is particularly directed towards threat detection, but also argued that some unwanted biased estimates of threat might arise. Importantly, I stressed how there seems to very little studies of how this perceptual shift derived from anxious states affects overall social perception, with the few done so far being solely (or at least predominantly) isolated to the perception of faces. As such, and considering the role body postures, gestures and actions partake in providing meaning to social interactions, as well as the common presence of anxiety in our lives, my objective is to explore how this latter state might either impair or increase one's ability to extract social meaning. I began by exploring single interactions between a social agent and the viewer. Specifically, I started by assessing how different anxiety-inducing methods affect 1) our tendency to perceive approaching motion in ambiguous PLWs, an innocuous stimulus that can, nonetheless, signal some threat given that it represents a possible impending interaction with a stranger. I then explored 2) how threat-induced anxiety affects one's ability to use contextual cues in inferring the presence of ambiguous and noisy social agent partaking in a possible interaction. This task was then adapted to instead capture the identification of aggressive gestures within an interaction, measuring 3) participants' sensitivity, biases, and ability to use contextual cues when judging these potentially aggressive interactions. Lastly, I investigated 4) how potentially aggressive gestures, this time directed towards the viewer, were perceived under anxiety. Here, I also probed if a more direct relationship between aversive event (shock delivery) and the presence of aggression by the agent (PLD) further affected any perceptual measure or bias. These questions are explored across four chapters that are briefly summarized below.

Chapter II (Study 1: 1a, 1b and 1c). This chapter explored if, and to what extent, one's FTV bias is affected by states of anxiety. To achieve this, this study was divided into three individual, but similar experiments, where participants were asked to judge the direction of PLWs. Each experiment varied, predominantly, in the method used to induce anxiety. Experiment 1a used imagery of scenarios containing potential threats compared to imagery of neutral (safe) scenarios. Experiment 1b used the possibility of exposure to loud screaming sounds to induce anxiety, with a no-sound safety condition used as control. Lastly, Experiment 1c exposed participants to threat of shock, also having a safety (no shock) block.

Chapter III (Study 2). This study evaluated how the communicative nature of an action, either individual or communicative, is used (as a contextual cue) to infer the presence of a noisy and degraded second agent that might be present in the same video (see Manera, Del Giudice, et al., 2011). By manipulating participants' anxiety via threat of shock, this study investigated if such state, compared to a control (safe) one, impaired one's ability to use contextual cues when trying to perceive (infer) the presence of the second agent.

Chapter IV (Study 3). Afterwards, to assess if more threat-related social contexts were perceived differently as a function of anxiety, this study employed different social scenarios with varied emotional content, making use of aggressive and neutral social interactions. This is a partial adaptation of Study 2, where, this time, participants needed instead to identify the presence of aggressive gestures in a degraded and noisy two-person interaction. Contextual cues were provided in the form of facial expressions (fearful *vs* neutral) exhibited by a third member, described as an observer who was watching and reacting to the central interaction. Once more, a state of anxiety was induced via threat of shock, with a safety (no shock) block used as control.

Chapter V (Study 4). Lastly, this final study explored if further increments in an actions' intrinsic (threat-related) value might lead to different perceptual performances in identifying the presence of aggression therein. As such, this last experiment was a variation of Study 3, having the participant identify aggression in potentially aggressive gestures. This time, the action (noisy and degraded) was performed by a single individual and was directed at the participant. Again, this task was performed both under threat of shock and safe conditions. Moreover, a third block was also introduced to measure the effect of associating the aversive event (electric shock) with the aggressive action.

Chapter VI (Discussion). In the last chapter of this thesis, I will summarize all of the findings gathered from the studies described above and integrate their respective conclusions together, and with the current literature. I will also discuss the implications and contributions of this thesis, as well as its limitations, whilst providing some guidance for future work. I will end this last chapter with some final brief remarks.

CHAPTER II

Study 1: Inbound friend or foe: How motion bistability is resolved under threat

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This study was pre-registered in Open Science Framework: osf.io/c395q

Abstract

Anxiety primes our vision for the possibility of threats, such as the approaching of an unknown person. Studies have shown our innate tendency to see approaching motion in ambiguous walkers in what was termed facing-the-viewer (FTV) bias. Here we investigated if states of anxiety further contributed to this bias, hypothesizing that such states would increase overall FTV biases. Throughout three experiments, we asked participants to judge the direction of ambiguous point-light walkers and measured their respective FTV biases under safe and anxiety-related conditions induced via imagery (Experiment 1a), screaming sounds (Experiment 1b), and threat of shock (Experiment 1c). Across all experiments, we showed that anxiety does not affect our tendency to perceive an approaching behavior in ambiguous walkers. Based on our findings, and the discrepancies found in the literature, we emphasize the need for future studies to paint a clearer picture on the nature and aspects capable of affecting this bias.

Keywords: Anxiety; Point-light walkers; Facing-the-viewer bias; Threat; Anticipatory anxiety

Introduction

Vision is not a one-way street. How we see the world depends not only on sensory information but also on other factors, such as expectations and motivations. Expectations are constructed based on our current context and learned statistical regularities that associate sensory input with its causes. For instance, noisy visual information (e.g., a blurry shape in a painting) is perceived and interpreted differently depending on its surrounding information (Brandman & Peelen, 2017). Motivation, in the form of desired outcomes, also affects perception in clear ways. For example, we are more prone to perceive objects associated with reward (Bruner & Goodman, 1947; but see McCurdy, 1956; Dunning & Balcetis, 2013; Voss et al., 2008) and objects that align with basic needs (Changizi & Hall, 2001).

On the other hand, and despite being unnoticed most of the time, other sources of motivation, such as emotions, seem to also influence how we perceive the world (Zadra & Clore, 2011) – although some studies argue that such conclusions are not yet warranted (Niedenthal & Wood, 2019). This can be seen over more basic characteristics of visual perception, such as how feeling fearful, for example, increases contrast sensitivity (Phelps et al., 2006). Additionally, states of joy and sadness (positive and negative states) induce a more global (e.g., see the whole forest) or local (e.g., see the trees) perception, respectively (Gasper & Clore, 2002). More practical (direct) examples come from studies showing that, for instance, sad people judge a hill as steeper compared happier people (Riener et al., 2011), with this same phenomenon being observed when people are afraid (Stefanucci et al., 2008).

Anxiety is yet another emotional state that implicates changes in perception. Although some perceptual changes are already seen in dispositional (trait; e.g., K. L. H. Gray et al., 2009; Rossignol et al., 2005) and pathological anxiety (e.g., E. C. Anderson et al., 2013), this is particularly noticeable under anxious states (high state anxiety). Being a preventive emotional state that promotes a defensive stance in the face of potential threats, such changes are directly tied to improving threat detection (Grillon & Charney, 2011). For instance, feeling anxious improves the visual perception of coarse features by favoring low spatial frequencies in detriment of high-spatial frequencies, promoting quicker threat detection (Lojowska et al., 2015, 2019). This allows us to rapidly gather a rough representation of the stimuli in our surroundings, aiding the deployment of quick defensive responses, even if resulting in more misrepresentations of threat (Bar, 2003). It further improves the perception of fearful faces, compared to happy (Robinson et al., 2011) and neutral faces (Sussman, Szekely, et al., 2016), and leads to different judgments made over facial expressions. Specifically, threat-related expressions, such as fear and anger, are more accurately identified as fearful and also as exhibiting more intense expressions (Kavcıoğlu et al., 2019). Even anxiety cues delivered via olfactory chemosignals, whilst not creating a conscious feeling of anxiety, predispose people to judge ambiguous fear faces as more fearful than when individuals are not exposed to such cues (Wudarczyk et al., 2016; Zhou & Chen, 2009). Despite being documented for facial expressions signaling threat, the effects of anxiety over other socially relevant (and potentially threat-signaling) stimuli, remain lacking. One relevant example concerns bistable point-light walkers (PLWs) and how we resolve their directional/facing ambiguity, a process which has, as described below, been associated with internal factors, such as social anxiety.

Although we can readily interpret point-light displays of humans (Alaerts et al., 2011; Dittrich, 1993; Manera et al., 2010; Pollick et al., 2001), some can easily create ambiguous or even bistable percepts of human motion. One relevant instance, as mentioned above, is the display of a moving walker with no depth cues (i.e., orthographic display). Interestingly, a number of studies have shown that individuals have a natural tendency to identify these depth-ambiguous walkers as facing toward them more often than as facing away from them (Vanrie et al., 2004; Verfaillie, 1993, 2000). This phenomenon became known as the facing-the-viewer bias (FTV) and has been explained through several different theories. Some suggest that this bias reflects our visual system's default towards attributing convexity to ambiguous planes of vision when extracting 3D information from 2D stimuli (Weech et al., 2014). However, the most adopted theory stands upon the idea that this bias is a result of the biological and social relevance of the stimuli. Namely, mistaking an approaching person might be less costly than failing to detect one, since one fails to prepare for a potential social interaction (which in itself can be considered threatening) or to a general dangerous encounter (Brooks et al., 2008; Han et al., 2021; Vanrie et al., 2004).

Several studies have come to support the last theory mentioned above by evidencing various sociobiological factors that affect this bias. For instance, the gender of the point-light walker appears to contribute to the intensity of the FTV bias experienced, with male PLWs (compared to female) resulting in aggravated FTV biases (Brooks et al., 2008). This effect appears to be further modulated by the sex of the participant, with male participants having increased FTV biases when facing male PLWs compared to female participants (Schouten et al., 2010). Other studies have also implied a role for social anxiety and threat on the FTV bias. Namely, increased social anxiety (but see Peng et al., 2021) appears to be related to a reduced FTV bias (Van de Cruys et al., 2013). The authors of this latter study interpret this as reflecting wishful thinking by the individual, where the desired scenario (i.e., individual walking away) is perceived more readily (Dunning & Balcetis, 2013). However, later studies revealed opposite scenarios, with greater social (but not state or trait) anxiety being associated with a higher FTV bias (Heenan & Troje, 2015). A follow-up study showed that inducing relaxation via exercise (reducing anxiety) also significantly reduced the FTV bias. Furthermore, threat, as induced by presenting anger faces in the background, complements this result, being associated with a superior FTV bias overall, with higher social anxiety levels further increasing this tendency (Yiltiz & Chen, 2018).

Although Heenan and Troje (2014) have studied induced anxiety (and relaxation states) before to assess FTV bias, they only showed a reduced bias from relaxation (but no increase from anxiety). Importantly, the anxiety induction was done uniquely with stories/imagery. In this study, we expanded on this previous work using three distinct experiments to more thoroughly explore if anxiety states lead to changes in FTV bias on healthy adults. Specifically, we considered multiple anxiety induction methods, inducing anxiety via imagery (Experiment 1a), loud screaming sounds (Experiment 1b), and electric shocks (Experiment 1c).

Although observing a reduced FTV bias in anxiety conditions was a possibility (wishful thinking hypothesis; Van de Cruys et al., 2013), we followed the few (but majority of) findings from prior studies that assessed threat and anxiety (social and non-social) on FTV bias. Accordingly, we expected that feelings of anxiety (threat) would result in greater FTV bias (greater tendency to perceive approaching behaviors) compared to safe (neutral) conditions.

Experiment 1a

In Experiment 1a, and in line with one of the experiments conducted by Heenan and Troje (2014), we induced anxiety via imagery. Namely, we used small vignettes that could either depict safe day-to-day scenarios or scenarios where a potential (but not obvious) threat was present.

Method

Participants

Our sample size was defined based on guidelines for a simple two factors within-subjects design by Brysbaert (2019), which yielded a conservative minimum of 52 participants for an effect size of *d* = 0.4 (a typical effect in psychology; see Brysbaert & Stevens, 2018). The same guide was followed in all other experiments. All participants were Portuguese speakers and had between 18 and 35 years of age. Additionally, exclusion criteria included: diagnosis of a neurologic or psychiatric disorder and current medication related to anxiety or depression (or with mood/cognitive implications). A total of 80 participants were collected for this online experiment. Of those, a total of 39 were eliminated: 17 due to incomplete data (closing task halfway), 17 for reporting a fixed direction (no change between approaching/receding) which indicated inadequate calibration (see below), one for reporting major video problems during their task, and four for having existing psychiatric conditions (e.g., depression) or being on psychiatric medication (e.g., benzodiazepines). Our final sample was composed of 41 participants (31 females, $M_{\text{age}} = 22.33$, $SD_{\text{age}} = 4.32$). The sample size was slightly below our established minimum sample size due to an unplanned number of participant exclusions, yielding a slight divergence from our pre-registration (osf.io/yhq6k). The current experiment, as well as the following two, were conducted with permission from the ethics committee (reference 02-CED/2021) and in accordance with the data protection regulation from the University of Aveiro.

Stimuli and apparatus

The stimuli used for this experiment consisted of videos of male point-light human walkers retrieved from the study of Schouten and Verfaillie (2010). The PLWs were composed of 13 black dots on a gray background, covering the main areas that convey meaning to biological motion, such as the major joints of the body (i.e., wrists, shoulders, elbows, hips, knees, and ankles) and the head. Importantly, the PLWs had different levels of depth cues, which could gradually be adjusted to reach the participants' point of subjective ambiguity (i.e., where their perception varied in equal proportion between approaching and receding). These levels ran from zero (complete orthographic projection, i.e., no 3-D information) to 12, where depth cues were either manipulated to provide a FTV bias (0 to +12) or a facing-away bias (0 to -12). Given the results from a prior pilot study (N=29; see Appendix A for more information), we selected five levels that were identified as most perceptually ambiguous (-7 to -3). Furthermore, stimuli size was scaled based on the size of the participants' computer screen/window (height units), which could vary between 1280x720 and 1920x1080 pixels. The videos had an original resolution of 1024x576 pixels and a height (unit normalized to window resolution) size of 0.75x0.5 and were trimmed to a 3-second duration. This experiment was created in Psychopy (Peirce et al., 2019) and ran on an online platform (pavlovia.org).

A total of 24 vignettes were used. These were divided into two categories (12 per category): threatening and neutral (safe). The threatening vignettes represented instances of potentially threatening situations of a social nature and the neutral vignettes described neutral social scenarios. The vignettes used were previously validated (N = 54; see Appendix B for more details and analyses), supporting the ability of the threatening vignettes to induce an above-average feeling of threat in the participants.

Procedure

Participants were first directed to an online form, where they were explained the aim of the study and shown a list of necessary requirements to be eligible for the study. They were then asked to provide their informed consent and fill out the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Barros et al., 2022; Ree et al., 2008) and the Liebowitz Social Anxiety Scale (LSAS; Caballo et al., 2019; Liebowitz, 1987).

Afterwards, participants were redirected to an online platform (Pavlovia; pavlovia.org) where the experiment would take place. Initially, they were shown the instructions for the adjustment (calibration) block. Here, participants were asked to report the direction of motion of several PLWs (one at a time), while focusing on a central white dot. This white dot gave a reference point for all participants to focus on, preventing participants, as much as possible, from adopting different focus points.

They were shown five levels of PLWs, varying their level of depth cues, with levels varying between -7 (most receding) to -3 (most approaching). Each level was randomly presented six times to the participant throughout the block (30 trials total). The level which provided a response criterion closer to 50% (i.e., 50% of the times judged as going away and 50% as coming towards the participant) was established as the default level of maximum ambiguity for that participant. In the case of ties, the level closest to 0 (with less depth cues) was selected. This level was then used throughout the rest of the task. Participants gave their response only after the end of the video (no time limit).

Participants then performed a single practice block, that mimicked the main task, but with an unrelated (not used in the main task) neutral vignette. They were instructed to first read and imagine themselves in the story presented by the vignette (no time limit). After doing the above they were told to press a key to move to the PLW presentation (3 seconds). At the end of this video, participants were prompted with a response screen and asked to judge the direction of this previously seen PLW, as either facing towards or away from them. They were instructed to press the up arrow on their keyboard to signal receding and the down arrow to indicate approaching. Finishing this trial would lead participants to the instruction screen for the main experimental task.

Participants underwent a total of 24 trials. As with the practice trial, they first read a story and then proceeded to view a PLW. Afterwards, they would be prompted to judge the direction of the PLW they had just seen, as with the practice trial (see Figure 1). At the end of the 24 trials participants answered just three final questions. The first question was answered on a visual analog scale, ranging from 0 (Nothing) to 100 (Completely), and inquired as to how vivid the stories were when participants were reading and imagining themselves in them. The second question asked if any video problems (e.g., stuttering, slow loading times) in the task were noticed and how disruptive they were. Finally, they were asked where they focused their attention when they were trying to decipher the direction of the PLW (even though instructed to focus on the central dot). They could choose between five different answers (feet/legs, arms/hands, both feet/legs and arm/hands, head, or central dot). Answering this question would lead to an end screen where participants were thanked for their participation and the task automatically closed.

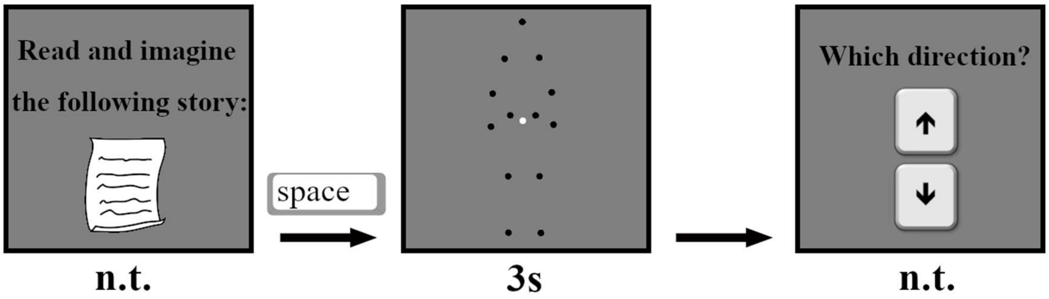

Figure 1. General structure of each trial. Participants began each trial by reading and imagining themselves in a story (vignette). After completing this (no time limit) they were instructed to press the spacebar, leading them to a video of a PLW with a 3 second duration. At the end of the video they were prompted with a response screen (no time limit) and had to decide if the previously observed PLW was approaching (down arrow) or receding (up arrow). n.t.= no time (limit).

Statistical Analysis

Considering the short length of the stories, trials where participants spent less than five seconds per story, or over 30 seconds, lead to the exclusion of that trial/observation. We removed a total of 135 trials (~14% of our total trials).

The variable quantifying FTV bias was computed by calculating the ratio of "approaching" answers in the total amount of trials of the experiment ($FTVb = N_{approaching} / N_{total}$). In this case values below 0.5 would imply a more receding bias, whilst bias above this value would mean an approaching bias. In addition, the difference between FTV bias between threat and safe condition was also calculated for each participant ($Delta\ FTVb = FTVb_{threat} - FTVb_{safe}$).

All analyses were performed in R. The lme4 package (Bates et al., 2015) was used to perform the analysis. A generalized linear mixed effects model fit by maximum likelihood (Laplace Approximation) with a binomial distribution (logit link function) was used to measure the effect of vignette type on the FTV bias, with participants as random intercepts with random slopes per vignette type. We additionally explored adding covariates to the model relating to anxiety, social anxiety, vividness of the stories, and focus of attention (head, legs/arms, hands/arms, central dot), by using AIC as a goodness-of-fit measure. None of these covariates appeared to improve our model, nor changed any conclusion regarding the effects of Vignette Type. Our final model was the one described above, with no covariates. To assess the support for the null hypothesis, additional Bayesian analyses, with the respective Bayes factors for the fixed effect (vignette type), were also performed and are provided in full in Appendix C. Lastly, we performed correlation analyses (Spearman correlations with Bonferroni corrections) for both adjusted FTV level and observed FTV bias with anxiety scores (state, trait and social).

Results and discussion

Our main analysis showed no effect of the type of Vignette on the FTV bias exhibited by the participants ($\chi^2(1) = 0.012$, $p = .916$), meaning no statistically significant difference between threat ($M = 0.627$, $SD = 0.274$) and safe ($M = 0.624$, $SD = 0.284$) vignettes. This lack of effect was further supported by a Bayesian analysis ($BF_{01} = 2.95$; see Appendix C for the full analysis). No correlation between adjusted level of ambiguity or overall FTV bias and STICSA (state and trait), or LSAS was found ($p > .05$; see Appendix D).

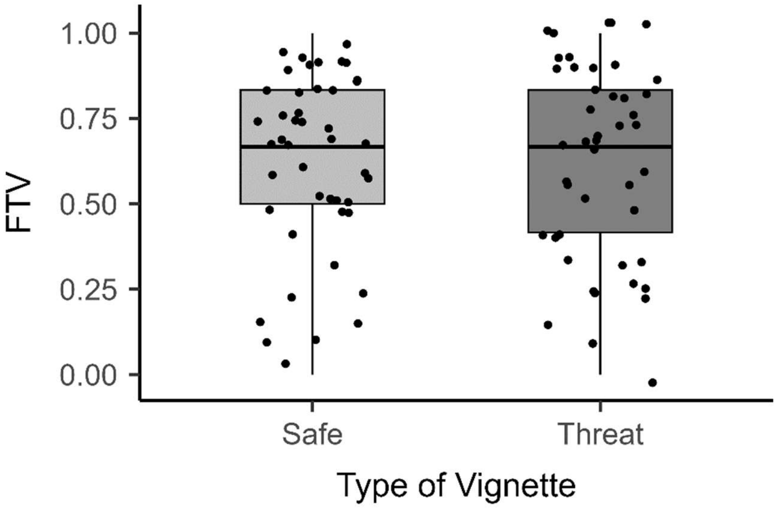

Figure 2. Observed FTV bias distribution in each condition (neutral vs threat vignettes) for Experiment 1a.

Our results showed that making participants imagine themselves in anxiety-inducing situations did not affect their tendency to judge a bistable PLW as either more approaching or receding, compared to when imagining safe scenarios. Despite some studies hinting at the positive association between threat and the FTV bias (Yiltiz & Chen, 2018), this type of threat condition (induced via imagery) did not yield the same type of results. This conclusion aligns with that of Heenan and Troje (2014), who failed to evoke any differences in the FTV bias with recalled stressful events. Furthermore, no correlation between anxiety (state, trait or social) and FTV bias (both adjusted level and observed FTV bias during the task) was found. These results go against prior findings that evidenced either a positive (Heenan & Troje, 2015; Yiltiz & Chen, 2018) or a negative (Van de Cruys et al., 2013) relation between social anxiety and FTV bias, and, instead, support studies that have been claiming no such relation exists (Peng et al., 2021).

This first experiment faced some limitations that should be acknowledged. The first one regards sample size which, due to an unplanned number of participant exclusions, our actual sample was slightly below ideal (given the guidelines used as described above). Another limitation concerns the sex ratio. Since the sex of the participant has been shown by at least one study to be an influential factor in the FTV bias (Schouten et al., 2010), an equal sample of female and male participants would be desired. Another potential limitation concerns the use of only one final depth level for the PLW (i.e., PLW ambiguity level) for each participant (even if calibrated). A bigger set of levels centered around the participants' point of subjective ambiguity (as opposed to just one level), with the addition of more trials, might have aided in capturing any effects regarding the FTV bias. Given our limited number of vignettes, we were limited in implementing these measures, but this change is something we consider in the next studies. Another critical concern was that being an online study, no control over viewing distance, screen size and testing environment were possible. Lastly, and arguably our most limiting factor, concerns the type of anxiety-induction method used. Although a common method known to induce anxiety (Kimbrell et al., 1999; Talisman & Rohrbeck, 2022) – and while the vignettes used were previously validated as threat-inducing – we argue that this method can be less effective at inducing anxiety states compared to other anxiety-induction methods (e.g., screaming sounds, electric shocks), which we investigate in the following experiments.

Experiment 1b

To address the limitations discussed in Experiment 1a, we next employed a different anxiety-induction method based on Beaurenaut and colleagues (2020) and slightly modified our task. Here, we relied on randomly and sporadically presented loud screaming sounds to induce a state of anticipatory anxiety in threat blocks. We presume this would create a more intense anxiety state, where the anticipation of a screaming sound at any moment would sustain an anxious state during the entire block and every phase of the trial (from observing the video to giving the response). We further employed more depth levels per participant, in the hope of reducing a fixed percept of the walker (e.g., always approaching) and to better capture any FTV bias difference between conditions. We posited the same initial hypothesis, i.e., participants' FTV bias would be greater in threat blocks (where sudden screaming sounds could be heard), compared to safe blocks (no sounds).

Method

Participants

A total of 54 participants were collected. As in the previous experiment, to be included participants had to be Portuguese speakers and between 18 and 35 years of age. Additionally, participants were only included if they had no current psychiatric/neurological disorder and were not taking any medication either related to anxiety/depression or with clear implications over mood/cognitive function. Two participants were removed given problems in the adjustment phase of the task (only one response was given regardless of the depth-level of the PLW). Our final sample was comprised of 52 participants (38 females, $M_{age} = 21$, $SD_{age} = 3.4$), in line with our statistical power calculation (see Experiment 1a). This experiment was pre-registered (osf.io/24smr).

Stimuli and apparatus

The stimuli used was the same as those employed in the previous experiment. However, this time we employed a greater number of depth levels, ranging from -10 to 0.

The auditory stimuli used to induce anxiety were screaming sounds previously validated by Fecteau and colleagues (2005). Based on the study of Beaurenaut and colleagues (2020), we used these distress signals (screams) to generate transitory states of anticipatory anxiety. The screaming sounds were trimmed to one second in duration, and were controlled, with the usage of a decibel meter (Trotec24 SL300), to an intensity of around 70dB.

Similarly to the previous experiment, this task was created in Psychopy (Peirce et al., 2019), but this time run directly in this platform, in a lab (offline). The task was presented in a MSI PRO MP241 monitor (1920 by 1080 resolution), and the screaming sounds were delivered through the Sony MDR-XD150B headset. Participants' distance to the monitor was controlled to about 55cm. The PLW stimuli had an approximate vertical size of 8.3 visual degrees and a horizontal size of 4.1^{o} visual degrees. The central dot had a diameter of 0.3 visual degrees.

Procedure

Participants began by filling out an online questionnaire. Based on their sociodemographic and health responses, they were then selected to participate. Additionally, they also completed the trait portion of the STICSA and the LSAS.

Upon arriving at the laboratory, participants were explained in writing and verbally the objectives and details of the study. Upon giving their informed consent, they started by responding to the state portion of the STICSA.

Afterwards, they were introduced to the computerized task, where they began by performing the adjustment phase. This phase was also similar to the one described in Experiment 1a, but this time the range of depth levels used for the PLW varied between -1 and -9 (-1, -3, -5, -7, and -9) Again, each video was shown a total of six times (a total of 30 trials) with participants having to select the direction of the PLW at the end of the video using the up and down arrows. The level which provided a response criterion closer to 50% was established as the default level of maximum ambiguity for that participant. This level, plus the adjacent levels (the one above and below) were then used throughout the rest of the task. For instance, if, based on the calibration phase, the level for a participant was defined as level -3, he would be presented with levels -2, -3, and -4, randomly but equally represented, during the main task. In the case of ties, the level closest to 0 (less depth cues) was chosen (plus the adjacent levels).

After completing the adjustment phase, an instruction screen was presented that introduced the participants to the practice phase. This phase had six trials in total. Participants were instructed to indicate, after watching each video (three seconds), the direction of the PLW, either by pressing the down-arrow key to indicate "approaching" or the up-arrow key to indicate "receding". A white fixation circle, which would be located at the center of the PLW, was presented one second prior to the appearance of the PLW. They had no time limit but were told to give their first impression as their answer. Importantly, they completed this task in two different blocks, threat and safe. In the safe block (first three trials) participants performed the task with two green bars on the side of the screen, with no headphones and thus not hearing any screams. In the threat block, they were instructed that they would, at any point, hear a screaming sound and, thus, were instructed to wear the headphones (only one screaming sound was administered in this phase). Screaming sounds appeared randomly during the first three seconds of each trial (total trial duration was four seconds). During this block, two red bars accompanied the trials. Each block was preceded by a screen letting them know which block they would enter.

After finishing the practice phase, participants proceeded to the main experimental task (see Figure 4 for a schematic of each block and trial). Similarly to the practice phase, they were tasked with indicating the direction of the PLW. This time they performed four safe and four threat blocks, each with 15 trials (120 total trials). Unbeknownst to the participant, only one screaming sound was heard in each threat block, corresponding to around 7% of the block. The threat and safe blocks were accompanied by red and green bars, respectively. Block presentation alternated between threat and safe, with the starting order being counterbalanced across all participants.

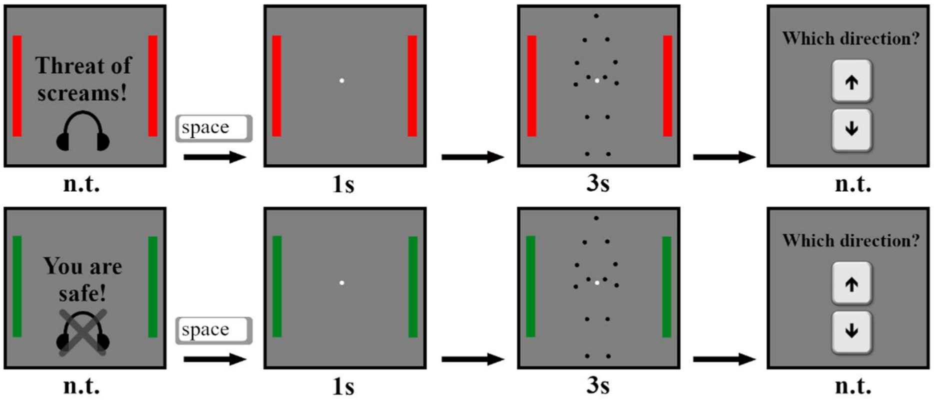

Figure 3. Generic example of threat and safe blocks. In the threat block, participants would be initially presented with a warning message and were required to put on headphones. Each trial was presented with two parallel red bars at the sides. In the safe blocks, participants were presented with a message indicating that they would be safe and must remove headphones. n.t.= no time.

After finishing the main task, participants were asked to indicate how anxious they felt during threat and safe blocks on a visual analog scale (0 – Not anxious; 100 – Very Anxious).

Lastly, they had to respond to a last question about their visual focus during the task (same as the one asked in the previous experiment), which would show if they deviated from the central dot and to where they moved their visual focus in the search for depth cues. The task then ended, participants were thanked for their participation, and finally debriefed on the whole experiment.

Statistical analysis

The procedures taken for the statistical analysis were very similar to those in Experiment 1a (see Statistical analysis section in Experiment 1a). The model structure was the same, just with block type as a fixed factor (and random slope), instead. A paired samples t-test was used to assess the subjective ratings of anxiety in the different blocks. Subjective measures of anxiety were gathered from the last question of the main task.

Results and discussion

Our main analysis revealed that block type did not have a significant effect over FTV bias ($\chi^2(1) = 2.367$, $p = .124$; $BF_{01} = 2.57$; see Appendix C for the full Bayesian analysis), with threat blocks having a mean FTV bias of 0.51 (*SD* = 0.15) and safe blocks of 0.48 (*SD* = 0.14). No correlation was found for both adjusted PLW level and FTV bias with any anxiety or social anxiety inventories ($p > .05$; see Appendix E).

Subjective feelings of anxiety were significantly greater ($t(51) = 10.97$, $p < .001$, $d = 1.52$, 95% CI [1.12, 1.92]) in the threat blocks (*M* = 54.06, *SD* = 29.6), compared to the safe blocks (*M* = 10.52, *SD* = 12.6).

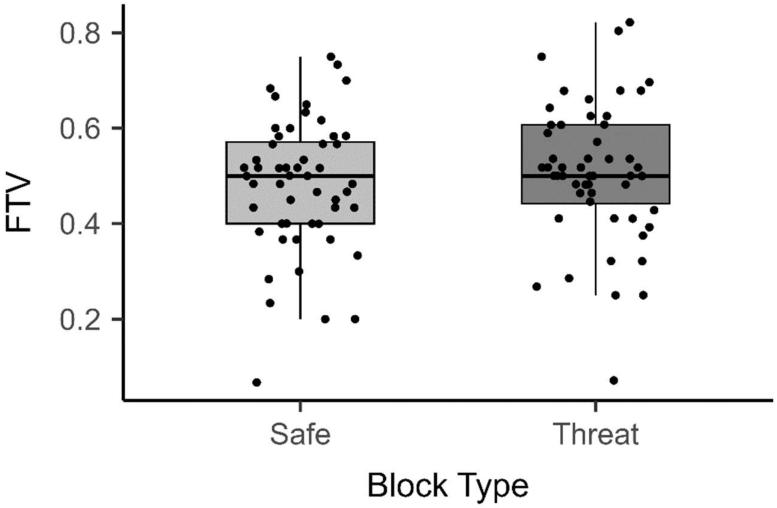

Figure 4. Observed FTV bias distribution in each condition (safe vs threat block) for Experiment 1b.

In this experiment, we investigated if a sustained state of unpredictable threat would affect the FTV bias over bistable PLWs. This expanded on Experiment 1a, addressing some of its limitations, particularly in regard to the anxiety-inducing method (using threat of scream this time around).

Once more, we did not verify our hypothesis, with our results supporting instead the conclusion drawn in the first experiment, indicating that anxious states – this time of a sustained anticipatory nature – do not affect FTV bias. Furthermore, as in our first experiment, no correlation between any anxiety inventory and FTV bias related measures was observed, which, along with Experiment 1a, questions prior findings relating social anxiety and FTV bias (Heenan & Troje, 2015; Van de Cruys et al., 2013; Yiltiz & Chen, 2018).

Despite addressing most of the limitations raised in Experiment 1a – except the female-to-male ratio – one could still argue that, given its novelty (Beaurenaut et al., 2020), the method used to induce anxiety did not do so to the extent required. In our next and last study we use a threat of shock manipulation of anxiety to determine whether this finding is robust or, alternatively, if other anxiety-inducing methods, such as threat of shock, are capable of inducing a greater FTV bias for threat.

Experiment 1c

In this third experiment, we aimed at building upon the prior experiment using another anxiety-induction method that is more generally used across the literature, namely threat of electric shocks. As with previous literature using this method these shocks were administered randomly and sporadically throughout the task (Schmitz & Grillon, 2012). With this method we hope to disentangle if the lack of association between anxious states and increased FTV bias is due to the type of induction method. As such we used threat of shock, since it's a more common and, arguably, more effective method to induce states of anticipatory anxiety. We maintained our initial hypothesis, positing that FTV bias would be superior in blocks where shocks could be delivered (threat blocks) compared to safe blocks (no shocks).

Method

Participants

We collected a total of 65 participants. Our desired minimum sample size, as well as all eligibility and exclusion criteria, were the same as the previous task. This time, however, data collection was only stopped after all registered participants were able to participate. One participant was removed due to providing just one type of response across all trials. Our final sample was comprised of 64 participants (41 females; $M_{age} = 20.6$, $SD_{age} = 2.95$). This experiment was pre-registered (osf.io/3stuc).

Stimuli and apparatus

Based on adjustment levels found in the prior task, we created 4 sets of 3 levels ([-2,-3,-4], [-4,-5,-6], [-6,-7,-8], [-8,-9,-10]) that were to be used in the task. Given technical issues, we chose to remove our level adjustment phase, and each set of level possibilities was instead distributed in a counterbalanced order across all participants (16 participants per level set). Hence, this last task had level set as a between-subjects parameter.

The task was adapted from Experiment 1b and ran in a laboratory. The same monitor, resolution, screen distance, size of PLWs, and central dot were employed (see Experiment 1b).

Electric shocks were administered with the Biopac STMISOLA current stimulator, via two electrodes placed in the participants' left forearm. The electric shocks were 100 ms in duration and ranged between 2 mA and 6 mA (calibration procedure described below).

Procedure

The experimental procedure was similar to that of Experiment 1b. This time, however, participants underwent a shock workup (calibration) procedure (similar to Robinson et al., 2011; Sussman, Szekely, et al., 2016) prior to beginning the task. Here, participants received a graded series of electric shocks, starting at 2 mA and going up to a maximum of 6 mA. After each shock, the participants were asked to answer, on a scale between 1 (barely felt) and 5 (very unpleasant/uncomfortable), their discomfort towards the shock they had just received. The shock intensity was increased in steps of 1 mA until the rating of 4 (quite unpleasant/uncomfortable) or the 6 mA level was reached. The calibrated rating for each participant would be used throughout the rest of the experiment. If the rating of 4 was reached before the 6 mA level, shocks of the same intensity were given until 5 shocks in total (since the beginning of the workup procedure) were delivered.

The practice phase as well as the main experimental task were structured in the same way as in the previous experiment, but this time they received an electric shock as opposed to hearing screaming sounds (see Figure 5).

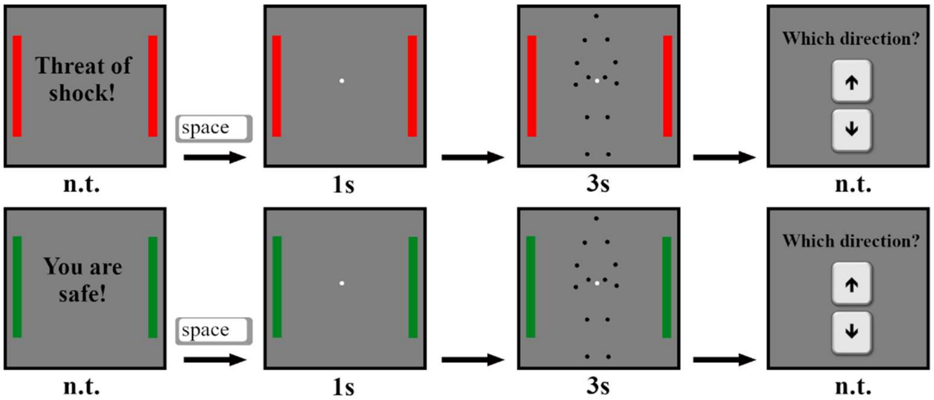

Figure 5. *Similar block and trial structure to Experiment 1b. This time, however, participants were warned that they would be at risk of receiving an electric shock during threat blocks and that no electric shock would be delivered during the safe blocks. n.t.= no time.*

At the end of the main task, participants, as in Experiment 1b, rated their anxiety levels during threat and safe blocks on a visual analog scale and responded to the question regarding their visual focus during the task. Participants were finally thanked for their participation and debriefed on the whole experiment.

Statistical analysis

The same statistical methods and analyses were used as those in the previous experiments. Our final model consisted of block as fixed factor, with participants as random intercepts and block type as random slope. The level set to which the participant was allocated was added as a random variable in our model. Other variables were considered for the model, but the best model remained the one described above (same as in Experiment 1b). In the same way as the prior experiment, we performed several correlations between FTV bias and anxiety scores (state and trait) and social anxiety scores. A paired samples t-test was used to assess the subjective ratings of anxiety in the different blocks.

Results and discussion

The type of block had no statistically significant effect over FTV bias ($\chi^2(1) = 0.754$, $p = .385$; $BF_{01} = 6.54$; see Appendix C for the full Bayesian analysis), revealing no difference in these scores between safe ($M = 0.521$, $SD = 0.164$) and threat blocks ($M = 0.533$, $SD = 0.158$). No correlation was found between FTV bias and STICSA-State, STICSA-Trait, and LSAS (see Appendix F).

Concerning our manipulation, participants reported feeling, on average, more anxiety during threat blocks ($M = 0.52$, $SD = 0.268$) compared to neutral blocks ($M = 0.083$, $SD = 0.115$; $t(63) = 13.224$, $p < .001$, $d = 1.65$, 95% CI [1.27, 2.03]).

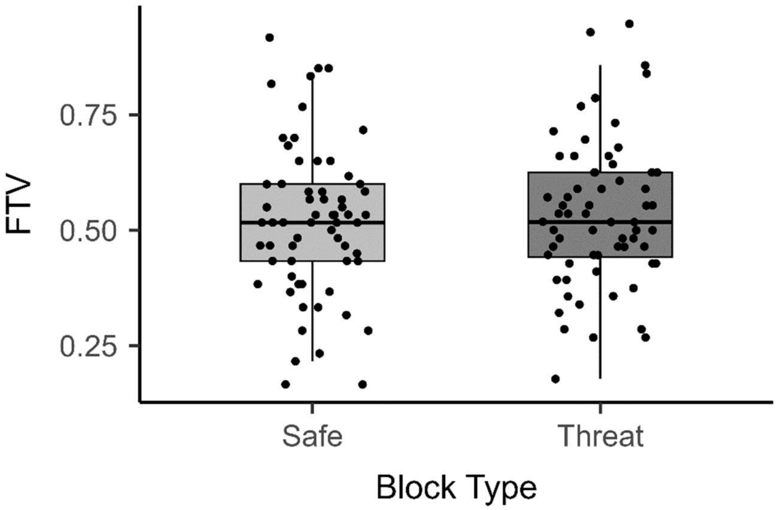

Figure 6. Observed FTV bias distribution in each condition (safe vs threat block) for Experiment 1c.

In this final experiment we wanted to broaden and strengthen previous findings by using a different, but more commonly used, type of anxiety induction (i.e., threat of shock; Robinson, Vytal, et al., 2013). The results, once more, did not follow our initial hypothesis, showing that states of anticipatory anxiety, this time induced by threat of shock, do not affect our perception of bistable PLWs. This final result lends support to our previous conclusions, evidencing the same result pattern. Again, we found no relationship between anxiety inventories (general and social) with the FTV biases reported by the participants, contradicting prior studies (Heenan & Troje, 2015; Van de Cruys et al., 2013; Yiltiz & Chen, 2018).

General Discussion

In the present study, we investigated how feelings of anxiety, elicited through several different methodologies, affected how we judged a bistable walking figure, either as more approaching or as more receding. This research question was brought out by studies showing that these bistable walking figures are subject to top-down influences, such as social anxiety (Heenan & Troje, 2015; Van de Cruys et al., 2013) and threat-signaling cues (Yiltiz & Chen, 2018). With this in mind, and the assumption that an impending social interaction (or dangerous encounter) is more threat-related (Brooks et al., 2008; Han et al., 2021), we hypothesized that feelings of anxiety would also increase one's proneness towards greater FTV biases. Our results, however, converged over the same conclusion, namely that under anxiety we do not suffer changes in our tendency to see an ambiguous walker as an approaching person (FTV bias). This was replicated across a set of three experiments, the first inducing anxious feelings via imagery, and the second and third inducing sustained anticipatory anxiety via threat of scream and shock, respectively.

Only one previous study has explored the role of anxious states in this type of paradigm (Heenan & Troje, 2014). While they showed that relaxation, either through physical exercise or through progressive muscle relaxation techniques, reduces the FTV bias, they found no increase in this measure when inducing anxiety. Notably, they only induced anxiety by asking participants to read scripts and imagine past stressful events. Here, we found similar result patterns, using the same (imagery) as well as two other different anxiety inducing methods (threat of scream and electric shock). As such, our conclusions align with this study, showing no effect of anxiety over the perception of ambiguous PLWs.

Concerning the association between social anxiety and FTV bias, already explored by other studies – but showing opposing conclusions – we found, across all experiments, no relationship between these two measures. This aligns with a recent study by Peng and colleagues (2021), conducted with a much larger sample, showing also no apparent association between social anxiety and FTV biases. Furthermore, we observed no association between subjective state, as well as trait anxiety, and FTV measures.

It is possible that differences in the experimental designs may be a cause for these discrepancies. Here we adopted a technique used by Schouten and Verfaillie (2010) where the bistability of the stimuli was manipulated and adjusted for each participant, by presenting different levels of perspective information. These different values were embedded into the dots representing the PLW, leading to changes in the dots' size, shape and location, and a subsequent appearance of a more approaching or receding PLW. With this variation we had a total of 25 different levels of ambiguity of the same PLW, which were, in a previous pilot study, calibrated to the levels where most ambiguity was reported. These were then further calibrated for each participant, as described in each method section. Other studies, however, achieved a bistable PLW by presenting an orthogonal display (no depth cues) and varying the angle of presentation (Troje & McAdam, 2010; Weech et al., 2014). Namely, they showed the PLW rotating in its vertical axis, and asked participants to, at all times, hold down a key reporting the direction of rotation (clock or counterclockwise) of the human PLW (Heenan & Troje, 2014, 2015; Peng et al., 2021). These studies then used different formulas to derive the degree of FTV bias. Relevantly, even those using the paradigm discussed initially (used here), present considerable changes in their approach to the task. For instance, in the study by Yiltiz & Chen (2018), no calibration procedure was done, and only two types of orthogonal PLW were displayed. Moreover, the PLW was shown for 70 seconds in each trial, and participants had to press the key that corresponded to their current perceived direction (which would change during the trial). Another study instead presented a total of 15 types of depth cues and asked participants to judge the facing direction of each level in multiple trials (Van de Cruys et al., 2013). Given the high variability shown across studies that are effectively measuring the same target (i.e., FTV bias), it could be argued that some study-specific variables (e.g., individual calibration of the ambiguity level of the PLWs) in the design of the task might be responsible for the contradictory results found in the literature. Specifically, certain paradigms might display bigger PLW ambiguity, making the task more fitting to capture any motivational influences over the perception of these same PLWs. Thus, and although hard to establish if this is indeed the case, it might be worth for future studies to pursue the idea that possible influences on FTV bias (e.g., social anxiety or anticipatory anxiety, as used here) might be dependent on the type of paradigm employed.

Considering the lack of consistent results regarding the effects of sociobiological-related factors, such as social anxiety, on the FTV bias, it is instead possible, as argued by some studies, that this measure (FTV bias) is in fact unaffected by these top-down factors (Peng et al., 2021). Whilst the idea that we have an innate tendency towards perceiving approaching (rather than receding) biological motion is well established (Vanrie et al., 2004), its root causes are not. Earlier studies have suggested that this perceptual bias is an adaptive behavior, influenced by top-down factors, which, from a survival standpoint, make erroneously perceiving an approaching person (possibility of threat) less costly than the reverse (Han et al., 2021; Shen et al., 2018). This was supported by other studies showing both an effect of walker and viewer sex over the FTV bias, with the effects on the latter being increased for males, who are more connected to threat (Brooks et al., 2008; Peng et al., 2021; Schouten et al., 2010) – although these effects do not necessarily imply top-down influences (see Schouten et al., 2010). However, as some studies have highlighted, this can be instead explained by the predisposition of our visual system to interpret ambiguous circular planes as convex, instead of concave (bottom-up approach), when reconstructing 3-D from 2-D information. Schouten and colleagues (2011) have demonstrated that the upper body part (torso and head) and the lower body part (legs and feet) shown in isolation lead to opposing perceptual biases – facing against and towards the viewer, respectively. This was further supported by Weech and colleagues (2014), who added landmarks to the bistable human figure either in the upper or lower body parts, inducing the same reduced and increased FTV bias, respectively, as shown in the study above. Regardless, the conclusion as to whether FTV bias is indeed affected by top-down factors remains open for discussion. Our study, since it was not directly designed to address this debate, can only partly support the idea that FTV bias might, indeed, be an entirely bottom-up process.

Limitations

In terms of overall limitations, and adding to those already mentioned, an important factor that might have hindered the results concerns the design of the task. Ideally, gathering data across a bigger set of levels of PLW ambiguity, instead of just one (Experiment 1a) or even three (Experiments 1b and 1c), could have painted a better picture regarding the participants' true FTV bias. Instead of calibrating the ambiguity levels of the stimuli for the overall population (pilot study), and then for each participant (calibration task), using a vaster set of levels with more trials might yield more accurate results and better reflect FTV bias alterations. Again, this would bring its own limitations (fatigue), but it is something that other studies might consider when designing future experiments.

Conclusion

With a set of three experiments, inducing anxiety through imagery, threat of screams and shocks, we assessed how these induced anxiety states might alter our tendency to perceive approaching ambiguous walking figures. Our results were internally consistent in showing that, contrary to our initial hypothesis, anxiety does not appear to modulate FTV biases. We were also unable to replicate prior studies showing an association (positive and negative) between trait/social anxiety and general FTV bias. Our results can further lend some support to studies suggesting that this type of perceptual bias is of a bottom-up nature and unaffected by top-down factors, such as anxiety.

CHAPTER III

Study 2: Anxiety's grip over social perception: How are visual predictions used when under threat

Preprint available at: **Silva, F.**, Ribeiro, S., Silva, S., Garrido, M., & Soares, S. C. (2023). Anxiety's grip over social perception: How are visual predictions used when under threat. PsyArXiv. https://doi.org/10.31234/osf.io/pwerc

This study was pre-registered in Open Science Framework: osf.io/6vawb

Abstract

The repercussions of anxiety in one's mood and social interactions are well known. One of its less recognized effects, however, lies in perception alterations caused by how one weighs sensory evidence, that in turn might affect social communication. Here, we investigated how anxiety affects our ability to gather and use social cues to anticipate the actions of others. We adapted a paradigm to assess expectations in social scenarios, whereby participants were asked to identify the presence of agents therein, while supported by action cues (communicative vs individual actions) from another agent. Participants (N=66) underwent this task under safe and threat of shock conditions. We extracted criterion and sensitivity measures to evaluate participants' response patterns. Gaze data was also collected. Our analysis showed that whilst the type of action had the expected effect (i.e., lower criterion for communicative actions), threat of shock had no effect over any response measurements. Furthermore, eye tracker data revealed no differences in dwell time across conditions when exploring the visual cues but showed that, under threat, participants exhibited shorter fixation durations. Our findings suggest that anxiety does not appear to influence the use of expectations in social scenarios.

Keywords: Anxiety; Expectations; Social Communication; Visual Perception

Introduction

Anxiety has been widely studied and the its burden, both for the individual and society itself, cannot be overstated (Baxter et al., 2013). It is no surprise then, that a vast amount of published literature is dedicated to exploring the behavioral and cognitive ramifications of pathological anxiety and high dispositional anxiety (i.e., high trait anxiety). Although not entirely aligned, the conclusions gathered from the literature for these two types of anxiety have underscored its cognitive effects, both adaptive and disruptive. One such effect concerns attention, specifically, how one is more prone to distractors as well as exhibiting greater difficulty in directing and maintaining attentional focus (e.g., Mogg et al., 2015; Pacheco-Unguetti et al., 2010). Another cognitive change resulting from anxiety concerns a heightened sensory-perceptual processing, showcasing a greater ability to detect (process) and perceive sudden or minor changes in our environment (e.g., Ge et al., 2011; Morgan & Grillon, 1999; Hogan et al., 2007; but see C. Chen et al., 2017).

An area of literature that remains less explored, however, concerns how normative (non-pathological/functional) anxious states affect cognition (Robinson, Vytal, et al., 2013). Whilst research has shown that certain cognitive changes mimic those found in individuals with anxiety disorders or high dispositional anxiety, some differences have also been found (e.g., Bishop, 2009; Pacheco-Unguetti et al., 2010). Nonetheless, the cognitive processes most notoriously affected by high state-anxiety remain the sensory-perceptual and attentional processes.

Attentional control seems to be improved under threat of shock, with studies, in general, reporting a reduced interference from distractors (Lago et al., 2022; Torrisi et al., 2016; but see Choi et al., 2012) and an increased sustained attention (enhanced vigilance; Bradley et al., 2018; Robinson, Krimsky, et al., 2013). As for sensory-perceptual processing, this mechanism also appears to be enhanced during induced anxiety. This is supported by several distinct paradigms showing amplified and accelerated cortical activation during threat states (e.g., Laretzaki et al., 2010; Shackman et al., 2011). Moreover, this is further seen in studies showing increased mismatch negativity (MMN) evoked potentials, where one's brain response to deviant/unexpected stimuli is enhanced (Cornwell et al., 2007, 2017). Indeed, this is even observed prior to any cortical involvement as shown by increased brainstem auditory evoked potentials (Baas et al., 2006). Importantly, these results indicate a heightened response to stimulus novelty, supporting the idea that anxious states bolster/prioritize a sensory-driven perception, as opposed to pre-established visual expectations (Cornwell et al., 2007, 2017; but see Fucci et al., 2019). This favored weighing of sensory input to the detriment of expectations hastens the detection of sensory changes but does so at the cost of reduced discrimination (i.e., sensitivity over specificity). This aligns with the idea that, in threatening situations, an increase in false positives is an adequate price to pay to reduce any false negatives (Carlsson et al., 2004; van Marle et al., 2009).

Importantly, managing a proper weighing between visual expectations (e.g., learned and present contextual cues) and sensory input is of key importance towards a quicker and more efficient visual processing (Meijs et al., 2018; Pinto et al., 2015; T. Stein & Peelen, 2015). In conditions where visual stimuli are unambiguous, or under new and unpredictable scenarios, expectations will carry less bias (have a subtler influence) over visual perception. However, in situations where sensory input is less reliable, such as when interpreting ambiguous or noisy visual information (e.g., hearing someone talk in a loud place), expectations make a larger contribution when forming our perceptual scenery (Weilnhammer et al., 2018).

One particularly relevant case concerns scenarios of social communication (Becchio et al., 2012). Given the natural ambiguity of social communication, where gestures and speech can have multiple meanings depending on social context, expectations are thought to have a vital role in deciphering and interpreting social communication (Manera, Becchio, Cavallo, et al., 2011; Sartori et al., 2011). A study by Manera and colleagues (2011) showed this remarkably well by making participants determine the presence of a masked agent (under noise). Importantly, this agent (person) was positioned in either a communicative setting, with another agent acting/gesturing towards the position where the to-be identified agent would (if present) be located, or with this additional agent acting individually. They showed that when inserted in a communicative context (compared to an individual one), participants more often (even if erroneously) reported seeing the masked agent, depicting a reduced response criterion (more bias towards signaling presence).

Thus, although a more sensory-driven processing during anxiety (downplaying expectations) might prove advantageous in certain situations, it remains unclear how these changes (i.e., a more sensory-driven perception) might affect the individual in social circumstances. Here we specifically raise the question of if (and how) our ability to interpret ambiguous social actions is compromised when under anxiety. We plan on answering this question by comparing how individuals under threat of shock (an anxiety inducing condition), compared with safe conditions, extract and use cues from social gestures to infer the presence of a second agent (under noise) that might be partaking in a social interaction with a first agent (similar to the task by Manera, Del Giudice, et al., 2011 described above). Based on the literature above we expect that, under induced anxiety, participants will be less reliant on (less influenced by) the actions of a communicative agent compared to when under safe conditions. Specifically, we posit that 1) in safe contexts/blocks (but not during threat blocks), criterion will be lower (more bias towards signaling presence) in communicative actions compared to individual scenarios, and 2) in communicative actions, the criterion will be lower in the safe compared to the threat contexts. Furthermore, with the use of an eye tracker, we plan on investigating the visual exploration patterns in these social scenes and comparing them across threat and safe conditions.

Methods

Participants

The sample size used in this study was estimated based on 2000 simulations assuming expected means and standard deviations (estimated with the aid of prior studies; e.g., Zillekens et al., 2018), using the Superpower package for R (0.2.0; Lakens & Caldwell, 2021). Given these parameters, and assuming our statistical design (2 by 2 within-subjects) and desired power of 0.8 (for a partial eta-square of 0.15), this method yielded a minimum required sample size of 65 participants.

To be included, participants needed to be between 18 and 40 years of age, Portuguese speakers, and have normal (or corrected) eyesight. They also needed to have no past or current diagnosis of any neurologic or psychiatric disorders, and not to be taking any study-relevant medication (e.g., for anxiety or depression). A total of 72 participants were initially recruited for the experimental session. Of these, one was excluded for disclosing taking anti-depressive medication after the study's conclusion, four for reporting the presence of agent B in less than 5% of the trials (where agent B was actually present) and one participant for exhibiting a low identification accuracy (i.e., less than our predefined threshold of 75%) regarding the type of actions (communicative vs individual). Our final sample consisted of 66 participants (52 female; M_{age} = 21, SD_{age} = 2.3). The present study was conducted with permission from the ethics committee (reference 18-CED/2020) and in accordance with the data protection regulation from the University of Aveiro.

Stimuli and apparatus

The experimental task was presented on an MSI Pro MP241 monitor with a 1920 by 1080 pixels resolution and programmed using Psychopy version 2021.2.3 (Peirce et al., 2019). Behavioral responses were given through a standard QWERTY keyboard. The data from online questionnaires were collected using the Limesurvey platform. The eye tracker used was a Gazepoint GP3 (150 Hz).

The device used for current stimulation (electric shock delivery) was a Biopac STMISOLA module. The electric shocks were administered via two electrode pads placed in the participants' forearms. The electric shock intensity was controlled, ranging from 2 mA to 6 mA, with a 100 ms duration for each stimulation.

For the communicative and individual actions we used videos of point-light displays of human figures from the Communicative Interaction Database (Manera et al., 2015). Each person (agent) was represented by 13 white dots attached to the major joints and head (see Figure 1). Prior to usage in the main experimental task, we performed a brief pilot study (similar to Manera et al., 2015) for the Portuguese population (N = 31) that allowed us to select the actions that were, on average, more accurately discriminated (less error-prone). We selected “drink”, “lateral steps” and “turnover” for our sample of individual actions, and “sit down”, “pick this up” and “squat down” for the communicative actions sample. Subsequently, the dots for the selected actions were manipulated using Matlab (R2019b) to create versions with one of the agents (agent B; see below) under a noise mask that varied in the number of dots. A limited-lifetime technique was also implemented (see Figure 1), making a maximum of six randomly chosen dots of the agent visible, at any time, for 200 ms; dot appearance and disappearance were asynchronous across dots. Additional versions of these videos were created, where the dots representing agent B were also temporally and spatially scrambled while keeping their trajectory and velocity, effectively removing a coherent representation of the agent from the scene (absence condition).

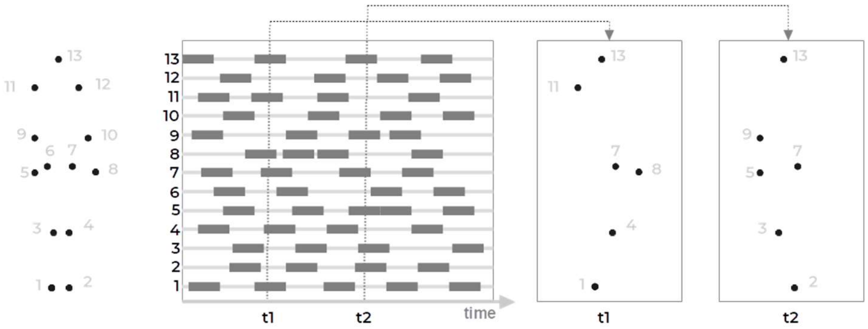

Figure 1. The main agent was represented by 13 white dots (left), shown here as black to facilitate the illustration. Limited-lifetime technique: Of the 13 dots composing each agent, only 6 are visible, at each time. Visible dots are chosen randomly and remain visible for 200 ms. From left to right: the 13 agent dots, an illustration of dot visibility, over time, and two samples of the agent, as shown to the participants, at two different time points.

The noise masks (see Figure 2 for an illustration) consisted of a fixed number of dots randomly added over the agent (the number of noise dots was adjusted to each participant; see below) and adopted a limited-lifetime technique. Each of the noise dots was built by sampling a random 200 ms interval of an agent’s dot trajectory, over the complete action of the agent, and placing it in a random position. This meant that each noise dot was present for 200 ms, being replaced by another noise dot, afterwards, and had a trajectory and velocity akin to the agent’s dots. To further prevent any familiarity due to stimulus repetition, each type of action had five versions, each exhibiting different limited-lifetime agent sequences and noise masks. Each video was presented occupying 12.5 by 18 visual degrees and averaging 4.3 seconds in length. This same video creation process was performed for the set of three videos used in the adjustment phase (with only one agent present, this time; see below).

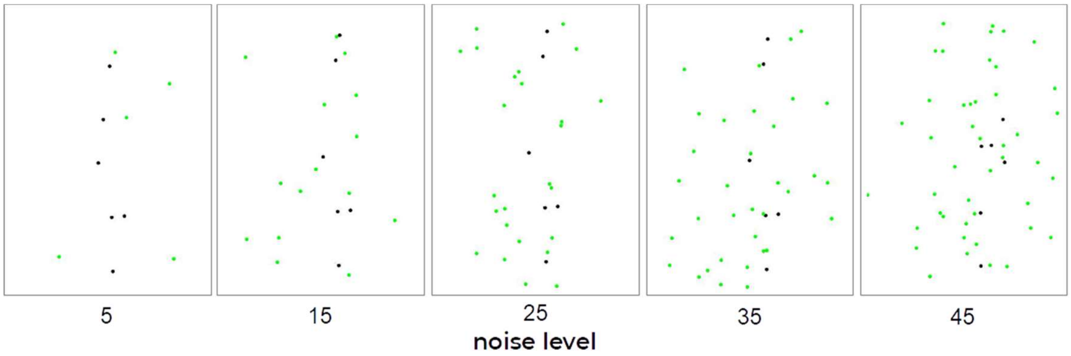

Figure 2. *Illustrative examples of noise masks. The masks were created considering 5 noise levels: 5, 15, 25, 35 and 45 dots. The noise level considered during the main task was selected for each participant during the adjustment stage. Noise dots are shown in green (agent in black) for illustration purposes only but were presented with the same color as the agent dots, during the experiment.*

Procedure

Prior to their lab session, participants filled out a brief online form, providing their informed consent and completing socio-demographic information (i.e., age, sex, currently diagnosed diseases, etc.), the trait part of the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Barros et al., 2022; Ree et al., 2008) and the Liebowitz Social Anxiety Scale (LSAS; Caballo et al., 2019; Liebowitz, 1987). If eligible, they were then contacted, and the experimental session was scheduled.

In the experimental session participants began by completing the STICSA-State, followed by the shock calibration procedure. Here, participants received a graded series of electric shocks, starting at 2 mA and going up to a maximum of 6mA. After each shock, participants were asked to indicate how uncomfortable that shock felt on a 5-level scale (from 1 “barely felt” to 5 “very unpleasant/uncomfortable”). The shock intensity was increased in steps of 1 mA until they reported a rating of four (“quite unpleasant/uncomfortable”) or the 6 mA (maximum) level was reached. If the rating of four was reported before the 6 mA level, shocks of that same intensity were administered until five shocks in total (since the beginning of the workup procedure) had been delivered. The intensity for the electric shock defined in this task was kept constant throughout the main task.

Participants were positioned in front of the computer screen and asked to position their heads on the chinrest, adjusting the chair, if needed. A brief eye tracker calibration was then performed. Two more calibrations were also done, one just prior and one in the middle of main task (roughly ten minutes apart).

Participants were then introduced to the main computerized task. The task began with an adjustment phase (60 trials), where the amount of noise dots each participant would be exposed to during the experimental task was determined. Participants were presented with a video of a point-light display of either an agent performing a simple individual action (an agent looking under their foot, sneezing or stretching) or a scrambled agent (absent condition), both superimposed by one of five different noise mask levels in total (i.e., 5, 15, 25, 35 or 45 noise dots). Thus, the agent could either be present (agent plus noise dots) or absent (scrambled agent plus noise dots). After watching each video (average duration of five seconds), participants were tasked with indicating if any agent was present using the mouse cursor (no time limit). The level selected, which would be used throughout the experiment, was the noise level that reached an accuracy level closest to 75%. These actions were only used during this phase.

Before starting the main experiment, participants were provided with a detailed description of the instructions, as well as some animated examples of the type of stimuli they would be exposed to during this task. In the experimental task, participants were shown videos depicting either one or two agents. On the left side of the video, Agent A was always present and shown clearly (i.e., without any noise or limited-lifetime technique). This agent could either perform an individual action (e.g., drinking a glass of water) or a communicative action (e.g., asking the agent beside to “look over there”). The agent to the right, Agent B, could either be present or absent from the video. If present, Agent B would be shown with a limited-lifetime technique and a superimposed noise mask (based on the participant’s initial calibration), making their identification difficult. Furthermore, their action would either be individual, if agent A’s action was also individual, or a communicative response to agent A’s action, if Agent A was performing a communicative gesture. On the other hand, if agent B was absent, the agents’ dots would instead be spatially and temporally scrambled, and once more shown with the limited-lifetime technique and under a cloud of noise dots.

After each video, a response screen was shown, and participants were tasked with indicating, using the mouse cursor, if only one (just agent A) or two agents (A and B) were present. Importantly, participants were previously told that agent A’s actions were semantically related to Agent B (if present) and that they should, therefore, direct their attention to Agent A at the beginning of each trial. To emphasize their initial evaluation of agent A’s actions, the fixation cross presented in each inter-trial period (one second duration) was located over the position agent A would appear in. Additionally, to ensure participants attended over agent A, in around 8% of the trials (two per block, see below), an additional response screen was shown, prompting the participant to answer if agent A’s previously seen action was communicative or individual in nature.

Lastly, it is important to note that participants completed this task under two conditions (blocks). In one type of block, labeled threat blocks, participants were randomly exposed to electric shocks. This would occur in approximately 8% of the block’s trials (i.e., two trials per block); participants were unaware of how many shocks they would be receiving. The other block type, labeled safe blocks, were performed without the delivery of any electric shock. Participants were always alerted to the type of block they would be going into and, as such, were fully aware if they were at risk of receiving an electric shock or not. Furthermore, during threat and safe blocks, two lateral red and green bars, respectively, were presented, to remind participants of the block they were currently in. Six blocks (three threat and three safe blocks) with a total of 144 trials (24 per block) were presented (see Figure 3). At the middle mark of the task, participants were encouraged to take a small break. At the end of each block, they were asked to indicate how anxious they felt on a visual analogue scale (from 0 "Not anxious" to 100 "Really anxious").

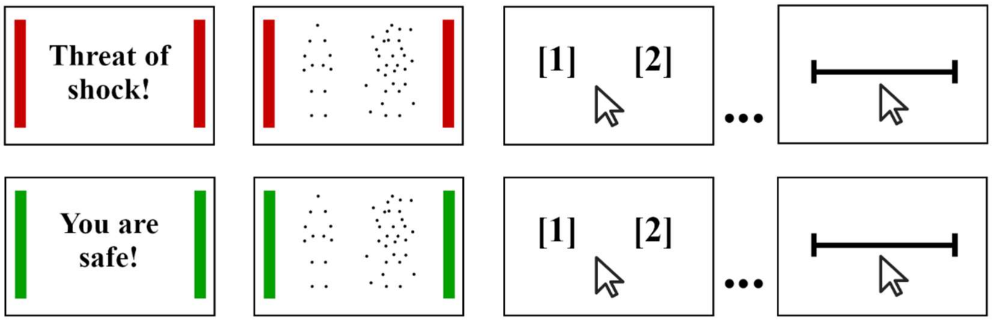

Figure 3. Illustrative temporal structure of a block and trial. Each block began with a warning screen, either indicating that participants would be safe during the next block or that they would be at risk of getting an electric shock. Each trial was composed of a video of one or two agents, followed by a selection screen, where participants had to decide if one or two agents were present in the video they just watched. At the end of each block they had to answer how anxious they felt during the previous block on a visual analog scale.

Upon finishing the task, participants were asked to indicate, on a visual analogue scale (0-100) how much, during the whole task, did they rely on agent A to gather clues as to the presence of agent B, and how much did they thought the actions of agent A were related to the actions of agent B. In a final task participants watched each video/action used in the main task (without any noise or limited-lifetime technique) and were asked to determine the type of action in each video (communicative or individual) and choose which description, based on 5 alternatives, better described the actions in the videos (adapted from Manera et al., 2015). This was done to assess both ability to discriminate the communicative intention of the actions as well as to probe how well they were able to understand the actions.

Statistical Analysis

All behavioral data treatment and statistical analysis were performed with R (2022.02.1) and with JASP (0.16.3). Signal detection theory measures of sensitivity and criterion were acquired with the psycho package (0.6.1; Makowski, 2018). A p-value below 0.05 was set for statistically significant effects.

Criterion (c) and sensitivity (d') were analyzed in two repeated-measures ANOVAs, with block and action type as fixed factors. The addition of STICSA (state and trait) and LSAS as covariates was also considered. The final model, as judged by the significant values and AIC/BIC indices, did not include any covariates. As a measure of effect size, we used the partial omega squared (ω_p^2). Residual analysis of the model was evaluated graphically and did not display any major violations from normality. For the manipulation check analysis, we performed a pairwise t-test between average anxiety ratings in the threat and safe blocks, with effect sizes being reported as Cohen's *d* (*d*). Correlations between the anxiety inventories and the overall criterion and sensitivity were additionally explored in a separate analysis with Pearson correlations. Lastly, an exploration of measures gathered in the final questions regarding the usage of agent A's cues, and how these related to agent B, is detailed in Appendix A. To assess the support for the null hypothesis, additional Bayesian analyses for the criterion and sensitivity, with the respective bayes factors for each parameter, were conducted and are provided in full in Appendix B.

Eye tracker data was extracted and processed in R. Trials where track loss was superior to 25% were removed (220 trials across all participants). Since no participant revealed an overall track loss superior to 20%, no participant was removed from the data set. Only three participants were removed due to recording issues. The final number of participants with valid eye tracking data was 63. Data transformation for window time and sequential analyses was performed with the package eyetrackingR (0.2.0; Dink & Ferguson, 2015) for R. For the proportion analysis, the data were binned into 200 ms intervals and analyzed in a generalized linear mixed model with a beta family. This model had block and time bin (centered) as fixed factors, with ID as random intercepts, with respective slopes per block and time.

For the analysis of fixations, we used linear mixed models for the duration analysis and a generalized linear mixed model for the count data (Poisson family). The minimum fixation duration was established at 50 ms (Rayner, 2009). Considering the distribution of time spent gazing at agent A, the time of interest for this analysis was limited to the first two seconds (which corresponded to ~80% of the time participants spent on agent A, overall).

This study was pre-registered prior to any data collection (osf.io/6vawb). All data analyses concerning our hypothesis (criterion measure) were pre-registered analyses, with the remaining analyses (sensitivity and eye tracking data) being interpreted as exploratory analyses.

Results

Behavioral and subjective results

Participants' subjective anxiety ratings were, on average, higher for anxiety blocks (*M* = 38.5, *SD* = 26.8), compared to safe blocks (*M* = 7.96, *SD* = 10.9; $t(65) = -10.18$, $p < .001$, $d = -1.25$, 95% CI [-1.57, -0.93]).

Beginning with criterion, our analysis showed that only action type had a significant effect (*F*(1, 65) = 9.823, $p = .003$, $\omega_p^2 = 0.052$, 95% CI [0.0, 0.19]; see Figure 4), with communicative actions depicting a lower criterion than individual actions. No statistically significant effect of threat of shock (*F*(1, 65) = 0.270, $p = .605$, $\omega_p^2 = 0$, 95% CI [0.0, 0.0]), nor any interaction between this and action type (*F*(1, 65) = 1.425, $p = .237$, $\omega_p^2 = 0$, 95% CI [0.0, 0.04]), was found. This lack of effect was further supported by a Bayesian analysis with the following bayes factors: BF_{01} = 6.25 and BF_{01} = 4.9, respectively (see Appendix B for the full analysis).

Concerning sensitivity, our analysis showed that threat of shock was not significantly different from safe conditions (*F*(1, 65) = 0.837, $p = .364$, $\omega_p^2 = 0$, 95% CI [0.0, 0.0]). Action type did show a marked tendency, with increased sensitivity in individual actions, but remained not statistically significant (*F*(1, 65) = 3.856, $p = .054$, $\omega_p^2 = 0.004$, 95% CI [0.0, 0.08]). The interaction between threat of shock (vs safe) and action type was also not statistically significant (*F*(1, 65) = 0.054, $p = .817$, $\omega_p^2 = 0$, 95% CI [0.0, 0.0]; see Figure 4). Again, this lack of effect of block was further supported by the Bayesian analysis (BF_{01} = 4.425 and BF_{01} = 3.718, respectively).

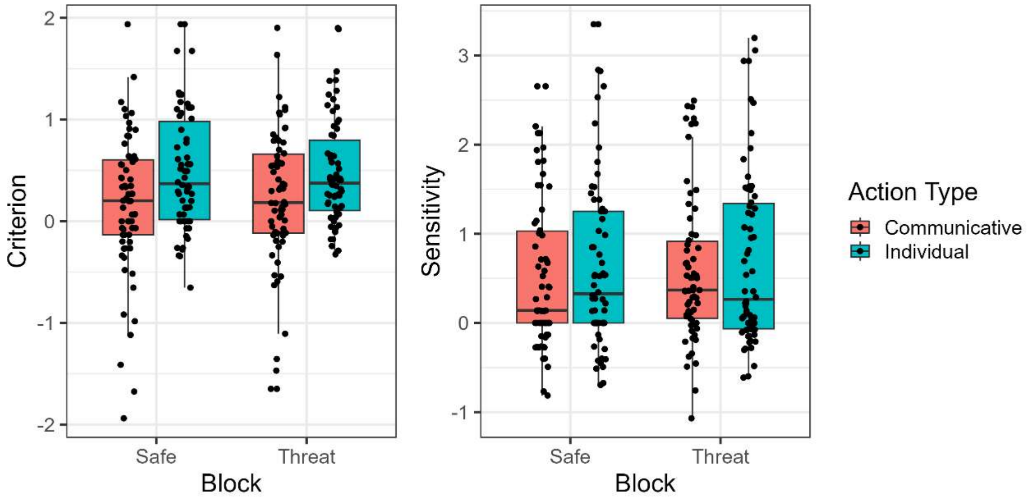

Figure 4. Observed criterion and sensitivity data across block and action types.

Lastly, we analyzed the correlation between our target measures (criterion and sensitivity) and the anxiety questionnaires (STICSA and LSAS). All analyses revealed no correlation between any of the latter and either criterion or sensitivity ($p > .05$).

Eye tracker

The proportion of time looking at the regions of interest containing agent A (compared to agent B) in the first two seconds of the task was different across time ($\chi^2(1) = 651.94$, $p < .001$), as expected. However, threat of shock showed no effect ($\chi^2(1) = 0.044$, $p = .834$), nor was there any significant interaction between this and time ($\chi^2(1) = 0.24$, $p = .624$; see Figure 5).

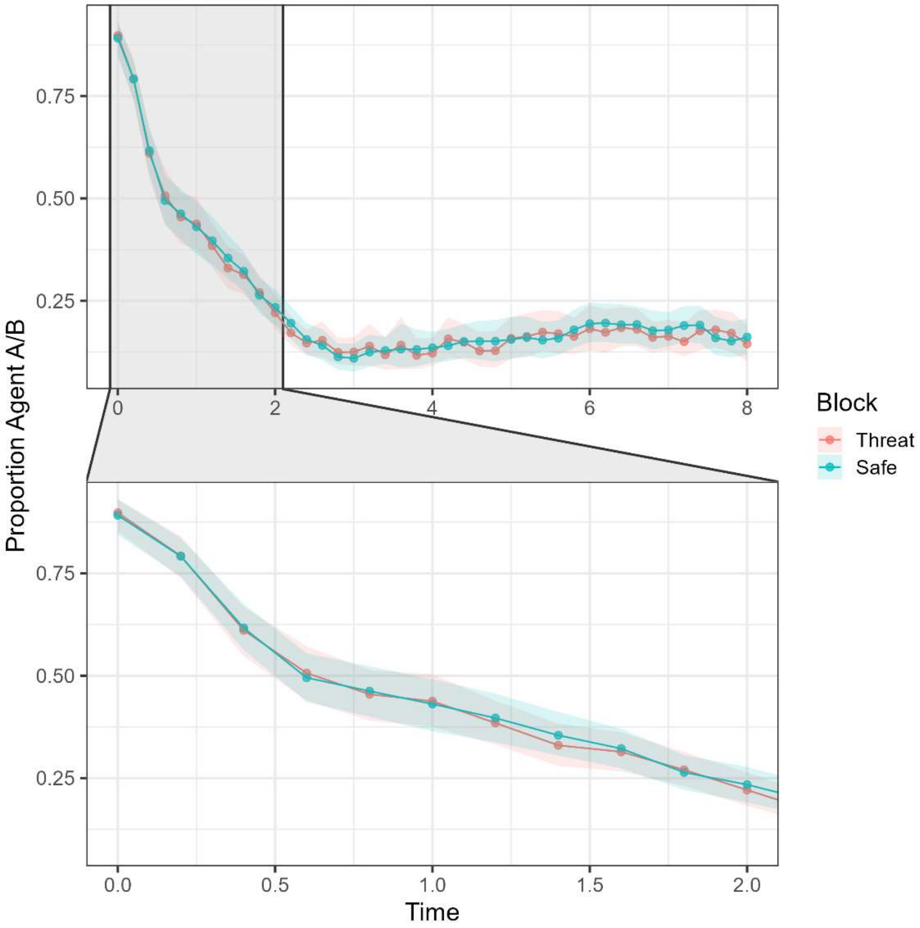

Figure 5. *Proportion of time spent looking at agent A compared to agent B. Top image shows the maximum possible time of a trial. Bottom image shows just the first two seconds. Each point is a time-bin of 200 ms. Higher values reflect more time spent gazing at agent A compared to agent B.*

When looking at the fixations for the first two seconds of each trial, we found that the average duration of fixations on agent A were smaller during threat blocks, compared to safe blocks ($\chi^2(1) = 4.305$, *p* = .038; see Figure 6). As for the number of fixations on agent A during this time period, no significant difference between blocks was found (*t*(62) = -1.248, *p* = .217, *d* = -0.16, 95% CI [-0.41, 0.09]). No statistically significant difference between threat and safe blocks in the average fixation duration ($\chi^2(1) = 2.633$, *p* = .105) or the number of fixations ($\chi^2(1) = 0$, *p* = .982) was found for agent B after the first two seconds (two to eight seconds).

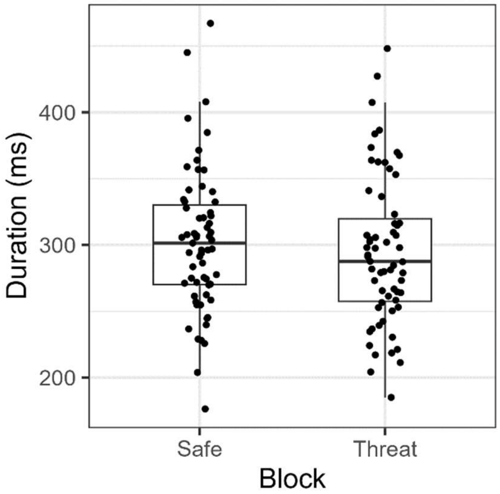

Figure 6. Average fixation durations (in ms) for the first two seconds for each block (safe vs threat). Safe and threat blocks are significantly different in terms of average fixation durations.

Discussion

In this study, we investigated the extent to which anxious states affect the weight given to expectations, when interpreting the presence of a social agent in a noisy environment. To this end, we presented participants with a task where they had to judge the presence of a masked agent (B) considering the different cues (communicative vs individual) provided by a second agent (A). Importantly, this task was performed in both safe and threat of shock conditions. We measured the participants' criterion and sensitivity in perceiving agent B as a function of the type of cue and condition that they were in, and we also gathered eye tracking information.

As with prior studies using this interpersonal predictive coding paradigm (e.g., Manera, Del Giudice, et al., 2011; von der Lühe et al., 2016), we observed an effect of action, where communicative actions displayed by agent A led to significantly lower criterion in signaling the presence of agent B. Contrary to what we expected, however, threat of shock played no significant part in shaping participants criterion (hypothesis 1). In other words, threat of shock neither affected the overall criterion nor did it moderate the effect of type of action over the criterion. Likewise, a direct comparison of the criterion shown during communicative actions across blocks (safe and threat of shock) revealed no significant difference between these two contexts (hypothesis 2). Overall, the results above seem to suggest that being under threat-induced anxiety is not enough to affect the weight given to expectations in these types of social settings.

Albeit surprising, given prior results that suggest a more stimulus-driven processing (Cornwell et al., 2007, 2017), we posit some possible explanations. One such explanation falls upon the differences between the measures used to capture the weight given to expectations. Whilst noticeable in terms of brain activation (evoked-related potentials) following a mismatching stimulus (i.e., in MMN responses), changes directed at the valorization of sensory input (and consequently expectations) might be harder to capture with behavioral paradigms, where subjective answers are used as markers. This is further supported by at least one other study (Okruszek et al., 2017) which saw no difference in this same paradigm between schizophrenic and control patients. This was observed despite evidence of a reduced mismatch negativity associated with this disorder (schizophrenia) from other MMN-base studies (e.g., Michie et al., 2016) and other neuroimaging studies (Horga et al., 2014). Together with the high variation of the criterion shown by participants in our task, it might be the case that changes in expectation reliance might be harder to capture using self-reporting measures (as in our study).

In line with the above, the modality of presentation is also worthy of discussion. Most studies investigating evoked potentials to deviants (i.e., MMN) do so in the auditory domain. Visual mismatch negativity (vMMN) is considerably less explored than its acoustic counterpart (Czigler, 2014; Czigler et al., 2006) but, nonetheless, both versions of MMN appear to share similar characteristics between them (see Wei et al., 2012). Only one study related vMMN (with emotional faces) and anxiety, investigating this relationship in patients with panic disorder (Tang et al., 2013) and showing instead a reduced vMMN in this population. This conclusion is supported (Cheng et al., 2021) but also contradicted (Chang et al., 2015) by other studies that use auditory MMN. Thus, it is currently hard to say if conclusions regarding MMN in the auditory modality are transposable, as expected, to paradigms using visual stimuli (as with our study).

It is also worth mentioning that, despite the majority of the studies aligning with those found by Cornwell and colleagues (2007, 2017), other studies exhibited contrasting results (Cheng et al., 2021; Tang et al., 2013; Zheng et al., 2019). As highlighted by Fucci and colleagues (2019), this could be due to these effects manifesting themselves only on highly anxious individuals, be it in individuals with trait anxiety or in those experiencing really high levels of anxiety, who would thus show a measurable increase in sensory-driven perception. In other words, only during truly elevated states of anxiety, which might not have been fully achieved with our manipulation, or with people with elevated proneness towards experiencing anxiety, would this effect manifest itself. While in our study both state and trait anxiety did not exert a significant impact on our results, it is possible that the overall anxiety experienced by participants (compared to other highly stressful daily situations) was still low.

Other factors related to the characteristics and design of our experimental task might also have contributed to the lack of differences shown between safe and threat contexts. One such factor might pertain to the low accuracy observed. Accuracy across blocks and types of action ranged from 57% to 61%. This is a little less than intended since the calibration performed at the beginning of the task aimed at approximating accuracies towards the 75% value. One could argue that perhaps the task difficulty was higher than expected, with participants having a harder time identifying agent B. This could have led to responses, in the case of some participants, being given at random, or with their responses being overly dependent on agent A, which seems to be at least partially supported by the answers given at the end of the main experimental task (see Appendix A). Of note, the accuracy reported here was similar to another study using this paradigm, in which no differences in the task between people diagnosed with schizophrenia and healthy subjects were found (Okruszek et al., 2017).

In line with the low accuracy during the task, another possibility might be the, arguably, low accuracy observed in the attention check task (~77%), where participants had, on random trials, to indicate the type of action displayed by agent A. This task was meant to ensure that participants paid sufficient attention to agent A at the beginning of the trial, which might still not have been to the extent desired. This is, in part, also supported by eye tracking data, which showed that in 25% of all total trials, participants had less than half a second of time spent on agent A (see Appendix C). Nonetheless, we believe that this low accuracy was more a result of forgetfulness rather than of lack of attention, and that participants did, indeed, pay sufficient attention to agent A (even if not the idealized amount). This is supported by both the participants' self-reports at the end of the task and, pivotal to this argument, the fact that sufficient attention had to be given to agent A for the effects of action type to emerge. Thus, we see little reason to believe that the lack of attention towards agent A might be explaining the results found here.

Regarding sensitivity, we did not observe any effects from block, only showing that individual actions were marginally associated with increased sensitivity. Other studies have managed to show an opposite pattern, i.e., more sensitivity in communicative actions (von der Lühe et al., 2016; Zillekens et al., 2018), but some, as with this one, showed no significant difference (Manera, Del Giudice, et al., 2011). Since exploring why this is the case remains outside the scope of this study, we merely highlight the need for future studies to explain why such differences might emerge.

To rule out any effect of the self-reported anxiety on both measures discussed above (criterion and sensitivity), we also explored and showed that neither measure was associated with self-reported state, trait, or social anxiety. While past studies have hinted at a positive relation between either trait and/or state anxiety and MMN (Fucci et al., 2019; Hung et al., 2013; Schirmer & Escoffier, 2010), which would possibly be expected to reflect on criterion, others revealed opposite patterns (C. Chen et al., 2017; Cheng et al., 2021). Furthermore, many of the latter findings connecting levels of anxiety with increased or decreased amplitudes of MMN are not generally observed but are instead dependent on the type of population (e.g., panic disorder patients) and emotional characteristics of the stimuli (e.g., fearful; Cheng et al., 2021; Hung et al., 2013; Schirmer & Escoffier, 2010). Perhaps only in more severe cases (e.g., pathological population) or with negative-valence stimuli (e.g., fearful/threatening interactions) could any of any of these self-reported anxiety measures be associated with actual response criterion.

Concerning gaze analysis, no apparent difference between safe and threat of shock conditions in the proportion of dwell time over agent A compared to agent B (during the first two seconds) was found. Aligned with the behavioral results, this supports the idea that the time allocated to agent A during the start of each interaction was consistent, irrespective of context. However, when exploring the average fixation duration towards agent A during the initial moments of each video, participants under threat, compared to safe conditions, depicted, on average, shorter fixation times. This finding aligns with literature depicting gaze behavior in different types of sports tasks, revealing that in highly anxious individuals (trait and state anxiety), the average fixation duration tends to be smaller, when compared to controls (e.g., Murray & Janelle, 2003; Wilson et al., 2009). It is also known that, under threat, participants tend to have higher volatility regarding their visual fixations (Laretzaki et al., 2011). Alongside the findings above, and the ones in this study showing a reduced fixation duration, this might suggest an increased difficulty (decrease in efficiency) in extracting information from the environment. However, this finding remains speculative, but should be considered in future studies.

Limitations and future studies

Some limitations should be pointed out. One limitation pertains to the lack of a confidence rating measure regarding the participants' response on each trial. This could have provided valuable cues as to whether responses were given at chance and to the degree of confidence deposited in each decision. It could also potentially reveal differences in response confidence between threat and safe blocks. In line with this limitation, but disregarding fatigue factors, we believe that adding more trials to the calibration phase would better fine tune the task towards each participant. Since a too easy or too hard a task could either prevent biases from agent A from emerging or give way to random responses, respectively, this might be something to be better considered in future experiments.

Another limitation worth mentioning concerns a possible lack of statistical power. This could have arisen due to two factors. One is that our power analysis might have been designed using overly optimistic estimates and strived to capture bigger effect sizes than those actually present. This could mean that effects with smaller magnitudes might still be present and yet were not captured. A second factor is the limited sample of actions representing the communicative and individual actions (three per category). This is due to the limited size of available databases and to the validation of these same actions for the Portuguese population. Although we note the number of stimuli is similar to prior studies with this paradigm (e.g., Okruszek et al., 2017; von der Lühe et al., 2016), future studies should still expand on these existing databases and broaden the representation of their study variables.

Finally, as Zheng and colleagues (2019) have shown, the valence of the stimuli, namely its association with threat, appears to be a critical factor in determining increased MMN. Future studies could attempt to manipulate the emotional nature of stimuli or manipulate the relationship between the response and the probability of shock, clarifying the role of emotion and threat-relevance of the stimuli in the effects explored here.

Conclusion

We sought to investigate if anxiety states, induced via threat of shock, affect how social interactions are perceived. Namely, we meant to evaluate if our ability to extrapolate and apply expectations from communicative gestures to infer the presence of a second agent partaking in the interaction remains intact under anxiety. We saw no evidence that being under anxiety, compared to a safe/neutral contexts, affects our weighing of expectations in the perception of social scenes. This conclusion was further extended by the lack of association between anxiety questionnaires (state, trait and social) and decision criterion. Lastly, gaze analysis revealed that time spent collecting cues was similar across threat and safe contexts. Only some hints of a more erratic fixation pattern (shorter fixation times) were shown during threat in comparison to safe contexts. Thus, we conclude that being under a state of induced anxiety does not appear to affect how expectations are formulated and used to anticipate social interactions.

CHAPTER IV

Study 3: The effect of anxiety and its interplay with social cues when perceiving aggressive behaviors

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Abstract

Contextual cues and emotional states carry expectations and biases that are used to attribute meaning to what we see. In addition, emotional states, such as anxiety, shape our visual systems, increasing overall, and particularly threat-related, sensitivity. It remains unclear, however, how anxiety interacts with additional cues when categorizing sensory input. This is especially important in social scenarios where ambiguous gestures are commonplace, thus requiring the integration of cues for a proper interpretation. To this end, we decided to assess how states of anxiety might bias the perception of potentially aggressive social interactions, and how external cues are incorporated in this process. Participants (N = 71) were tasked with signaling the presence of aggression in ambiguous social interactions. Simultaneously, an observer (facial expression) reacted (by showing an emotional expression) to this interaction. Importantly, participants performed this task under safety and threat of shock conditions. Decision measures and eye tracking data were collected. Our results showed that threat of shock did not affect sensitivity nor criterion when detecting aggressive interactions. The same pattern was observed for response times. Drift diffusion modelling analysis, however, suggested quicker evidence accumulation when under threat. Lastly, dwell times over the observer were higher when under threat, indicating a possible association between anxiety states and a bias towards potentially threat-related indicators. Future probing into this topic remains a necessity to better explain the current findings.

Keywords: Anxiety; Threat; Visual Perception; Social Perception; Expectations

Introduction

The way we see the world is subject to a constant, but ever-changing, filter of influences. Some of these influences can be more accurately identified, such as the influence of alcohol on perception (Calhoun et al., 2004), whilst others are less obvious. These latter ones are the result of internal cognitive processes that integrate external information, such as our context and prior experiences, and internal states themselves, such as motivations and emotional states. Taken together, these form the basis of the expectations that we use in attributing meaning (interpreting) to our visual world (de Lange et al., 2018; Dunning & Balcetis, 2013).

The benefits of expectations are mostly seen when the quality of our sensory input is ambiguous or degraded – i.e., less reliable (de Lange et al., 2018). This happens when one is clearly aware of the limited (degraded) sensory input, such as when interpreting a conversation in a loud place, or under more subtle conditions that require us to resolve ambiguous interpretations. This is particularly the case during social interactions, since communication is riddled with subtle nuances that rapidly change the meaning/intent of the communicator (Campbell et al., 2022; Friston & Frith, 2015). In these cases, context provides an important aid when interpreting our social environment (Manera, Del Giudice, et al., 2011; Zillekens et al., 2018).

Likewise, emotional states can also alter our visual system and bias expectations, shaping how we view our world (Gasper & Clore, 2002; Riener et al., 2011; Stefanucci et al., 2008), and in specific, our social environments (Jolij & Meurs, 2011; Niedenthal et al., 2000; Niedenthal & Wood, 2019). Here, we focus on the specific affective state of anxiety and how it affects visual perception. These changes have already been documented in relation to high-trait anxiety (e.g., K. L. H. Gray et al., 2009; Rossignol et al., 2005), but remain less explored in the case of functional anxiety states. A few studies have shown that states of anxiety enhance sensory-perceptual processing, leading to a rougher, but quicker (even if, perhaps, more error-prone), detection of salient stimuli (Lojowska et al., 2015, 2019; Robinson, Vytal, et al., 2013). For example, when faced with repeating patterns of sensory-input, deviants generate greater mismatch negativity (MMN) event-related potentials when under threat (Cornwell et al., 2007, 2017; but see Fucci et al., 2019). This gain is even shown to take place prior to any high-order (cortical) processing of the sensory information (Baas et al., 2006).

An additional characteristic of this increased sensory-perceptual processing seen during anxiety is the fact that it is predominantly directed at threat-signaling stimuli (Robinson et al., 2011; Sussman, Szekely, et al., 2016). For instance, in line with the increased MMN research exemplified above, there is an increased response to fearful (but not happy) facial expressions in the ventral striatum when such faces are unexpected (Robinson, Overstreet, et al., 2013). Other studies have come to support the idea that, just as in high-trait or pathological anxiety (Bui et al., 2017; Capitão et al., 2014), one's sensitivity towards a threat-related stimuli is increased when under threat, leading to quicker and/or more accurate detections (Sussman, Szekely, et al., 2016; see Bar-Haim et al., 2007). Aside from being more quickly identified, facial expressions that signal threat (i.e., fear and anger) are also perceived as being more intense and more easily judged as fearful (Flechsenhar et al., 2022; Kavcıoğlu et al., 2019; Wudarczyk et al., 2016; Zhou & Chen, 2009).

One question that has gotten little attention, however, concerns how we incorporate contextual cues, namely those that can be used to signal threat or lack thereof, under states of anxiety. This is of particular importance since an enhanced sensory-driven perception, typical of such states, consequently, implies a lesser dependency on expectations (prior information). In turn, this is supposed to result in a reduced specificity when interpreting and discriminating visual information (Cornwell et al., 2007, 2017; van Marle et al., 2009). However, an earlier study conducted by the authors (Silva, Ribeiro, et al., 2023; Chapter III) has failed to evidence shifts in participants' perception under anxiety when judging ambiguous social interactions. Crucially, all the visual elements in this task, both contextual cues and target stimulus, were emotionally neutral. A natural follow-up question, given the association between threat-related sensitivity and anxiety, concerns how emotional social scenes are perceived under threat. Namely, how are both sensitivity and criterion (related to specificity) measures affected by anxious states when the social stimuli have a threat-related emotional appraisal.

The idea that under anxiety, the presence of other threat-related factors (e.g., a fearful face as opposed to a neutral one) further potentiates anxiety-related effects has already been suggested (Grillon & Charney, 2011). Sussman and colleagues (2016) explored this by measuring if when under anxiety, compared to safe conditions, participants benefited from being exposed to a fearful cue when identifying fearful expressions (among neutral expressions). They showed a greater perceptual sensitivity under threat in detecting fearful expressions compared to safe conditions, with this effect being conditional on high levels of trait anxiety. However, by not directly comparing different types of priming cues (fear vs neutral) when detecting fearful expressions, no conclusions concerning how the identification of threat is boosted by fearful cues seems yet warranted. Furthermore, no measurement of criterion was calculated, thus not revealing the extent of any general bias (expected likelihood of fearful expression) induced by the context and cues.

The present study

Thus, in this study, our aim is two-fold: 1) explore the decision parameters (sensitivity and criterion) related to the identification of aggression when under an anxiety state and 2) assess how emotional cues are incorporated in the perception of aggression in ambiguous social scenes when under anxiety. To this end, we used ambiguous social displays that could either convey an aggressive (anger gesturing) or an innocuous interaction. Additionally, we paired these scenes with an external agent (observer) that was depicted as reacting to the interaction taking place. By manipulating its facial expression, either showing a fearful reaction or a neutral facial expression, we created contextual cues that participants were exposed to before judging the nature of the scene taking place (aggressive or not). Importantly, participants undertook this task whilst under safe and threat of shock conditions. We collected response data to establish their sensitivity (d') and criterion (c), as well as response times (RTs), and gaze data.

With this in mind, and considering the literature discussed above showing that anxiety improves perceptual sensitivity towards threat, we expected the following: when under threat (compared to the safe condition) participants would exhibit 1) an overall higher sensitivity in detecting aggression; 2) a bigger gain in sensitivity when presented/primed with a fearful facial expression (compared with a neutral one); 3) an overall reduced criterion (general tendency to report aggression); and, lastly 4) quicker reaction times. The remaining comparisons involving anxiety inventories as well as gaze data, will be interpreted as exploratory analyses.

Methods

Participants

Sample size was determined with the use of Superpower package for R (v. 0.2.0; Lakens & Caldwell, 2021). Based on prior literature, we hypothesized expected means and a standard deviation for our analysis design (2 by 2 within-subjects), running a total of 2000 simulations. We arrived at a minimum of 62 participants for a desired power of .8 (and a partial eta-squared of .15). To account for possible exclusions, we collected a total of 73 participants. Of these, one was removed for having more than 25% of the trials with no-response. Another was removed for showing a threat-identification accuracy in the final recognition task below 75%. No highly abnormal patterns regarding facial expression identification were found (no participants removed). Our final sample consisted of 71 participants (57 females; $M_{\text{age}} = 21.5$, $SD_{\text{age}} = 3.9$). The present study was conducted with permission from the ethics committee (reference 02-CED/2021) and in accordance with the data protection regulation from the University of Aveiro.

Stimuli and apparatus

The point-light displays of agents performing different actions were gathered and generated with the Social Perception and Interaction Database (Okruszek & Chrustowicz, 2020). We selected "Altercation", "Denying accusations", "Stopping the conversation" and "Taking the blame" for our aggressive set of actions and "Come close", "Give me that", "Look there" and "Pick it up" for our neutral set ($M_{\text{duration}} = 3.8$, $SD_{\text{duration}} = 0.4$). The actions "Confronting an aggressor" (aggressive) and "Sit down" (neutral) were used in the practice phase. Each action (used in main task) was generated with a flicker (limited lifetime technique) set at six points, with asynchronous appearance and disappearance varying between 150 and 250 ms. To avoid familiarity due to repeated exposure, six different versions per action (and accompanying flickering pattern) were generated. Each video was presented in a window of 1280 by 720 pixels. Considering the chin-rest position (60 cm away from the screen), the effective size of the area occupied by the agents was 19 by 11.4 visual degrees.

The fearful and neutral facial expressions were retrieved from the PLAViMoP database (Decatoire et al., 2019). Each expression (fearful and neutral) was manipulated so as to present a ~30º angle towards the left and right. This angle allowed the faces to be perceived as directed towards the interaction that would take place in the middle of the screen (see Figure 1 below). Each video was presented in a window of 512 by 288 pixels. The faces occupied an area of 3.8 by 4.8 visual degrees and were positioned at around 14.3 visual degrees away (diagonally) from the center of the screen (see Figure 1).

The electric shocks, used to induce anticipatory anxiety, were delivered with the STMISOLA module from Biopac. The shocks ranged from 2 to 6 mA and had a duration of 100 ms. The two electrodes were attached to the participants forearm, with a distance of about three cm between them.

The experimental task was displayed on an MSI Pro MP241 monitor with a 1920 by 1080 pixel resolution. Behavioral responses were given through a standard QWERTY keyboard. The data from online questionnaires were collected using Limesurvey (forms.ua) and the experimental task was programmed using Psychopy version 2021.2.3 (Peirce et al., 2019). The eye tracker used was a Gazepoint GP3 (150 Hz).

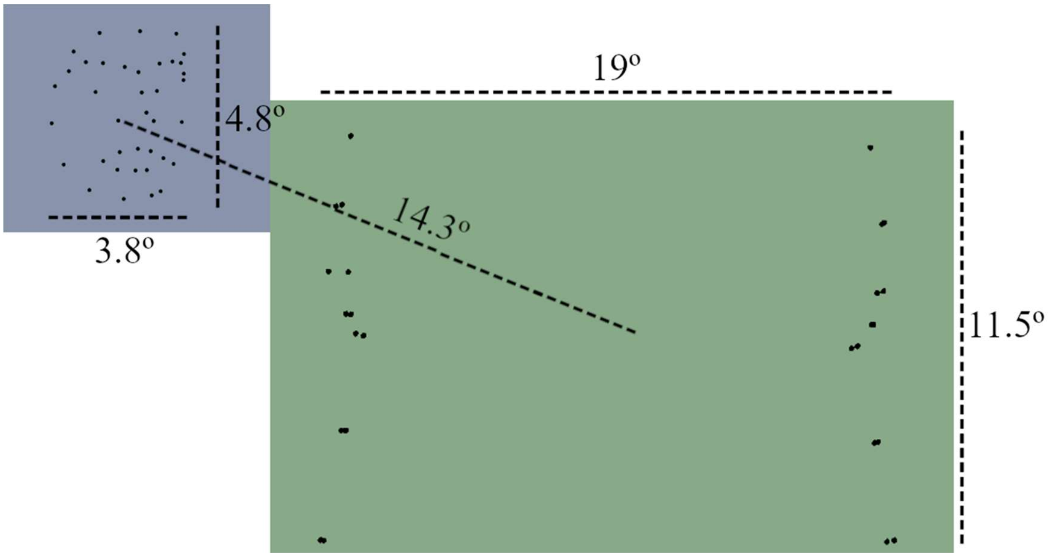

Figure 1. Scheme of the overall disposition of the stimuli, their respective occupied area (in visual degrees) and their regions of interest (ROIs). The blue color represents the face ROI and the green color represents the central/main action ROI.

Procedure

Recruitment took place via a brief online form, where participants, after providing their informed consent, filled out socio-demographic information (age, sex, etc.), and completed the trait portion of the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Barros et al., 2022; Ree et al., 2008) and the Liebowitz Social Anxiety Scale (LSAS; Caballo et al., 2019; Liebowitz, 1987). If eligible, they were then contacted, and the experimental session was scheduled.

The experimental session began with an initial description of the study and the presentation of the informed consent. Afterwards, participants were asked to fill in the state portion of the STICSA. The shock workup procedure followed, with two electrodes being applied in the left forearm of the participant. Here, they received a graded series of electric shocks, starting at 2 mA and going up to a maximum of 6 mA. Each shock was followed by a question where participants had to indicate how unpleasant the shock they had just received had felt on a scale from one (barely) to five (very unpleasant/uncomfortable). The shock intensity was increased in steps of 1 mA until the rating of four (quite unpleasant/uncomfortable) or the maximum intensity level was reached. The calibrated intensity for each participant was used throughout the rest of the experiment. Importantly, if the rating of four was reached before the 6 mA maximum level, electric shocks of that same intensity were administered until a total of five shocks (since the beginning of the workup procedure) were delivered.

After this stage, participants were positioned in front of the lab computer, and asked to position their head on the chinrest. A brief eye-tracker calibration was then performed, prior to initiating the experimental task. Two more calibrations would occur, one at the start and another at the middle point of the main task (after, roughly, 10 minutes).

A practice phase followed. Each trial began with the presentation of an external observer (face) followed by a central video of two agents interacting with each other. Participants were asked to initially focus their attention on the external observer, who could appear at the upper left or upper right quadrants of the screen (indicated by a prior loading/fixation cross). Only after the two agents showed up (1.3 seconds after the trial began, with a fade-in of 0.2 seconds), should they redirect their attention to the central interaction. The observer would only be “looking” towards the central interaction, but not showing any type of emotional expression. The participants’ task was to identify, by means of keypress, if the central action between the two agents was aggressive or not, as quickly and accurately as possible. They had until one second (blank screen) after the video ended to provide their answer. The observer remained on-screen until the end of the video. As previously mentioned, the actions presented during this practice phase were different from those shown in the main task and were only displayed with a reduced amount of flickering to facilitate identification. Importantly, the task was completed in two different types of blocks (two trials per block). In one block (safe), participants were told that they would not be receiving any electric shock. In the other block (threat), they were informed that they would receive one electric shock at any given moment. These two blocks were accompanied by two lateral rectangles that would either be empty (only white outline; safe block) or colored in yellow (threat block). Additionally, participants received feedback after each practice trial, indicating whether their response was correct or incorrect; this was not the case in the main task.

In the main task (see Figure 2 for an illustration of a trial), participants were asked to follow the same instructions as before. However, they were told that this time the observer would be reacting to the central action that would be presented after (and alongside) him. In addition, this time the central action would be more difficult to identify (full flickering). Moreover, this time the blocks were longer, and, in the threat block, participants were told that they could receive a random number of electric shocks. However, unbeknownst to the participants, they would only receive two shocks per block (six in total), corresponding to around 8% of the trials in the threat blocks. Importantly, to ensure that participants were paying attention to the observer at the start of each trial, in two random trials per block they were asked to identify if the observer had exhibited any facial expression (answered by keypress). At the middle mark of the main task, they took a small break.

After the main task, participants had three brief additional tasks/questions. In the first one, they had to identify the emotion associated with each action observed during the main task (now fully visible, i.e., no flicker/limited-lifetime technique). The second task asked participants to rate what emotions best described each facial expression shown by the observer (both left and right oriented versions) during the task. They did do so by rating how each emotion (happy, sad, angry, fear, disgust, and surprise) was associated with the facial expression displayed in a visual analog scale (0-100). Finally, they were asked if they felt that the relationship between the observer (facial expression) and the central action was different between blocks (threat and safe) and, if so, in which block did they believed the association was higher. This marked the end of the experiment, and participants were then debriefed and thanked for their participation.

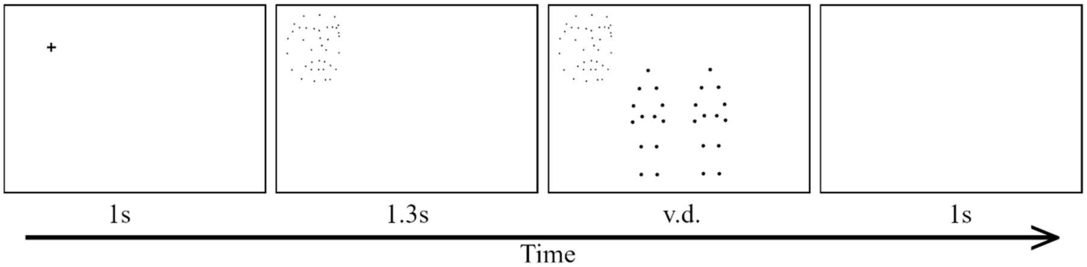

Figure 2. General illustration of a trial. Lateral rectangles are omitted. Participants had a one second fixation cross. This cross could be shown in the left (as in the picture) or right upper portions of the screen. This cross was replaced by a face (observer) which could either show a facial expression or remain neutral. After 1.3 seconds, the

central video (with a 0.2 s fade-in) was presented. After the video ended, if no answer was provided, they were shown a blank screen for one second, giving the participants extra time to provide their answers.

Statistical Analysis

All data treatment and statistical analyses were performed with R (2022.02.1). Prior to any analysis, data from trials containing no response were removed (around 3% of all trials), as well as trials where response times were inferior to one second after the central action appeared (around 1% of all trials). As measures of effect size, we used partial omega-squared (ω_p^2) for ANOVAs and Cohen's *d* (*d*) for the t-tests.

Signal detection theory measures of sensitivity and criterion were acquired with the psycho package (0.6.1; Makowski, 2018). A p-value below 0.05 was set for statistically significant effects. Normal distribution of residuals was assessed visually and with Shapiro-Wilk tests. All post-hoc analysis used Bonferroni corrected p-values.

Sensitivity, criterion, RT and drift diffusion modelling (DDM) measures were analyzed with repeated measure ANOVAs. The introduction of covariates was considered, but the best models, as measured by model p-values and AIC values, were those without any covariate. For RT analysis, only correct trials were considered. To additionally provide support for the null hypothesis in our main analyses, Bayesian analyses were performed (Appendix A) with their respective bayes factors (BF) being reported in the main results section.

We also performed a DDM analysis to allow both RTs and decision criteria into one single analysis. Here, the response time variable was transformed to start only after the first fixation over the region of interest (ROI) containing the central action in each trial (and not since the beginning of the video). This allowed us a clearer measurement on initial attention over the target (central action). Given the track loss experienced in some of the trials, around 3% of trials were excluded for this analyses, since in these cases we were unable to derive time of first fixation. In addition, around 2% of the trials were excluded due to first fixation times superior to one second after action onset, indicating either inattentiveness or calibration problems. The DDM parameter estimation was performed with the Fast-dm software (v. 30.2; Voss & Voss, 2007), using maximum likelihood as a computation method (precision at 4.0). Parameters for boundary separation (alpha) and starting point (z) were estimated separately per block and facial emotion, whilst drift rate was additionally estimated for the type of action (aggressive versus neutral). Drift rate was analyzed as a function of magnitude towards the correct response (values were transformed accordingly; Myers et al., 2022). Given our prolonged trial responses, and limited number of trials, the non-decision time was fixed at 0.3 (default of the software) for every individual and condition, and all other parameters concerning inter-trial variability of parameters were fixed at zero (Lerche & Voss, 2016).

Concerning eye tracking data, trials with track loss (loss of correct tracking of the participants eye) superior to 25% were removed, resulting in the exclusion of 237 trials (1.7% of the data). Due to calibration issues, one participant was removed due to an overall track loss superior to 25%. The final number of participants in the eye tracking data was 70. Data transformation for window time and sequential analyses was performed with the package *eyetrackingR* (0.2.0; Dink & Ferguson, 2015) for R. For the proportion analysis, data were binned into 200 ms intervals and analyzed in a generalized linear mixed model with a beta family. Additionally, the time window for analysis was set between 800 and 1800 ms (centered at 1300 ms, when the main action was shown). This model had block, face emotion and time (centered) as fixed factors. Participant IDs were incorporated as random intercepts (no random slopes were added due to convergency issues).

When analyzing time until first fixation over the central ROI (see Figure 1 above), only trials in which the first fixation was less than one second after central video onset (1.3 second mark) were considered. For the fixation duration and count analysis over the observer ROI, only fixations with a minimum duration of 50 ms were used (Rayner, 2009). The period for this analysis was established from the beginning of the trial until the appearance of the central action (1.3 s) plus the time it took for the participant to remove its gaze from the face/observer ROI. No fixation that went over the two second time mark of the trial was considered for this analysis. Fixation duration and count were analyzed with linear mixed models and generalized linear mixed models (Poisson family), respectively. In both models, block was added as a fixed factor and the random structure of the model was comprised of random intercepts per participant ID, with varying slopes per block.

Descriptive and graphical analyses over the last questions of this experiment are described in Appendix B. This study was pre-registered (osf.io/2c8sg).

Results

Manipulation check

Analysis over reported values of anxiety showed that our threat manipulation worked as intended, with threat blocks eliciting greater feelings of anxiety ($M = 38.1$; $SD = 25.2$) compared to safe ones ($M = 14.1$, $SD = 15.8$; $t(70) = 11$, $p < .001$, $d = 1.29$, 95% CI [0.97, 1.60]).

Sensitivity and criterion

Our analysis showed that threat of shock had no statistically significant effect over sensitivity ($F(1, 70) = 1.782$, $p = .186$, $\omega_p^2 = 0$, 95% CI [0, 0.06]; $BF_{01} = 5.05$). The same was observed for the facial expression of the observer ($F(1, 70) = 0.004$, $p = .948$, $\omega_p^2 = 0$, 95% CI [0, 0]; $BF_{01} = 4.72$), as well as the interaction between threat of shock and the latter ($F(1, 70) = 0.076$, $p = .783$, $\omega_p^2 = 0$, 95% CI [0, 0]; $BF_{01} = 3.86$).

For criterion, threat also showed no statistically significant effect on this measure ($F(1, 70) = 0.005$, $p = .943$, $\omega_p^2 = 0$, 95% CI [0, 0]; $BF_{01} = 6.71$), whilst the facial expression of the observer did ($F(1, 70) = 36.93$, $p < .001$, $\omega_p^2 = 0.11$, 95% CI [0.01, 0.26]; $BF_{10} = 73.14$). In particular, fearful/surprise expressions lead to lower criterion values compared to neutral expressions (see Figure 3). No interaction between threat of shock and facial expression of the observer was found ($F(1, 70) = 1.87$, $p = .176$, $\omega_p^2 = 0$, 95% CI [0, 0.05]; $BF_{01} = 4.42$).

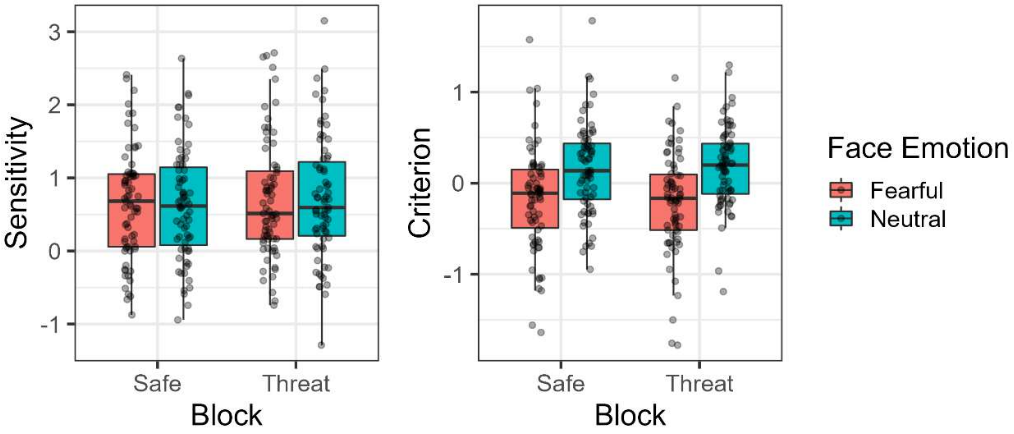

Figure 3. Observed sensitivity and criterion values per block and facial expression of the observer.

No statistically significant correlation was found between criterion or sensitivity and anxiety inventories (STICSA-Trait, STICSA-State and LSAS; $p > .2$).

Response times

In terms of RTs, no apparent differences were found between threat and safe blocks ($F(1, 68) = 0.067$, $p = .796$, $\omega_p^2 = 0$, 95% CI [0, 0]; $BF_{01} = 7.19$). However, RTs were, on average, faster for aggressive actions, compared to neutral ones ($F(1, 68) = 39.717$, $p < .001$, $\omega_p^2 = .034$, 95% CI [0, 0.15]; $BF_{10} = 6$), as well as for fearful compared to neutral expressions by the observer ($F(1, 68) = 29.934$, $p < .001$, $\omega_p^2 = .005$, 95% CI [0, 0.09]; $BF_{10} = 2.9$). No interaction between threat of shock and any of these variables was found ($p > .05$). However, face emotion did interact with type of action ($F(1, 68) = 9.552$, $p = .003$, $\omega_p^2 = .002$, 95% CI [0, 0.07]; $BF_{10} = 4.76$), with aggressive actions being detected quicker if preceded by fearful compared to neutral expressions ($t(68) = -5.858$, $p < 001$, $d = -0.234$, 95% CI [-0.36, -0.11]; see Figure 4). No significant three-way interaction was observed ($p > .1$).

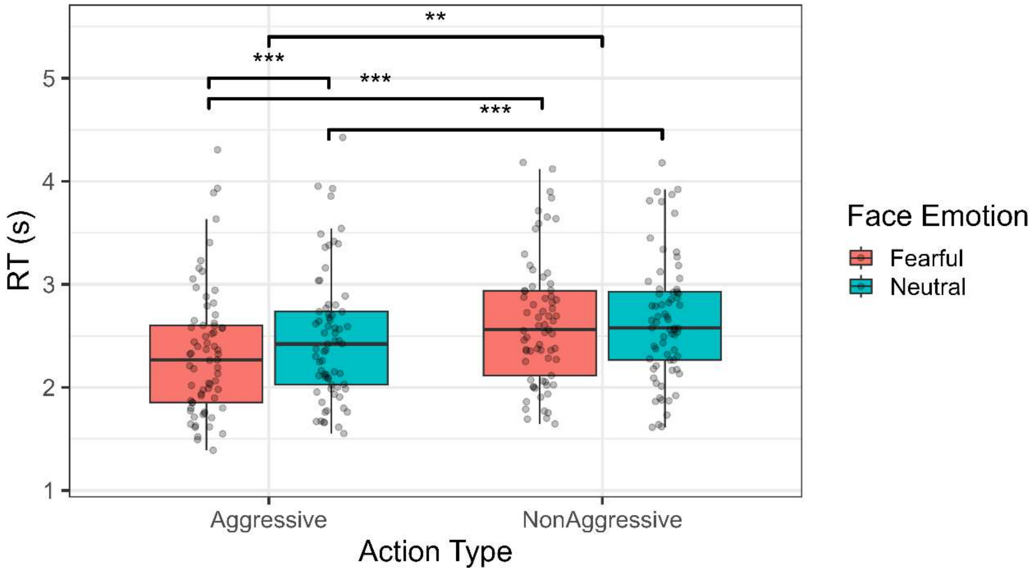

*Figure 4. RT distribution per type of action (aggressive vs non-aggressive) and face emotion (fearful vs neutral). "**" = p < .01. "***" = p < .001.*

Drift diffusion modelling

Regarding the DDM analysis (see Figure 7 for a general graphic view), in terms of boundary separation (α), no statistically significant difference was found between block types (*F*(1, 69) = 0.26, *p* = .61, ω_p^2 = 0, 95% CI [0, 0]), face emotion (*F*(1, 69) = 3.34, *p* = .072, ω_p^2 = 0.001, 95% CI [0, 0.06]) and their respective interaction (*F*(1, 69) = 1.18, *p* = .28, ω_p^2 = 0, 95% CI [0, 0.01]). As for starting point, block alone did not significantly affect this measure (*F*(1, 69) = 0.88, *p* = .35, ω_p^2 = 0, 95% CI [0, 0]). In the case of face emotion, however, we saw that, on average, participants had a higher starting point (towards signaling aggression) when the facial expression of the observer was neutral as opposed to fearful (*F*(1, 69) = 19.5, *p* < .001, ω_p^2 = 0.04, 95% CI [0, 0.17]). Additionally, the difference between these two facial expressions in terms of starting point was larger for threat blocks compared to safe blocks (*F*(1, 69) = 4.41, *p* = .039, ω_p^2 = 0.004, 95% CI [0, 0.08]; see Figure 5). Post-hoc comparisons for starting point showed that face emotion was significantly different in the threat blocks (*t*(123) = -4.830, *p* < .001, *d* = -0.44, 95% CI [-0.62, -0.25]), but not in the safe blocks (*t*(123) = -2.430, *p* = .099, *d* = -0.22, 95% CI [-0.40, -0.04]). No difference between face emotion was found across blocks (*p* > .05).

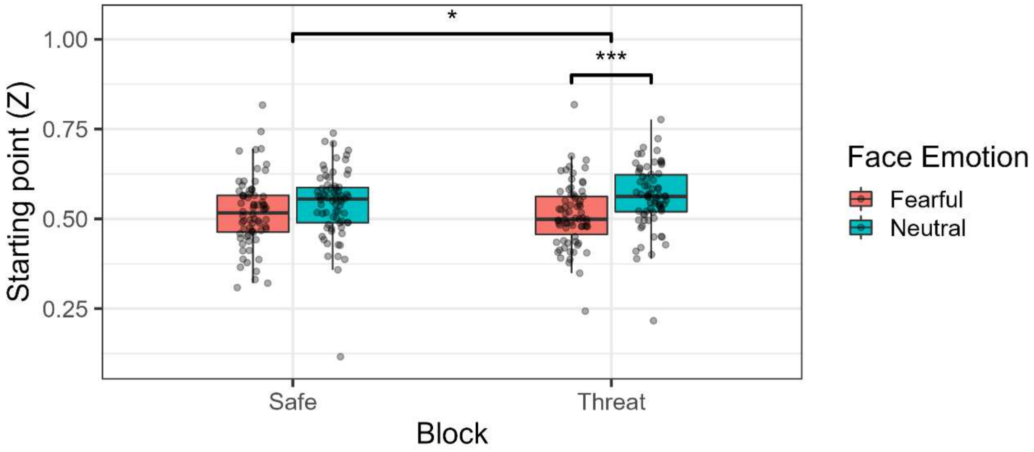

Figure 5. Starting point (Z) per block type and face emotion. Higher levels of starting point (above 0.5) mean a bias towards identifying the central action as aggressive. "" = p < .05. "***" = p < .001.*

In terms of drift rate magnitudes, threat of shock did significantly lead to bigger drift rates (faster evidence accumulation towards the correct response) compared to safe contexts ($F(1, 69) = 4.72$, $p = .033$, $\omega_p^2 = 0.007$, 95% CI [0, 0.09]; see Figure 6). No main effect of face emotion ($F(1, 69) = 0.03$, $p = .85$, $\omega_p^2 = 0$, 95% CI [0, 0]), nor any effect of action type was observed ($F(1, 69) = 0.25$, $p = .62$, $\omega_p^2 = 0$, 95% CI [0, 0]). The effect of block was not statistically different across face emotion ($F(1, 69) = 1.75$, $p = .19$, $\omega_p^2 = 0.001$, 95% CI [0, 0.06]) or action type ($F(1, 69) = 0.07$, $p = .79$, $\omega_p^2 = 0$, 95% CI [0, 0]). A significant interaction between face emotion and action type was present ($F(1, 69) = 38.8$, $p < .001$, $\omega_p^2 = 0.17$, 95% CI [0.04, 0.33]), with bigger drift rates in aggressive actions when presented with a fearful expression ($t(94.8) = 5.77$, $p < .001$, $d = 0.59$, 95% CI [0.37, 0.81]) and in neutral actions when presented with a neutral expression ($t(94.8) = -5.62$, $p < .001$, $d = -0.58$, 95% CI [-0.79, -0.36]). No three-way interaction was observed ($F(1, 69) = 2.67$, $p = 0.11$, $\omega_p^2 = 0.003$, 95% CI [0, 0.08])

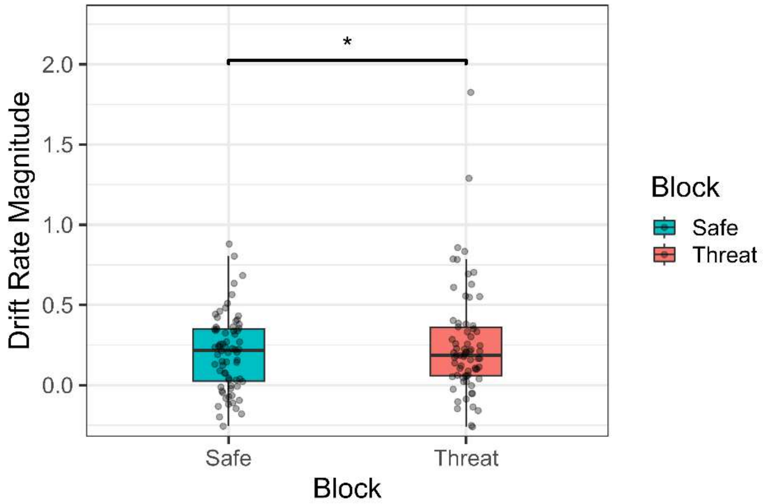

Figure 6. Absolute magnitude of the drift rate values per block type (threat of shock vs neutral). Higher values indicate a quicker accumulation of evidence towards a final correct response. "" = p <.05.*

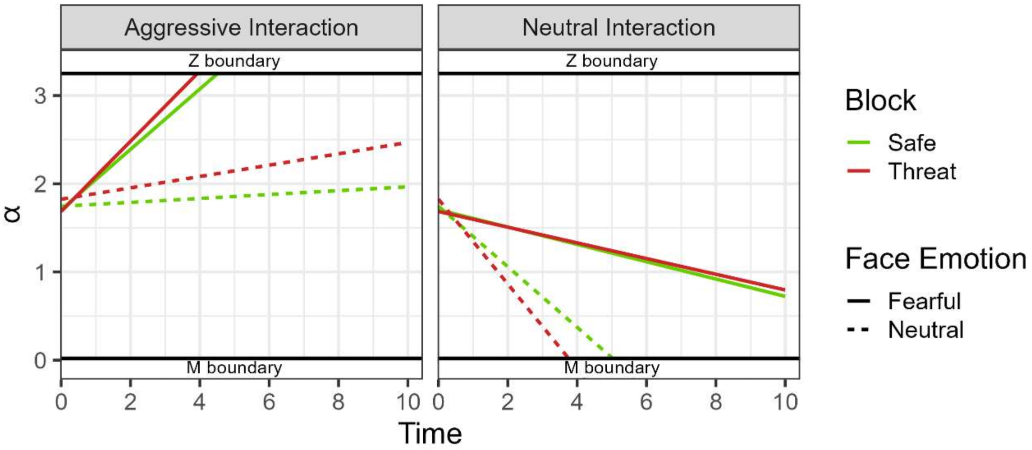

Figure 7. Generic DDM graphic, showing the estimated starting points (Z) and drift rates (D) per type of action, facial expression, and block across time. The y axis represents the boundary separation (α). M decision boundary was associated with a "non-aggressive" decisions, while the "Z" boundary was associated with an "aggressive" decision.

Eye tracker

Whilst under threat (compared to safe conditions), during the 800ms and 1800ms time mark participants showed a greater dwell time proportion between the face ROI compared and main/central action ROI ($\chi^2(1) = 5.73$, $p = .017$). Additionally, neutral faces were associated with greater dwell times proportions (face ROI over central action ROI), compared to fearful faces ($\chi^2(1) = 581.97$, $p < .001$). As expected, the time spent gazing at the face ROI diminished across the one second time window ($\chi^2(1) = 10980$, $p < .001$). No interaction was found between block and face emotion ($\chi^2(1) = 1.27$, $p = .260$), but the effect of block on dwell time proportion was significantly modulated by time bin ($\chi^2(1) = 5.52$, $p = 0.019$). Namely, as seen in Figure 8, participants under threat dedicated more time to the face ROI compared to the central ROI after the 1.3 second mark. The time variable also showed an interaction with face emotion ($\chi^2(1) = 885.70$, $p < .001$), with neutral faces having greater dwell times compared to fearful faces after the 1.3 second mark. No statistically significant three-way interaction was found ($\chi^2(1) = 0.14$, $p = .705$).

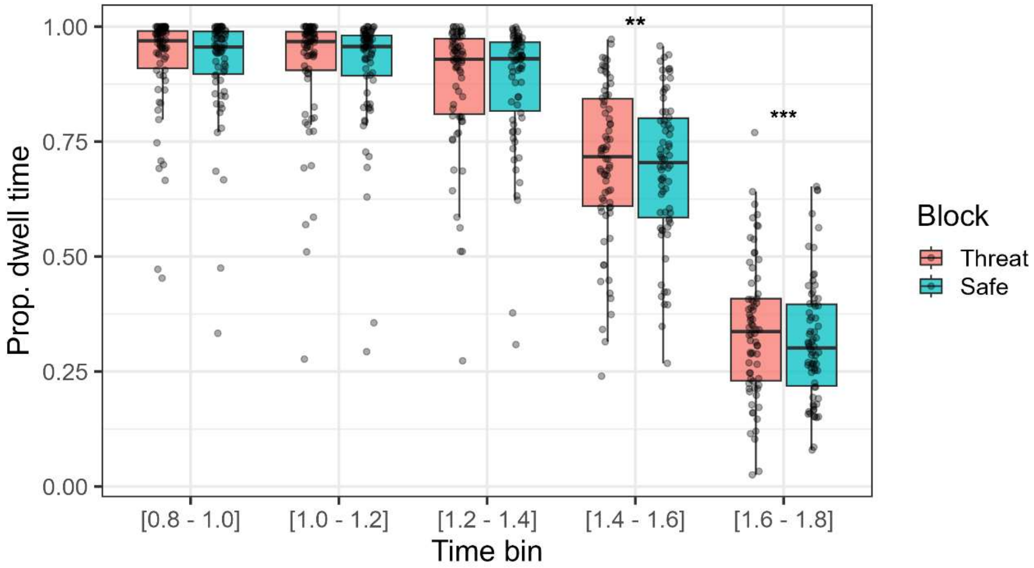

*Figure 8. Proportion of dwell time spent on face emotion ROI compared to central ROI at each time bin (200ms time bins). Higher dwell times signify more time spent gazing at the face ROI compared to the central ROI across trials and participants. "**" = p < .01. "**" = p < .001.*

When analyzing time until first fixation over the central ROI, we can see that, under threat, participants took, on average, more time to initiate their fixation over this ROI, compared to when they were under safe conditions ($\chi^2(1) = 5.05$, $p = .025$; see Figure 9). This longer gaze onset time over the central actions was also observed for neutral expressions compared to fearful faces ($\chi^2(1) = 1057$, $p < .001$). No interaction was observed ($\chi^2(1) = 0.006$, $p = .94$).

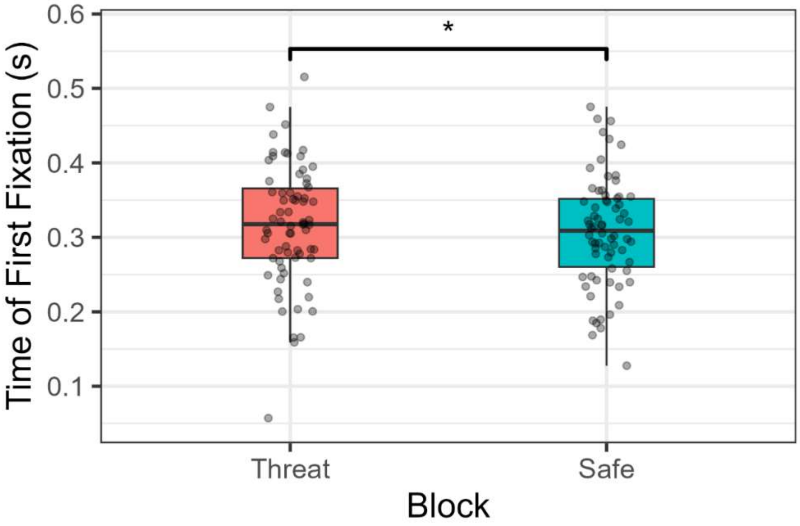

Figure 9. Time until the first fixation after the central action was shown. ""= p < .05.*

As for the average fixation number and duration, no effect of block was found in either one of those measurements ($\chi^2(1) = 0.39$, $p = .53$ and $\chi^2(1) = 0.5$, $p = .48$, respectively).

Discussion

In this study we investigated how states of anxiety affect how we perceive potentially aggressive social interactions and to what extent are we able to incorporate external cues to resolve these ambiguous percepts. We used threat of shock to induce anxiety states in participants and gathered decision and timing measures regarding their responses, as well as gaze data.

In terms of decision measures, our analysis showed that, contrary to our hypothesis (1) threat of shock did not affect sensitivity in identifying aggressive actions. In other words, participants' ability to correctly identify signal (aggressive actions) among noise was not affected by inducing a state of anxiety. In addition, this was also not moderated by the type of facial expression exhibited by the observer (against our hypothesis 2). As for criterion, we showed that, in accordance with prior studies (e.g., Manera, Del Giudice, et al., 2011), when presented with a cue signaling potential aggression (i.e., fearful expression by the observer), participants were more liberal when identifying potentially aggressive actions. Importantly, however, criterion was not affected by threat of shock (against hypothesis 3), nor was any interaction between this latter factor and the facial expression displayed by the observer.

These results come as a surprise and appear to contradict some previous findings that show a higher sensitivity under threat when detecting both innocuous (de Voogd et al., 2022) and threat-related stimuli (Sussman, Szekely, et al., 2016). The same contradictions are seen for findings regarding criterion, where biases (reduced criterion) towards signaling threat-related stimuli (as opposed to their innocuous counterpart) are reported to be inflated during states of anxiety (Flechsenhar et al., 2022; White et al., 2016). Regardless, it is worth highlighting that some recent studies have shown opposing results in respect to sensitivity (Flechsenhar et al., 2022; Karvay et al., 2022) and criterion (de Voogd et al., 2022). In addition, some studies suggest that the effects of induced threat over sensitivity and criterion are dependent on elevated trait anxiety. This relationship, albeit not observed in our analyses, might be a specific focus of attention in future studies that explore these types of questions (e.g., creating groups of participants with low and high trait anxiety).

One possible explanation for both the absence of an enhanced sensitivity, as well as a possible reduced criterion towards identifying aggression when under threat, might concern the timeframe of the decision. Most studies measuring sensitivity and criterion parameters do so with paradigms that require/imply fast decision processes. Namely, decisions are made during average time-windows that do not usually exceed the one to 1.5 second mark (e.g., de Voogd et al., 2022; Sussman, Szekely, et al., 2016). Given the nature of the stimuli used here, i.e., complex social interactions, identification times in our study were significantly higher than those studies (around 2.5 seconds on average and going up to a maximum of around 4.5). One could thus argue that when identification is made to be prolonged (over, for instance, two seconds), and not urged/possible in the first second or so of exposure (like in this study), sensitivity and criterion effects might not manifest themselves to the same extent. In other words, it may be the case that benefits from an enhanced sensitivity and reduced criterion are, usually, mostly valuable when a threat might be imminent. In these cases, a faster ability to detect, even if erroneously, threat-related stimuli, may prove essential in avoiding/minimizing unexpected dangerous events (Öhman & Mineka, 2001). This might not be the case, however, when one can more carefully consider/evaluate our surroundings, where more informed decisions might outweigh the benefits of a "quick and dirty" (LeDoux, 1994) visual perception. Thus, although first impressions may capture an enhanced sensitivity and a biased view of threat, a more careful (longer) consideration of the stimulus (such as in this study) might obscure these effects.

Another reason that might help explain the discrepancies found between this and previous studies, concerns how the cues and actions were related. Namely, other studies tend to depict a more direct relationship between cue and target (e.g., "fear" or "F" word followed by a possible fearful expression; Karvay et al., 2022; Sussman, Szekely, et al., 2016). Here, even though participants were instructed that actions and facial expressions were related (observer was presented as reacting to the central interaction), a fearful expression does not necessarily imply/lead to an aggressive interaction as directly as, for instance, the word "aggression" used as prime. As such, in the former studies, one could more clearly establish congruency and incongruency conditions, whilst in our experiment this relation is not as straightforward.

One final aspect worth noting is that, when assessing the detection of threat-related stimuli, prior studies tend to use facial expressions of either anger or fear, which can more directly imply a threat towards (or relevant to) the observer. Indeed, it has even been shown that fearful and anger expressions are capable of inducing fear-related mechanisms in participants (Springer et al., 2007; T. Stein et al., 2009; L. M. Williams et al., 2005). In our study, we attempted to generalize the effects of anxiety towards other treat-related social stimuli (i.e., aggressive interactions), but which may not implicate a direct threat towards the observer (participant). As such, it can be argued that threat-related sensitivity effects might be directed only towards threat stimuli that more directly signal danger towards the viewer. Future investigation might be useful to explore the difference between these two types of threats.

In what concerns RTs, we showed that being under threat did not contribute to changes in this measure (contradicting hypothesis 4). Once more, whilst observed in some studies (Wieser et al., 2010), this finding is not unanimous in the literature, with studies either contradicting (Flechsenhar et al., 2022) or finding no differences between safe and under threat conditions (Robinson et al., 2011). We did see that, on average, aggressive actions were identified more quickly than non-aggressive actions, which aligns with prior literature showing hastened detection towards threat-related stimuli regardless of anxiety (LoBue & DeLoache, 2010; Öhman & Mineka, 2001).

Drift diffusion model analysis revealed some interesting patterns. Beginning with starting point, neutral facial expressions led to starting points closer to the “aggressive” decision threshold compared to fearful expressions. This seems to suggest that participants start their decision making with a greater bias towards signaling aggression when presented with a neutral expression. Furthermore, this effect proved to be moderated by block, with participants under threat expressing a more marked difference in starting points between fearful and neutral facial expressions. This latter effect is surprising but, we believe, can be explained by two factors related to the task itself. Firstly, starting points are inherently hard to capture in this task, since participants were not directly looking at the central ROI when the central action began. Although we computed the RTs as a function of the time of first fixation on this central action, confounding effects regarding the latter (e.g., longer time until first fixation when shown an observer with a neutral expressions), might render these starting point estimates somewhat unreliable. Specifically, by gazing later towards the central action, this might have led DDM estimates to incorrectly assume bias differences between neutral and fearful expressions. This is especially the case since, as shown in our analysis, participants also took longer, on average, to fixate on the central action when under threat. Secondly, when looking at the full picture that incorporates both starting points and drift rates (Figure 4), it is clear that starting points played little part in the decision process compared to the drift rate (White et al., 2016).

The other effect concerns the increased magnitude of evidence accumulation (drift rate). Specifically, we observed that general accumulation towards the correct response (aggressive or neutral) occurred quicker during the threat of shock condition. This might hint that overall information processing speed and evidence accumulation is improved when under threat, since participants, on average, required less information to reach the correct decision threshold. Thus, it may be a direct reflection of the enhanced sensory-perceptual processing characteristic of anxious states (Cornwell et al., 2017). Indeed, whilst the literature seems scarce in this topic, studies have shown, for instance, that individuals under threat and with social anxiety have overall higher evidence accumulation rates (Dillon et al., 2022; Gorka et al., 2023). Nevertheless, other studies have instead suggested that anxiety is uniquely associated with an evidence accumulation towards negatively valanced stimuli (Globig et al., 2021; Yamamori & Robinson, 2023), which was not the case here. This, combined with the low effect size of this effect and the presence of some individual extreme values (plus the potential issue discussed below) should urge future studies to better investigate this finding before any robust conclusion can be drawn.

Importantly, since this task was not designed with DDM analysis in mind, the findings discussed above concerning DDM need to be interpreted with care, as they are merely exploratory. This is the case, because, firstly, DDM analyses were designed for tasks with mean RTs below 1.5 seconds, which is not the case in this task ($M_{\mathrm{rt}} = 2.53$, $SD_{\mathrm{rt}} = 0.65$). Nonetheless, recent studies have come to show that the validity of the model parameters extracted from this analysis still hold for tasks with longer response times (Lerche & Voss, 2019). Lastly, and perhaps more importantly, in our task participants did not start the task (to identify aggression) with their visual focus over the target area, a usual requirement from DDM. To overcome this problem, RT was calculated from the time of first fixation over the ROI containing the central action, and not from the time of movie appearance. However, this is still less than ideal, and should be acknowledged.

Gaze analysis showed that under threat, participants had significantly superior dwell times over the observer ROI, particularly in the time-windows closest to the appearance of the central actions. That is, participants took longer to gaze away from observer (and towards the central action) under threat of shock compared to safe contexts, which is also in line with the previously discussed difference regarding the time until first fixation over the central action between these blocks. These findings are in line with at least one study showing a later onset for first saccade for emotional faces when under threat of acoustic shock (Flechsenhar et al., 2022). An increased dwell time over faces is also observed in the literature for participants under anxiety and with elevated social anxiety, although this is particularly in cases where the face presents a threat-related expression (fearful or anger expressions; Flechsenhar et al., 2022; Lazarov et al., 2016). It is worth noting, however, that an earlier study conducted by the authors (Silva, Ribeiro, et al., 2023; Chapter III) found no evidence of superior dwell times over social cues, when these were emotionally neutral. This might suggest that the reason for the increased dwell time during anxious states observed in this study is due to the possible appearance of a threat-signaling cue (fearful expression) in that region. Lastly, it is worth noting that no fixation alterations from threat of shock were observed, which, particularly in the case of average fixation duration, goes against findings presented in the same earlier study conducted by the authors (Silva, Ribeiro, et al., 2023; Chapter III). Once more, the emotional nature of the stimuli might be a reason for this discrepancy, or perhaps other factors (e.g., size of the cue's ROI) might instead be explaining these results. This, however, remains speculative and future studies are needed to better explore these findings.

Limitations

Aside from the limitations already brought forward, some other potential concerns should also be acknowledged. One regards the facial expression exhibited by the observer. While intended to transmit mostly a fearful expression, this facial expression was predominantly recognized as surprise (see Appendix B). This occurrence (confusing fear for surprise) was, nonetheless, partially expected, as it is backed up by a number of studies (e.g., H. Kim et al., 2004; Roy-Charland et al., 2014). Since both surprise and fearful reactions are expected facial expressions when viewing a sudden aggressive interaction, we believe that, even if interpreted mostly as surprise, the fearful/surprise facial expressions remain congruent to the aggressive interaction. This is also, at least partially, supported by RT results, showing quicker RTs in identifying aggressive actions when shown a fearful/surprise expression.

Another possible limitation falls upon the attention dedicated towards the facial expressions. Although we controlled the initial attention focus of the participants so that they started each trial by looking at the observer, they might have redirected their attention towards the center of the screen without actually attending to its facial expression. Eye tracking data, however, does not seem to support this concern, with participants spending most of their initial time gazing at the face location. Moreover, the data concerning the attention check task showed that participants did, on average, pay attention to the facial expressions exhibited by the observer (see Appendix C).

Conclusion

We sought to explore if anticipatory anxiety states, induced by threat of shock, elicited changes in perceiving aggression on ambiguous social interactions, and how external cues are incorporated during this process. We saw no evidence of an altered perception of these social interactions under anxiety, as well as no change in the ability to use external cues when interpreting them. Nonetheless, exploratory findings showed that anxious states were associated with a faster evidence accumulation towards the correct perceptual decision, suggesting an increased sensory-perceptual processing. Furthermore, an apparent increased gaze dwelling time over external cues was found during the threat condition. Taken together, these findings appear to suggest some limitations to the conclusions brought forward by previous literature, whilst also implying other less known effects surrounding anxiety and visual perception. Future research is necessary to better disentangle and understand these incongruencies.

CHAPTER V

Study 4: Improved perception of aggression under (un)related threat of shock

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This study was pre-registered in Open Science Framework: osf.io/b6dpj

Abstract

Anxiety shifts visual attention and perceptual mechanisms, preparing oneself to detect potentially threatening information more rapidly. Despite being demonstrated for threat-related social stimuli, such as fearful expressions, it remains unexplored if these effects encompass other social cues of danger, such as aggressive gestures/actions. To this end, we recruited a total of 65 participants and asked them to identify, as quickly and accurately as possible, potentially aggressive actions depicted by an agent. By introducing and manipulating the occurrence of electric shocks, we induced safe and threatening conditions. In addition, the association between electric shocks and aggression was also manipulated. Our result showed that participants have improved sensitivity, with no changes to criterion, when detecting aggressive gestures during threat compared to safe conditions. Furthermore, drift diffusion model analysis showed that under threat participants exhibited faster evidence accumulation toward the correct perceptual decision. Lastly, the relationship between threat source and aggression appeared to not impact any of the effects described above. Overall, our results indicate that the benefits gained from states of anxiety, such as increased sensitivity towards threat and greater evidence accumulation, are transposable to social stimuli capable of signaling danger other than facial expressions.

Keywords: Anxiety; Threat; Sensitivity; Social; Point-light display

Introduction

As a survival response carved by evolution, anxiety comprises a set of physiological and behavioral responses suited for environments deemed unpredictably dangerous. As a consequence, we experience physiological changes tailored towards imminent defensive action, such as increased heart rate, blood pressure, and respiration rate (Lang et al., 2000). In addition, we also experience parallel cognitive and physiological effects that enable us to react to incoming danger in a more promptly manner, as is reflected, for instance, in increased startle responses (Grillon et al., 1991; Grillon & Charney, 2011).

At the core of the cognitive changes resulting from anxiety are those related to attentional and perceptual processes. One such feature concerns an exaggerated attentional bias toward threat, which leads to a rapid engagement of stimuli labelled as potentially dangerous (Robinson et al., 2012; Sheppes et al., 2013). Such bias is seen not only in normative states of anxiety but also in individuals with high dispositional (trait) anxiety and across anxiety disorders (Bar-Haim et al., 2007). In fact, some authors have even postulated that this attentional bias towards threat stands as a major contributor to the emergence and maintenance of anxiety disorders (Bar-Haim et al., 2007; MacLeod & Mathews, 2012).

An additional feature of anxiety – which partially precedes but also overlaps with the one described above – is an enhanced sensory-perceptual processing (oftentimes referred to as hypervigilance) of our external world. Put differently, cortical, and subcortical processing stages evidence an increased neural response to sensory stimuli. This is demonstrated in studies using mismatch negativity (MMN), an auditory event-related potential, which show a general increase in this response for individuals under threat compared to those in safe conditions (Cornwell et al., 2007, 2017; but see Fucci et al., 2019). This response is also observed in brainstem auditory evoked potentials, which precede any kind of cortical involvement (Baas et al., 2006). Furthermore, an increased MMN is also found across patients with panic disorders (Chang et al., 2015; but see Cheng et al., 2021) and post-traumatic stress disorders (Ge et al., 2011).

Aside from a general sensitization towards incoming sensory input, this particular shift in perception appears to be tuned towards threat-signaling stimuli. This has been well documented in individuals with elevated dispositional anxiety (Capitão et al., 2014; Rossignol et al., 2005) and anxiety disorders (Bar-Haim et al., 2007; Hayes & Hirsch, 2007). As for normative anxiety, albeit less explored, conclusions appear to favor the same idea (Preciado et al., 2017; Robinson, Vytal, et al., 2013; Sussman, Szekely, et al., 2016). For instance, fearful expressions are more rapidly (and accurately) identified compared to happy expressions (Robinson et al., 2011, 2012) and the MMN response is vastly increased for fearful facial expressions, compared to positive expressions (joy;

Robinson, Overstreet, et al., 2013). Another example by Grillon and Charney (2011) shows that anxiogenic contexts interact with the presentation of fearful faces (but not neutral faces), triggering an increased startle response, suggestive of an enhanced sensory-perceptual processing. As a consequence of these cognitive changes, one can more promptly detect (and thus react to) minor, but potentially threat-relevant, changes in our environment. Even if at the cost of reduced specificity, which directly translates into a more misleading identification of danger, these changes in sensory processing mechanisms can assure higher survival odds (LoBue & DeLoache, 2010).

It is useful, as such, to study how anxiety favors a biased perception of ambiguous content and increases the odds of it being interpreted in a more threatening manner (Hartley & Phelps, 2012). This can be particularly detrimental to the interpretation of social scenes, where ambiguous behaviors/gestures can sometimes carry mixed or contextually dependent interpretations. Once more, this has been more widely explored for dispositional anxiety (e.g., Koizumi et al., 2011; A. Richards et al., 2002) and anxiety disorders (e.g., K. G. Anderson et al., 2012; Yoon & Zinbarg, 2008), as opposed to normative anxiety states. Social anxiety, in particular, is one such case, where misattribution of negative intents toward socially ambiguous stimuli has been well documented and even suggested as a key to the maintenance of this disorder (J. Chen et al., 2020).

When it comes to states of anxiety, previous literature has shown that anxious states imply a shifted perception, leading to stimuli being more readily interpreted (or viewed more intensely) as fearful (Flechsenhar et al., 2022; Kavcıoğlu et al., 2019; Wudarczyk et al., 2016; Zhou & Chen, 2009; but see Engelmann et al., 2019). These effects – as well as the vast majority of studies exploring social threat – have, however, been related mostly to facial expressions of anger or fear. Oftentimes, however, danger is conveyed in a more subtle manner, such as in the case of a potentially threatening social gestures or actions (de Gelder et al., 2023). In certain occasions, body posture and movements can even provide a more direct clue as to the aggressive intentions of a person, thus making it a more clear cue of potential danger of physical harm (De Gelder et al., 2010).

Previous work conducted by the authors (Silva, Garrido, et al., 2023; Chapter IV) has shown no threatening bias, nor evidence of increased sensitivity, when detecting potentially aggressive interactions under threat of shock. Nonetheless, this task showed greater evidence accumulation (estimated with drift diffusion modelling) towards the correct perceptual decision when under threat, providing some evidence of a greater perceptual sensitivity during this state. However, this task contrasts with most tasks depicted in the literature (e.g., perception of fearful expressions), since the threat-related event was not directed at the viewer. This is also important when one considers that direct gaze (as opposed to averted gaze) in anger expressions (a marker of threat direction) leads to these expressions being perceived as angrier (R. B. Adams & Kleck, 2005; Ewbank et al., 2009). As such, it might be the case that the direction of the potentially aggressive gestures might help explain the incongruency between our work and prior literature. In fact, it might even be possible that this effect is potentiated when the aversive event (threat of shock) is directly related to the aggressive gestures.

The present study

To account for this, in this study we sought to demonstrate the effects of anticipatory anxiety over the perception of aggressive/angry social gestures directed at the viewer. Moreover, to associate aggressive gestures more directly with threat, we also explored how establishing a connection between electric shocks and these gestures might further contribute to these effects. To this end, we asked participants to identify aggression in noisy point-light displays of single individuals exhibiting different actions/gestures, both aggressive and non-aggressive (neutral). Importantly, they completed this task under safe and threat of shock conditions. This latter block was further divided into two, where either the threat (electric shock) was entirely random or dependent on aggressive actions being shown. We expected that when under threat, compared to safe conditions, participants would show both 1) a greater sensitivity but also 2) lower criterion (threat bias). Lastly, we further expected that 3) the evidence accumulation, as measured by drift diffusion modeling, would be superior under threat of shock. The remaining analyses, concerning response times and anxiety inventories, were all treated as exploratory.

Method

Participants

The sample for this study was estimated with the use of the Superpower package for R (v. 0.2.0; Lakens & Caldwell, 2021). Based on prior literature, we hypothesized expected means and a standard deviation for our analysis design (three within-subjects), running a total of 2000 simulations. We arrived at a minimum of 58 participants for a desired power of .8 (and a Partial Eta Square of 0.09).

To account for potential exclusions, we recruited an initial sample of 67 participants. To be included they had to be between 18 and 40 years old Portuguese speakers. Additional inclusion criteria were no past or current record of any major psychological or neurological disease and corrected to normal vision. Two participants were excluded for having less than 50% accuracy in the last recognition task. Our final sample was composed of 65 participants (55 females; $M_{\text{age}} = 22.3$, $SD_{\text{age}} = 5.51$). The present study was conducted with permission from the ethics committee (reference 02-CED/2021) and is in accordance with the data protection regulation from the University of Aveiro.

Stimuli and apparatus

The point-light displays of agents performing neutral and aggressive actions were generated with the Social Perception and Interaction Database (Okruszek & Chrustowicz, 2020). These actions were all shown by solo male figures facing the direction of the viewer. To portray aggressiveness, we selected the “Altercation”, “Denying accusations”, “Stopping the conversation” and “Taking the blame” actions. To convey neutral gestures we selected the “Come close”, “Give me that”, “Look there” and “Pick it up” actions. The videos had an average duration of 3.9 seconds (minimum of 3.59 and maximum of 4.4 seconds). The actions “Confronting an aggressor” (aggressive) and “Go over there” (neutral) were used for the practice phase.

To make each action more ambiguous (except those selected for the practice phase), while also creating different levels of ambiguity, each video was generated with a limited lifetime technique of either 7, 9, 11, or 13 points. Dot appearance and disappearance were set randomly between 150 and 250 ms. Additionally, to prevent the same video from being shown twice, we generated two versions of each video (total of eight videos per action). To further hamper action identification, a noise layer with seven dots randomly spread and moving around the field of the video was also used. The videos were presented in a 1280 by 720 pixel black window and occupied roughly 2.5 by 11 visual degrees.

The electric shocks were delivered with the STMISOLA module from Biopac. These shocks ranged from 2 to 6 mA and had a duration of 100 ms. The electrodes were attached to the participant's forearm at a distance of about 3 cm.

Online questionnaires were shown with Limesurvey. The experimental task was programmed using Psychopy version 2021.2.3 (Peirce et al., 2019) and displayed on an MSI Pro MP241 monitor with 1920 by 1080 pixels resolution. Responses were collected with a standard QWERTY keyboard.

Procedure

After providing their informed consent, participants initially filled out a brief online questionnaire regarding basic sociodemographic information (e.g., sex and age), as well as basic questions about medical history (e.g., health problems and medication). If eligible, they were then contacted, and their participation was scheduled. In the lab, they again provided informed consent, and were asked to fill out the State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Barros et al., 2022; Ree et al., 2008) and the Liebowitz Social Anxiety Scale (LSAS; Caballo et al., 2019; Liebowitz, 1987).

After completing the questionnaires, the participants then underwent the shock workup procedure. This procedure started with two electrodes being applied to the left forearm of the participant. After a brief explanation of the whole process, they were exposed to different shock intensities, starting at 2 mA, and increasing in steps of 1 mA. After receiving each shock, they reported how unpleasant that shock was on a Likert scale ranging from one (barely felt) to five (very unpleasant/uncomfortable). The shock intensity increased either until a rating of four (quite unpleasant/uncomfortable) was reported, or until they reached the highest and last intensity of electric shock (6 mA). If the rating of four was reached before maximum level, shocks of the same intensity were given until five shocks in total (since the beginning of the workup procedure) were delivered. The calibrated intensity for the participant would be used throughout the rest of the experiment.

Participants were then moved to the computer station where the experiment took place and presented with the instructions screen for the practice phase. In this phase, participants were instructed to observe each video shown and report, as quickly, but also as accurately as possible, if the video depicted an aggressive or non-aggressive action. These practice actions were not used in the experimental task that followed. They had until the end of the video plus a one second blank screen to provide their answer. They were also told that, if possible, they should provide an answer/guess before the end of the trial. To indicate aggressive or non-aggressive actions, they had to press the “Z” or “M” keys, respectively. After giving their answer or having the time run out, an inter-trial period (blank screen with a fixation cross) of 0.75 seconds was shown.

After the practice phase, they were presented with the instructions for the main task. These instructions were similar to those used in the practice phase, where participants were asked to identify the Action (Aggressive vs non-Aggressive) of the agent. However, here the task was divided into three different types of blocks (each with 64 trials): one Safe (control) block where no shocks would be delivered and two others where shocks were delivered to the participant (Threat blocks). These latter Threat (shock) blocks were composed of two distinct blocks labeled Block R and Block A. In Block R (as in random), shocks were delivered randomly throughout the task (regardless of the action shown). In Block A (as in aggression-dependent) shocks were, instead, distributed throughout the trials where the to-be-identified agent was showing an aggressive behavior; as such, shocks were contingent on the action shown being aggressive. Importantly, participants were told on the instruction screen, and reinforced by the experimenter, about random (Threat R) or semi-random (Threat A) nature of the shocks in each block type. Moreover, they were told that their answer had no effect on the probability of getting shocked in either block. These shocks were sporadic (~ 9% of the trials, i.e., six trials per block) and delivered only during a dark gray screen (2.5 seconds in duration) that immediately followed each action on the shock blocks. Actions were randomly distributed across each block and the presentation order of the shock blocks (R and A) was counterbalanced between participants. To reduce the number of versions (due to counterbalancing) the Safe block, where no shocks were delivered, was partitioned and always presented at the beginning, middle, and end of the task. To match the 64 trials, the middle section had 22 trials whilst the others had 21. Block presentation thus followed one of two possible orders:

1) 21 trials of Safe, followed by 64 of Threat R, followed by 22 trials of Safe, followed by 64 trials of Threat A, and ending with 21 trials of Safe.
2) 21 trials of Safe, followed by 64 of Threat A, followed by 22 trials of Safe, followed by 64 trials of Threat R, and ending with 21 trials of Safe.

In each block, the participant's task, as with the practice phase, was to indicate if the action they were observing was aggressive or not, as fast and accurately as possible. This time, these actions were presented with a limited lifetime technique and with noise dots that made the identification more difficult. Once more, participants had the duration of the video, plus one second of the dark screen, to provide their answer. After finishing each block, they were asked to judge, on a visual analog scale (0 - 100), how anxious they felt during the block they just finished.

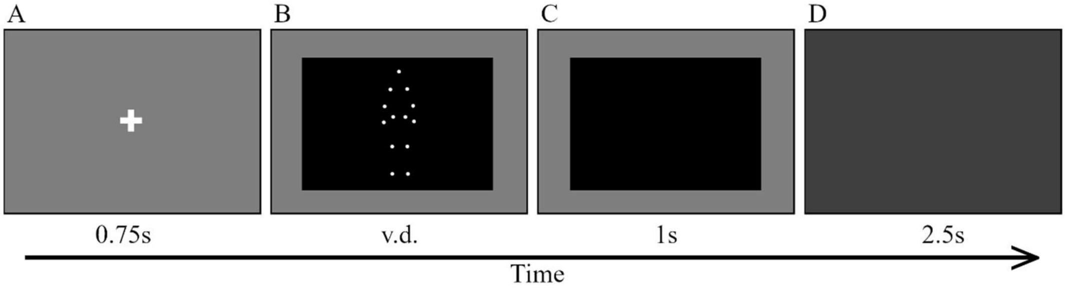

Figure 1. General illustration of a trial. ***(A)*** *Inter-trial screen, where a fixation cross is presented for 0.75 seconds.* ***(B)*** *Presentation of the PLD exhibiting different actions/gestures. v.d. = video duration.* ***(C)*** *Blank screen (with just the black video screen), where participants could still provide their response. This screen would only be presented if the participants did not provide their answer throughout the video.* ***(D)*** *Empty dark gray screen presented only during threat blocks (Threat R and Threat A) following the video or blank screen. During this screen participants could, at any moment, receive an electric shock.*

After finishing the main task, participants were asked on a five-items Likert scale (one – "Not related" to five – "Really related") to report how much they felt that their answer was associated with the outcome of the shocks on each threat block (R and A). Lastly, they performed a recognition task, where each of the actions they were exposed to during the main task was shown and they were asked to indicate if they depicted aggressive or non-aggressive behaviors. Importantly, this time these actions were shown without any limited lifetime technique or noise dots. Participants were then debriefed and thanked for their participation.

Statistical analysis

Data processing and statistical analyses were performed with R (4.2.1). Trials with no responses were removed, leading to the exclusion of a total of 177 trials (1.38% of all data). Trials with response times (RT) inferior to 0.5 seconds were also removed (12 trials, corresponding to 0.09% of the data). For the RT analysis, only correct responses were included. Signal detection theory measures of sensitivity and criterion were acquired with the psycho package (0.6.1; Makowski, 2018).

As measures of effect size, we used partial omega-squared (ω_p^2) for ANOVAs and Cohen's *d* (*d*) for the t-tests. Greenhouse Geisser corrections were applied in cases of sphericity violations (assessed with the Mauchly test). Normal distribution of the residuals was checked and confirmed visually and with Shapiro-Wilk tests. All post-hoc analyses used Bonferroni corrected p-values.

Sensitivity, criterion, RTs and drift diffusion modelling (DDM) measures were analyzed with repeated-measure ANOVAs. Covariates concerning anxiety inventories, as well as task order (version 1 or 2), were considered as additional variables, but the best models, as measured by p-values and AIC values, were those without any additional predictors.

DDM parameter estimation was performed with the Fast-dm software (v. 30.2; Voss & Voss, 2007), using maximum likelihood as a computation method (precision at 4.0). Parameters concerning boundary separation (alpha) and starting point (z) were estimated separately per block type. Drift rate was further estimated per action type (aggressive vs neutral actions) and analyzed as a function of magnitude towards the correct response (values were transformed accordingly; Myers et al., 2022). Given our prolonged trial responses, and the limited number of trials, the non-decision time was fixed at 0.3 for every individual and condition, and all other parameters concerning inter-trial variability, were fixed at zero (Lerche & Voss, 2016).

The last question and the recognition task are assessed descriptively and graphically in Appendix A and B, respectively. This study was pre-registered, and all available data and analyses scripts can be found in the pre-registration link (osf.io/b6dpj).

Results

Subjective anxiety, as reported at the end of each block, was affected by the type of block that participants had just undertaken ($F(1.435, 91.817) = 102$, $p < .001$, $\omega_p^2 = 0.29$, 95% CI [0.16, 0.4]). Further inspection revealed that Threat R ($M = 49.1$, $SD = 28.6$; $t(128) = -11.938$, $p < .001$, $d = -1.06$, 95% CI [-1.27, -0.84]) and Threat A ($M = 51.4$, $SD = 29.7$; $t(128) = -12.758$, $p < .001$, $d = -1.13$, 95% CI [-1.35, -0.91]) blocks led to greater subjective anxiety compared to the Safe block ($M = 15.3$, $SD = 18$). No difference was found between the two threat blocks ($t(128) = 0.820$, $p = 1$, $d = 0.07$, 95% CI [-0.10, 0.25]).

In terms of sensitivity, our analysis showed that block type did significantly affect this measure ($F(2, 128) = 4.34$, $p = .015$, $\omega_p^2 = 0.02$, 95% CI [0, 0.07]). Post-hoc tests revealed that both Threat R

($t(128) = -2.438$, $p = .0485$, $d = -0.22$, 95% CI [-0.39, -0.04]) and Threat A ($t(128) = -2.652$, $p = .027$, $d = -0.23$, 95% CI [-0.41, -0.06]) blocks exhibited a higher sensitivity compared to the Safe block (see Figure 2). Once more, no difference was found between the two threat blocks ($t(128) = 0.214$, $p = 1$, $d = 0.02$, 95% CI [-0.15, 0.19]). As for criterion, no effect of block was observed over this measure ($F(2, 128) = 0.458$, $p = .633$, $\omega_p^2 = 0$, 95% CI [0, 0]).

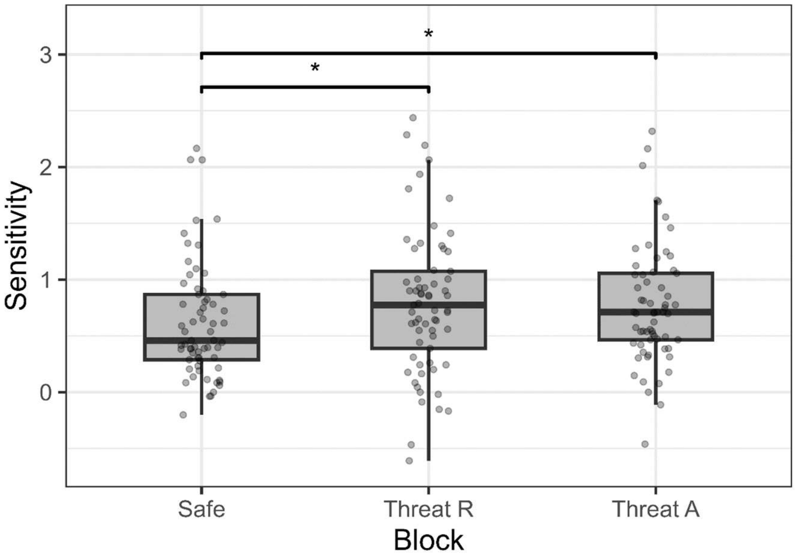

Figure 2. Average sensitivity per safe and threat blocks (R and A). The dots mark the observed mean sensitivity per participant. "" = p < .05*

Correlation analyses between the measures of sensitivity and criterion and the self-reported anxiety measurements showed no statistically significant associations ($p > .05$).

Response times also showed no effect of block ($F(2, 128) = 0.006$, $p = .994$, $\omega_p^2 = 0$, 95% CI [0, 0]). Action type did affect response times ($F(2, 128) = 85.66$, $p < .001$, $\omega_p^2 = 0.08$, 95% CI [0, 0.23]), with aggressive actions being identified quicker ($M = 2.44$, $SD = 0.51$) than non-aggressive actions ($M = 2.8$, $SD = 0.62$). No interaction was observed between block and action ($F(2, 128) = 0.736$, $p = .481$, $\omega_p^2 = 0$, 95% CI [0, 0]).

Drift diffusion model analysis showed that boundary separation (alpha) was not different across blocks ($F(2, 128) = 2.33$, $p = .102$, $\omega_p^2 = 0$, 95% CI [0, 0.04]). Starting points (z) showed a similar pattern, with block not affecting the average starting point of participants ($F(2, 128) = 0.879$, $p = .418$, $\omega_p^2 = 0$, 95% CI [0, 0]). Block did, however, affect the magnitude of drift rate ($F(2, 128) = 4.77$, $p = .01$, $\omega_p^2 = 0.02$, 95% CI [0, 0.08]), with Threat R ($t(128) = -2.547$, $p = .036$, $d = -0.23$, 95% CI [-0.4, -0.05]) and Threat A ($t(128) = -2.787$, $p = .018$, $d = -0.25$, 95% CI [-0.42, -0.07]) exhibiting a higher drift rate magnitudes compared to the Safe block (see Figure 3). No difference was found between the two threat blocks in this measure (*t*(128) = 0.24, *p* = 1, *d* = 0.02, 95% CI [-0.15, 0.19]). Action type had no effect on drift rate magnitude (*F*(1, 64) = 0.15, *p* = .7, $\omega_p^2 = 0$, 95% CI [0, 0]), with no interaction between this variable and Block being observed (*F*(2, 128) = 0.7, *p* = .5, $\omega_p^2 = 0$, 95% CI [0, 0]).

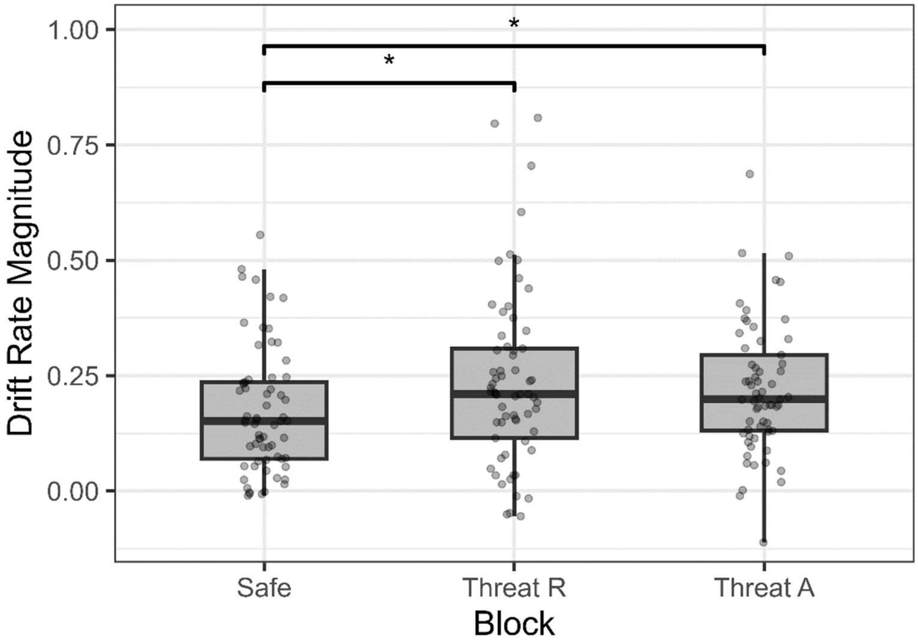

Figure 3. Absolute magnitude of drift rate per block types. Higher values indicate a quicker accumulation of evidence toward the correct response. "" = p < .05*

Discussion

In this study, we investigated how states of anxiety might sensitize and bias our perception toward the detection of aggressive social actions/gestures. We further assessed if this effect was dependent or modulated by an association between threat and the aggressive action itself.

Our analyses confirmed our first hypothesis, showing that states of threat lead to an increased sensitivity in detecting aggressive actions. This finding supports prior literature that shows an increased sensitivity toward threat-related visual targets. In particular, our conclusions expand on studies that used fearful facial expressions (Kavcıoğlu et al., 2019; Sussman, Szekely, et al., 2016) or neutral stimuli associated with threat (e.g., shock; Preciado et al., 2017), by demonstrating that these anxiety effects are also transposable to aggressive social gestures. Importantly, in a previous study (Silva, Garrido, et al., 2023; Chapter IV), we did, in fact, found no sensitivity gains under threat when identifying social interactions between two agents on screen. Whilst apparently at odds with the current findings, we believe that having the threat-related stimuli directed at the viewer, as is the case here and in prior studies using fearful expressions, might have been a determining factor. In other words, when dealing with more direct threats, we seem to benefit from an increased sensitivity in their detection, whereas this may be reflected to a lesser extent in the case for more indirect threats (e.g., an aggressive interaction taking place between two other people). Furthermore, we saw that benefits in sensitivity were not dependent on the threat being associated with the target action (Block A). This supports the idea that gains in perceptual sensitivity are not necessarily directed at the source of threat, nor do they appear to be improved when this connection is established.

No additional bias in signaling aggression was found under threat, however, as seen by our criterion analysis, which ended up not supporting our second hypothesis. This seems to go against literature showing an overall tendency to categorize ambiguous visual stimuli as more negative/threatening when under threatening contexts (Neta et al., 2017; Flechsenhar et al., 2022; but see de Voogd et al., 2022). Indeed, even when the probability of the aversive event (shock) was linked to the occurrence of the target stimuli (aggressive gesture; Block A), there was no apparent decrease in decision criterion. Overall, this lack of bias towards (or away from) aggression seems to be at odds with theories suggesting a negativity bias under anxiety, as well as those which actually posit a positivity (wishful seeing) bias (Engelmann et al., 2019).

One possible factor that might explain the lack of effect discussed above might concern the type of task employed here. Specifically, the elevated difficulty associated with the task, as evident by the low accuracy (63% average global accuracy) and long decision times (global average around 2.7 seconds), might not have posed an ideal scenario to capture biased interpretations of threat. Indeed, those studies who report biases usually show superior accuracies and, more importantly, quicker reaction times (e.g., Flechsenhar et al., 2022; Robinson et al., 2011). We believe that the more thorough contemplation (i.e., more careful consideration) of the visual stimuli required in the task presented here might have resulted in a less “quick and dirty” (biased) perception as shown in other studies. However, given the reasons above, it seems difficult to justify why sensitivity differences between blocks were still found. Furthermore, it is important to consider that a recent study by de Voogd and colleagues (2022) showed improved sensitivity under threat, without the expected biased decision criterion when detecting innocuous targets. Although we used threat-related targets, together these findings might suggest that whilst sensitivity is, overall, improved, criterion does not seem to be affected, irrespective of the threat-related nature of the stimuli in question. Regardless, we denote the need for future studies to provide more support before any solid conclusion can be warranted.

Aligned with the sensitivity findings, we also showed that under threat we have an increased evidence accumulation towards the correct decision threshold. That is, sensory evidence carries a bigger weight when we are trying to detect and judge the presence of threat in our visual environment, whilst under anxiety. This is in accordance with our third hypothesis, lending support to prior research showing a generalized increase in evidence accumulation rates during anxiety (Dillon et al., 2022; Gorka et al., 2023). Of relevance, this finding is also in line with a previous study by the authors (Silva, Garrido, et al., 2023; Chapter IV), in which we showed the same increased evidence accumulation under threat when asking participants to identify aggressive interactions between two people. This conclusion highlights the enhanced sensory-perceptual processing brought about during states of anxiety, which, by aiding a quicker, and even potentially more accurate, detection of threats, increases one's survival odds. In addition, and as with our previously discussed findings, a connection between the threat and the target action (Block A) bared no influence over this drift rate. It is hard to establish if these findings are expected, considering that studies measuring drift rates during anxiety states are both scarce and focused on the perception of reward (Globig et al., 2021; Yamamori & Robinson, 2023). We believe that future studies assessing perceptual decision-making and anxiety would benefit immensely from exploring these processes with this more encompassing modeling technique.

Lastly, and similarly to our previous study, threat of shock bared no difference over response times (for correct answers). Indeed, the literature paints a mixed picture in this regard, with studies showing improved response times under anxiety (e.g., Wieser et al., 2010) and others showing the opposite pattern (e.g., Flechsenhar et al., 2022). Furthermore, in our previous study (Silva, Garrido, et al., 2023; Chapter IV) we also found no differences in RT between threat and safe conditions when identifying potentially aggressive social interactions (as also observed in some studies; Robinson et al., 2011). Of note, in the study discussed here we found that aggressive gestures were accurately detected more quickly than neutral gestures, which aligns both with our previous study and existing literature (LoBue & DeLoache, 2010; Öhman & Mineka, 2001).

Limitations and future studies

Aside from the limitations already mentioned in this discussion, we would also like to acknowledge other potential caveats of this study. Due to the limited stimuli available, we used a small sample of aggressive/non-aggressive actions (four of each). This might have hampered the generalizability, and obscured other potential effects, given that a lower diversity of stimuli also affects statistical power (Westfall et al., 2014). In fact, even our estimated sample size, centered around a moderate effect size, might have been a further limitation, leading to smaller effect sizes going unnoticed. Another potentially limiting factor is the lack of an additional block where an association between threat (shock) and non-aggressive actions was established, providing a direct contrast to Block A. This more direct comparison might have provided some additional comparison points and should be of consideration in future studies.

An additional avenue of research might concern how positive gestures (e.g., dancing, waving) are identified under anxiety, compared to those used here signaling aggression. This would help to discern if the overall sensitivity and greater evidence accumulation rates seen during anxiety are also applicable to the detection of actions associated with positive outcomes. Also, this might help to elucidate if the possible higher speed of aggressive actions (that should be expected in dancing actions as well, for example) is the driving force behind the greater sensitivity in identifying aggressive actions when under threat.

Conclusion

In this study we demonstrated that when under anxiety participants exhibit a greater sensitivity in identifying aggressive gestures in ambiguous/noisy scenes. Aligned with this, we also found a greater sensory information uptake in states of threat when identifying these potentially aggressive gestures. Surprisingly, no bias towards signaling aggression was observed when under threat. Overall, our findings lend support to prior literature, simultaneously expanding their respective conclusions toward other threat-related stimuli, such as aggressive behaviors.

CHAPTER VI

General Discussion

Main results

Summary of the main findings

Experiencing anxiety was conceived and developed to be a beneficial and adaptive process, adding to one's surviving chances. Nonetheless, in today's modern society this event is overly experienced on unnecessary occasions, and, most importantly, in a far greater frequency than one would expect given the safety standards around most of us (Bandelow & Michaelis, 2015). Hence, it is of key importance to assess how these adaptive measures brought about during anxiety might carry unwanted, but also favorable, effects over normal (i.e., daily) situations. Here we focused on the how this state is associated with an enhanced visual sensory-perceptual processing (i.e., increased perceptual sensitivity) and assumed subsequent lower dependency on expectations (Cornwell et al., 2017; Robinson, Vytal, et al., 2013; Weymar et al., 2014). Specifically, we investigated how this perceptual shift might affect one's capacity to interpret social scenarios. To address this question, I presented here four studies that explored different nuances of how threat-induced anxiety might improve one's ability to detect targets amidst noise at the potential expense of creating unwanted biases and leading to a reduced ability to use contextual cues.

The first study (Study 1; Chapter II) assessed how potentially approaching (ambiguous) agents are interpreted differently depending on one's anxiety's state. In an attempt to also assess if different methods yielded different results, three anxiety-induction paradigms were used across three individual experiments. Regardless of method used, the results were unanimous across all three experiments in showing that anxiety does not affect how we perceive ambiguous walkers. In other words, no increase (or decrease) in FTV bias seems to be brought about during anxious states.

The next two chapters were dedicated to exploring how more complex social behaviors (i.e., social interactions) were perceived, and our ability to incorporate contextual cues into this process during anxious states. Study 2 (Chapter III) described an experiment assessing the extent contextual cues were used to infer the presence of a second agent that was potentially present in a social interaction in both safe and threat-induced anxiety. Gaze data was also collected to assess, primarily, how participants explored the visual area containing the contextual cues (i.e., the other agent partaking in the social scene). The results from this task showed that participants under threat of shock seemed able to use contextual cues to infer social aspects of a scene to the same extent as when under safe contexts. No gains in sensitivity were also observed when under threat. Gaze exploration patterns were similar across safe and threat conditions, with the exception of fixations which were, on average, shorter in the latter condition.

The next study (Study 3; Chapter IV) showed an adaptation of this prior study, measuring, this time, how potentially aggressive interactions are perceived under safe and threat of shock conditions.

Once more, this was done whilst accounting for how contextual cues were incorporated in this process. Similarly to the previous experiment, eye tracking was used to account for how the participants explored the facial expression of the observer present in the scene (source of contextual cues). Threat-induced anxiety did not result in a gain reflected over on the sensitivity index. Nevertheless, when simultaneously contemplating response times, inducing anxiety resulted in greater drift rates, reflecting increased evidence accumulation towards the correct perceptual decision, and thus suggesting increased perceptual sensitivity. No apparent decision bias towards threat was present, as reflected by criterion, and no differences in RT for correct responses were found when under threat. The presentation of fearful faces had no interactive effect with the presence of threat of shock in terms of decision criteria as well. Lastly, gaze analysis showed that participants dwelled longer over the facial expression of the observer when under threat.

The last study (Study 4; Chapter V) measured how potentially aggressive gestures directed at the viewer were perceived when under safe and threat-induced anxiety. Additionally, the association between the likelihood of electric shock (anxiety source) and an agent's display of aggression was also manipulated and probed. Here we showed that under anxiety we display an increased sensitivity to detect threatening gestures in ambiguous social behaviors. This finding was further supported by increased drift rates towards the correct decision threshold under anxiety, as seen in the previous study. Importantly, the presence of an association between threat of shock and aggressive displays did not play a significant role in modulating any perceptual measure exhibited by the participants. Additionally, while both sensitivity and drift rates were increased under states of anxiety, no subsequent bias in signaling threat was observed in this condition compared to safe states.

In brief, the findings above support an increased perceptual sensitivity when under anxiety in detecting threat-related stimuli. Relevantly, this happens without any subsequent biased perception towards threat and while maintaining a normal ability to use contextual cues when perceiving our social environments. To more carefully explore this, the rest of this discussion will be divided into three topics, followed by some general considerations. The first one will discuss the absence of any perceptual biases towards threat found during anxiety, detailing what the reasons for this might have been as well as how this can be incorporated into current literature. The second topic will integrate the evidence found suggesting an increased perceptual sensitivity toward threat targets during anxiety, addressing also the inconsistencies found between studies. Lastly, a third topic will be dedicated to taking an in-depth look into why anxiety played no part in how expectations were used during perceptual decisions. In the last portion of this thesis I will discuss its respective strengths and potential practical implications as well as its limitations, whilst providing some suggestions for future studies. I will finalize this thesis with some brief final remarks on this work's conclusions as a whole.

No perceptual biases whilst under threat

The first question this thesis set out to investigate was centered around perceptual biases during anxiety. Prior literature has already shown that both AD and anxiety feelings experienced by healthy individuals accentuate the threat-related features of stimuli, biasing one's interpretation when perceiving ambiguous scenes (e.g., Flechsenhar et al., 2022; Grupe & Nitschke, 2013). One factor that seems to limit this generalization concerns how these effects are almost exclusively studied using facial expressions. Here, we investigated how such biases might reflect themselves when perceiving other social stimuli that may also imply potentially dangerous encounters.

We began with how ambiguous PLWs were perceived under threat (Study 1). This study showed that regardless of the method used to induce anxiety-like states, either via imagery or threat of loud scream or shock, no apparent increased "approaching" perception of these agents was observed. This seems particularly at odds with the literature, since states of anxiety are known to deploy safeguards against false negatives when identifying threat (e.g., Bublatzky et al., 2020; Flechsenhar et al., 2022; Kavcıoğlu et al., 2019). Also worth mentioning, measures of trait and social anxiety were also shown not to be associated with the amount of FTV bias exhibited. Despite aligned with some recent studies (Peng et al., 2021), it is still hard to integrate this latter finding with the overall mixed picture shown in the literature (Heenan & Troje, 2015; Van de Cruys et al., 2013; Yiltiz & Chen, 2018). It is easy to see that in a threatening situation (i.e., under anxiety) reducing the extent to which we confuse approach for receding motion (false negative) can be detrimental for one's safety, as in the case, for instance, of avoiding predators. Mistaking potentially harmful behaviors for neutral ones is even more imperative when one considers how the misidentification of aggression being displayed towards us might result in slower defensive reactions, as was explored in Study 4. In the same line as the study above, however, no tendency to overperceive these more threatening outcomes (i.e., aggressive actions) was observed when under threat.

Contrasting with these results, an overall shift towards a more conservative perception as the potential danger/harm present in our surroundings, or derived from an interaction, increases has been shown in other studies. For instance, depending on the object in the hand of a stranger, either an innocuous one (e.g., watering can) or a more menacing one (e.g., knife), the facial expression of that same stranger is judged differently, being perceived as more angry when holding threatening objects (Holbrook et al., 2014). Representational momentum, a phenomenon where people tend to remember the position of a moving object as being displaced towards its direction of motion (Freyd & Finke, 1984), is also stronger (bigger forward displacement) for objects embedded in threatening scenarios (Greenstein et al., 2016). Even when perceiving simple sounds (basic tones) that do not, at least directly, signal any danger, there is a tendency to judge looming as changing faster (i.e., more quickly gaining intensity) than receding sounds (Neuhoff, 1998) – a tendency that is exacerbated by anxiety levels (Riskind et al., 2014). Indeed, the same rationale is thought to be behind the FTV bias seen in the population as well as perceptual biases towards threat, and thus expected to be further affected when under scenarios of possible threat (e.g., by the possibility of shock). Despite this, as mentioned, in our study, states of anxiety did not modulate FTV tendencies, nor did they create an exaggerated perception of aggression.

Starting with Study 1, some explanations have already been brought forward in Chapter II concerning, predominantly, task-related factors (e.g., possible inadequate number of PLW depth-levels and trials) in trying to explain this result. Despite this, another conceivable possibility targets the more general premise that FTV bias is derived uniquely from a need to reduce misinterpreting an approaching unknown (and potentially danger) conspecific as receding, when one is actually approaching. It is possible that FTV is more of a result of preparedness and motivation to engage in a social interaction. Indeed, some studies, as highlighted in Chapter I and II, have come to support this idea, showing, for instance, that guilty feelings towards an individual lead to increased FTV bias towards that same person (Shen et al., 2018). Here, the authors propose that such is explained by the increased pro-social behavior (i.e., tendency to engage in actions that benefit others) and consequent shift in approach/avoidance motivations seen in guilty people (De Hooge et al., 2011; Malti & Krettenauer, 2013; Nelissen et al., 2007). Furthermore, a study by Han an colleagues (2021) showed that manipulating certain cues (size, distance or speed) to indicate more imminent social interactions resulted in bigger FTV scores. Thus, it might be argued that although a defensive mechanism towards threat might be implicated in FTV biases, its main drive is associated with a general preparedness mechanism towards a possible social interaction. In other words, this latter mechanism might play the major role in defining our inherent tendency to perceive approach when viewing ambiguous PLWs. Irrespective of this, the fact that such stimuli might signal both potential danger but also a normative social behavior (i.e., impending social interaction) might contribute to the lack of interaction with states of anxiety we found in our study.

Along this line, it is also worth adding that perceiving a potentially approaching stranger during a state of anxiety might be seen through different points of view. While some participants might consider an approaching stranger an unwanted and potentially threatening event others might see potential help and, consequently, an increase in safety. Indeed, the presence of conspecifics is known to provide safety in threatening environments, as evident, for instance, in reduced vigilance rates compared to situations where one is alone (Gomes & Semin, 2019). Again, this would lead to different results according to the interpretation made of an approaching stranger. The vast individual-level variation seen across all three experiments seems to support such scenario (see main plots from

Study 1; Chapter II). Nonetheless, it is hard to incorporate both the aforementioned hypotheses considering that previous studies show that ambiguous neutral faces, which can also be interpreted by the rationale exposed above, are still subjected to a biased perception towards more fearful/anger-like when under threat (e.g., Bublatzky et al., 2020; Flechsenhar et al., 2022).

Looking further ahead at our Study 4 (Chapter V), helps to further refute, or at least to partially discredit, some of these ideas/points raised so far. Here (Study 4), we measured the quick identification of more direct and clear instances of potential danger under anxiety, showing, again, no apparent perceptual bias towards signaling threat. Indeed, even in cases where the danger-signaling stimuli (aggressive gestures) were connected to the source of anxiety (electric shock), participants' willingness to say the target (aggression) is present remained the same. This suggests that even in cases where it is clear that a social behavior is potentially threatening (aggressive gestures), perceptual biases towards threat are not intensified when one is under anxiety. Such is also the case even if the aversive outcome that is responsible for one's anxiety is viewed as originating from aggressive actions. Considering this, even if participants might have had different viewpoints on the approaching agent presented in Study 1, as either an indicator of safety or threat, this current study (Study 4) seems to discredit that such idea is responsible for the lack of a threat bias.

One final potentially important aspect about Study 1 that deserves some consideration, surrounds the timeframe concerning the identification of motion direction. Indeed, it is not just ambiguity that evokes perceptual heuristics that lead to preferential tendencies in interpretating our visual world (i.e., biases). The time-window of the decision, i.e., if a decision needs to be executed fast or with no apparent urgency, may also have been responsible for the results found. In fact, most experiments highlighting threat biases (e.g., Flechsenhar et al., 2022; Neta & Tong, 2016), or even differences in perceptual criterion (e.g., Bang & Rahnev, 2017), do so with tasks involving quick decision times or with very time-limited stimulus presentation. In contrast to these experiments, in the tasks of this first study, no time-limit was set, nor any urgency in the response was directly encouraged, which might have led to more careful considerations and less room for biases to emerge. Nonetheless, this would be a hard feature to implement with PLWs, since the stimuli must be present for a few seconds to complete at least two full step cycles (see Schouten & Verfaillie, 2010). Plus, looking once more at Study 4, where quick decisions (alongside proper accuracy) were encouraged, seems to argue against this explanation, since no threat bias was observed under these conditions as well.

In sum, it is hard to establish which factors, if any, might have been implicated in this lack of perceptual bias towards threat. The overall picture shown in both of these studies (1 and 4) seems to suggest that, at least for ambiguous social actions and gestures, no increase in false threat detections is present during states of anxiety. Furthermore, the remaining studies (Study 2 and 3), despite not directly assessing anxiety-driven biases alone (nor always employing threat-related stimuli), also seem to reinforce the idea that has been developed so far. In both studies we saw that anxiety does not seem to bias one's perception of social scenes, be it in the identification of a possible agent partaking in a neutral scene (Study 2) or the identification of threat-related behaviors between two agents (Study 3). In fact, in this latter study, we further showed that even in the presence of fearful/surprise faces, this expected tendency to judge ambiguous scenes as depicting aggressive behaviors whilst under anxiety was still not observed (more on this below).

The overall consistency of these findings across all studies seem to strongly suggest that under anxiety, uncertainty surrounding social actions is not necessarily subject to any evident perceptual bias, particularly a bias towards threat. As highlighted in the introduction (Chapter I) and above, these results do not seem to give support to previous literature that showed how threat-induced anxiety biases our perception of ambiguous faces (neutral or surprise-depicting faces) making them appear more intense and threatening (Bublatzky et al., 2020; Flechsenhar et al., 2022; Kavcıoğlu et al., 2019; Neta et al., 2017). To further break down this supposed incongruency, it is important to address the type of stimuli used in each experiment. Facial expressions, with all of their subtleties and inherent ambiguities (see Ekman & Friesen, 2003), may be far more prone to be misinterpreted, and, thus, victims of perceptual biases, even in comparison to degraded and noisy body gestures (as used here). Faces, specifically those expressing fear and anger, are also the most widely studied stimuli when it comes to social threat-signals, acting as the prototypical threat marker in social interactions. Indeed, threatening faces are shown to be intrinsically valuable, having a prioritized processing and being more quickly recognized among other faces compared to other facial expressions (Hansen & Hansen, 1988; Schupp et al., 2004; Pinkham et al., 2010; but see D. V. Becker et al., 2011). The research on threatening body gestures or actions has, on the other hand, lagged behind compared to research on threatening facial expressions, and has only recently been gaining more attention (De Gelder et al., 2015). The evidence available so far seems to show that we are wired to quickly distinguish between threat and non-threatening gestures, with certain neural regions involved in action preparation (e.g., premotor area) and threat processing (e.g., amygdala) showing increased activity when reacting to such actions (Pichon et al., 2009; Sinke et al., 2010). Yet, when comparing threatening facial expressions (fearful/anger) to threatening body expressions, there's a distinct pattern of neural activation for each, with, for instance, threatening facial expressions showing greater amygdala activation (Kret et al., 2011). Ultimately, it is difficult to draw conclusions as to if anxiety biases perception differently depending on the type of threatening stimuli present (body gestures *vs* facial expression). Such questions should be the target of future investigations.

Enhanced perceptual sensitivity to threat during anxiety

Starting with our third study (Chapter IV) – although also explored in Study 2 (Chapter III) – and followed by the fourth and final study (Chapter V), one of the additional inquiries of this thesis was to see if sensory-perceptual mechanisms were, indeed, augmented during states of threat. This finding has been widely observed in previous literature. Although, as I have shown in the introductory chapter (Chapter I), this has been mostly studied by measuring the brain's electrical activity (e.g., EEG) when facing unexpected sensory changes (e.g., Baas et al., 2006; Cornwell et al., 2017; Shackman et al., 2011). Moreover, alongside other visual changes (i.e., perceptual shift towards LSFs), this enhanced sensory-perception, as reflected in increase perceptual sensitivity, was shown to be particularly targeted towards the detection of threatening stimuli (Kavcıoğlu et al., 2019; Sussman, Szekely, et al., 2016).

In our studies, we did find evidence that such increased sensory-perceptual processing is also found when detecting threatening gestures in our field of view. Study 4 did, as expected, reveal that under anxiety one's perceptual sensitivity is improved. Namely, when asked to quickly detect (i.e., discriminate between) potentially aggressive and non-aggressive gestures in degraded visual displays of human motion, participants showed a greater capacity in doing so when exposed to threat of shock. This was also manifested as a function of evidence accumulation (drift rate), with participants needing less information to correctly make their decisions. Study 3 also assessed this perceptual sensitivity towards aggressive behaviors, this time asking participants to rapidly identify potentially aggressive interactions between two agents. Under these circumstances, and apparently contrasting with the second study, no apparent greater sensitivity, as measured by the sensitivity parameter (SDT), was observed. However, incorporating temporal dynamics (i.e., RTs) together with decision markers revealed the same picture as in the previous experiment, with states of anxiety being associated with a faster evidence accumulation towards the correct decision threshold. Thus, although in this study decision markers alone may not be reflecting one's increased perceptual sensitivity, it seems that we still need less evidence (sensory input) to reach correct perceptual decisions when under threat. Relevantly, we saw that adding an additional contextual cue signaling threat (fearful/surprise expression by the observer) did not increase perceptual sensitivity effects from threat of shock, apparently contradicting prior findings (more on this below; Sussman, Weinberg, et al., 2016).

Viewing these two studies together, a few differences and questions emerge that are worth digging into. Firstly, although both experiments showed some measure of increased sensory-perceptual processing, the last study (Study 4) provided clearer results with this effect being reflected both in sensitivity and drift rate measures. This was not the case in the second study (Study 3) where only drift rate was significantly higher during states of unpredictable threat. Nonetheless, drift rates towards the correct decision boundary capture, much like sensitivity, one's efficiency in discriminating between signal and noise, providing the additional advantage of incorporating time dynamics (i.e., RTs) when deriving this sensitivity-like index (Myers et al., 2022; Pirrone et al., 2017). Indeed, it may even be the case that such a measure might prove to be a more apt and powerful indicator of a truly enhanced sensory-perceptual processing. This would explain why such measure was able to capture increased perceptual sensitivity in both studies, as opposed to the sensitivity index, which relies solely on decision markers.

Another obvious difference between these two studies that should be discussed is that the Study 4 presents a more direct threat to the viewer whilst the Study 3 positions the threatening occurrence between two other strangers. Although tentative, it can be argued that more direct threats towards the viewer (as seen in the former study) carry stronger effects that resulted in clearer metrics reflecting enhanced sensory-perceptual processes under anxiety. A few studies have shown that how a threat, in this case a facial expression, conveys the direction of danger via gaze, affects how such stimulus is processed. For instance, the amygdala responds differently depending on whether the gaze is directed towards or averted from the viewer, with this being dependent on the type of threatening expression (fearful *vs* angry) and of time (R. B. Adams et al., 2012; Im et al., 2017). This is, perhaps, better demonstrated in behavioral studies, where, for example, expressions of anger with a direct gaze, implying possible danger towards the viewer, are more rapidly identified than angry expressions with averted gaze (which imply aggression towards someone else). In fact, the reverse pattern is seen for fearful faces since their averted gaze more commonly signals a general danger in our vicinity and their direct gaze does, instead, signal a more ambiguous (less clear) message (R. B. Adams & Kleck, 2003). Following studies have then come to show that attentional and perceptual biases appear to be dependent on the direction of gaze, particularly with anger expressions requiring direct gazes for such bias to emerge (Li et al., 2017; Veenstra et al., 2017). Importantly, one study by Beaurenaut and colleagues (2023), showed that under threat of scream, participants had a higher tendency to judge faces with averted gazes, as opposed to direct gazes, as expressing more fear. Crucially, under threat they also showed a prioritized processing of fearful faces with averted gazes compared to those with direct gazes, supporting the idea that it is not just the threat-related nature of the stimulus that matters, but also its direction in relation to the viewer (i.e., how it implicates the viewer). Thus, it might be the case that viewer-directed threats are more easily affected by enhanced sensory-perceptual processes compared to those that are more ambiguous in that regard. Nonetheless, it is somewhat difficult to explain why, in Study 4, no additional sensitivity was observed when the aggressive gestures were directly tied to the possibility of electric shock, since this is an even more concrete (direct) threat towards the viewer. This hypothesis remains an open question that should be addressed in future studies.

Although not the focus of our second study (Study 2), surprisingly, no sensitivity gains were displayed when trying to detect innocuous targets (presence of a second agent), which does not seem aligned with the overall – not just threat-related – enhanced perceptual sensitivity reported in the literature (e.g., Cornwell et al., 2017; de Voogd et al., 2022). Integrating this finding with the ones above and previous literature raises some interesting discussion points. Clearly, a big difference that carries some potential explanatory power to the subject at hand is related to the innocuous nature of the target, which carried no intrinsic value or saliency compared to its counterpart (absent target). In fact, studies demonstrating increased perceptual sensitivity (not just in anxiety) usually rely on the detection/identification of physical saliency (e.g., Cornwell et al., 2007, 2017; Robinson, Overstreet, et al., 2013). Thus, it might be the case that detecting the mere presence biological motion (as in Study 2) might be less affected by enhanced sensory-perceptual processes than detecting the presence of aggression in degraded biological motion (Study 3 and 4). Furthermore, despite, at a first glance, both looking like fairly complicated tasks, it could be argued that in detecting the presence of aggression, participants might have taken advantage of certain simple patterns/cues, which were not present in Study 2. Specifically, such patterns might be related to action speed, which, in the case of aggressive gestures (compared to neutral gestures) might have resulted in the more frequent occurrence of faster moving dots. Since quick motions are more associated with threat (Riskind, 1997), it might be the case that this simple feature, which is inherently a part of a threatening gesture, might have been susceptible to enhanced sensory-perceptual processes seen during states of anxiety. Conversely, in Study 2 the main objective was to identify the presence of a human entity among noise – which itself was biological motion spatially and temporally scrambled – and could not have been accomplished via quick shortcuts (e.g., motion speed). This rationale is supported if we consider how threatening stimuli are processed. For example, our innate sensitivity and prioritized attention towards threatening stimuli, such as fearful faces and snakes, is thought to be driven predominantly by their simple features (e.g., the shape of a snake; Gomes et al., 2019; Grassini et al., 2018) and patterns (i.e., contrast distribution in a fearful face; Bruchmann et al., 2020; Webb et al., 2020). Thus, it is not entirely possible to discard that other nuances of the task, rather than the emotional value embedded in the stimuli, are not driving these results.

One less obvious, but also potentially critical, difference between this (Study 2) and the aforementioned two studies (3 and 4) is that decision times were not considered in the former. As with Study 1 (see topic above), it might have been the case that the lack of pressure to make a quick decision may have obscured any sensitivity-related effects resulting from anxiety in this task.

Moreover, since drift rate measures, which are built around decisions and their respective RTs, were not able to be computed for Study 2, we were also missing a potential critical measurement in capturing such effects. It is hard to determine if in the case participants were instructed to provide rapid decisions this might have revealed the same pattern of increased sensitivity as found in the previous two studies. Indeed, the literature, to the best of my knowledge, provides no clear investigations as to how perceptual measures (i.e., biases and sensitivity) are determined as a function of time-to-decision. Nonetheless, since our principal objective with this task was to mimic the experiment conducted by Manera and colleagues (2011), assessing how anxiety might interfere with the effects reported by this study, we chose to follow their method as closely as possible, which meant adopting a fixed and unlimited response time window. Moreover, urging a quick response in this paradigm might have disrupted its intended purpose, making participants less willing to attend to the agent providing the contextual cues. Again, the arguments presented above are speculative in nature, and their primary objective is to caution one's quick interpretation and prompt future investigations on these matters.

Normative use of expectations when under threat

Two of the studies presented in this thesis (detailed in Chapter III and IV) were centered on its last goal which concerns the effects of anxiety on how expectations, built upon contextual cues, are used when giving meaning to ambiguous social actions. As detailed in Chapter I, the literature provides some hints that under states of threat we adopt a more sensory-driven perception, which should entail reduced reliance on expectations (Cornwell et al., 2017; Sussman, Jin, et al., 2016). Yet, most literature has only explored this shift based on MMN paradigms. The only study that more directly measured trade-offs between sensitivity and criterion as a function of anxiety, showed increases in sensitivity but no effects over the weight given to prior expectations (de Voogd et al., 2022). Moreover, in case where contextual cues are themselves indicators of threat, the pattern of results might be a bit different, instead reflecting an increase in one's anxiety by such cues, improving perceptual sensitivity (Sussman, Weinberg, et al., 2016).

Both studies (2 and 3) depict a similar picture, showing that states of anxiety do not affect how we use cues from contextual sources (in this case, other people) to infer the meaning behind ambiguous visual scenes. This seems to contradict what was expected based on the findings using MMN, which suggested that greater perceptual sensitivity, as evidenced by heightened prediction errors, would entail a cost related to the reduced weight of expectations (Cornwell et al., 2007, 2017). Indeed, the findings discussed in the previous topic do find evidence favoring this enhanced perceptual sensitivity seen during anxiety. Nonetheless, no apparent downplay of expectations accompanied this latter effect. In other words, albeit benefiting from an increased alertness to sensory changes in our environment, we still manage to effectively incorporate prior knowledge when attributing meaning to degraded/ambiguous sensory information. In fact, these conclusions side with the findings of de Voogd and colleagues (2022), with any shifts in criterion as a function of contextual cues being similar between threat of shock and safe conditions. Furthermore, it's worth noting that trait anxiety was also not associated with this process (and was the case with social anxiety), even if prior studies have suggested how elevated trait anxiety might be related with impairments when forming and using expectations (Berggren & Derakshan, 2013; Browning et al., 2015).

Although the picture painted so far seems confusing, and these apparent discrepancies between behavioral and neurophysiological studies seem difficult to reconcile, it is important to raise some critical distinctions that might help to integrate the findings above. Firstly, it is important to, once more, address the timeframes that both types of experiments strive to capture. MMN is an automatic reaction that corresponds to the immediate integration between sensory information and prior expectations (Garrido et al., 2009). This immediate process may, indeed, have its perceptual repercussions in terms of how prior expectations are valued, if a decision is to be made in an almost immediate fashion (e.g., less than 1 second) and, as such, without much examination or conscious thought. In the studies presented here the average decision times were considerably longer (above 2 seconds after stimulus presentation; Experiment 3) and, in the case of Experiment 2, no urgency (time-limit) was even applied. In fact, even de Voogd et al. (2022), despite presenting response times averaging around 600 ms, had a delay between target stimulus and response of around 4 seconds. It is possible that the shifts in weighs between sensory input and expectations observed in MMN studies (Cornwell et al., 2007, 2017) are not directly transposable to more deliberate and slower perceptual decisions. In this case, only more immediate and automatic perceptual processes effectively reflect this shift, with later (more elaborate and deliberate) perceptual decisions being less susceptible to the effects resulting from a more sensory-driven perception. Nonetheless, it is difficult to determine if this was truly the case, particularly considering that during this more prolonged decision times there was still evidence of enhanced perceptual sensitivity (Study 3) whilst under threat, something expected based on MMN findings.

Looking more specifically at Study 3, we can even see that threat-related cues showed similar effect patterns in both anxiety and safe conditions. In this case, however, it was actually expected that fearful faces would further prime a state of potential threat, leading to more emphasized perceptual sensitivity and a possible raised bias towards signaling aggression (Sussman, Weinberg, et al., 2016). Regardless, and as already mentioned throughout the discussion, no overall gain in perceptual sensitivity from fearful faces was reported, nor even when paired with threat of shock. In addition, the observed bias towards aggression (reflected in lower criterion), was seen across both safe and anxiety conditions, with seemingly no significant difference between the two. Thus, even though threat-related contextual cues are incorporated into one's perception of social scenes, such is executed irrespective of one's anxiety level. It is hard to directly compare our results with Sussman and colleagues (2016), since the latter study made no comparison between fearful and neutral cues in terms of perceptual sensitivity, and did not explore any criterion related effects. Furthermore, they showed that trait anxiety was a strong moderator of perceptual sensitivity, something our findings did not support. All things considered, it seems clear that future studies are still warranted before any concrete conclusion can be drawn. This is especially the case if we further account for how fearful faces were mostly interpreted as surprise in the study presented here (Study 3). Although already briefly discussed in Chapter IV, it is worth adding that if interpreted entirely as surprise, one cannot safely regard that this was indeed a threat-signaling prime. Instead, despite still signaling the occurrence of threat (as evidence by the bias elicited by this facial expression), it is not, by itself, a direct danger signal, as is the case with angry expressions or faces truly interpreted as fearful (Öhman et al., 2012; Wieser & Keil, 2014).

In both studies, gaze data concerning the visual exploration of contextual cues was also collected, in an attempt to complement the behavioral results. Some specific differences in visual exploration between safe and threat of shock conditions were found, albeit not entirely consistent between studies. In Study 2, we saw that during states of anxiety we spend a similar time exploring areas containing potential contextual cues, as when we are under safety conditions. Nonetheless, this was not the case with Study 3, with participants dwelling longer over the cue area, thus taking more time to actually focus on the to-be-identified central target. As suggested in this latter study, it is possible that the presence of a potential threat-related stimulus on the cue area might have resulted in slowed disengagement from this area. This would be aligned with the literature that shows impaired disengagement from threat in both high trait anxiety individuals (Massar et al., 2011), individuals with ADs (Goodwin et al., 2017; but see Yiend et al., 2015) and healthy individuals when faced with unpredictable threats (Sarapas et al., 2017). However, we cannot discard the possibility that a slower orientation to the central action was due to other factors, such as difficulties in retrieving the meaning of the cue, or deterrence/avoidance in orienting towards the possible threat shown in the central action. Disentangling these possibilities is not feasible given the current experiments and will require future investigations.

Another finding concerned shorter fixation times exhibited during threat states seen in Study 2 but not in Study 3. As mentioned in the discussion of the former, these shorter fixation times when exploring our visual fields has been report in some cases of high-trait and state anxiety (Murray & Janelle, 2003; Wilson et al., 2009). It is possible, as argued in the discussion of Study 3, that the smaller region of interest associated with the cue in that study (compared to Study 2) might have prevented any anxiety-driven decrease in fixation time from being pronounced enough. Regardless, this assumption is something that, once more, should be considered and expanded on in future research.

In sum, these two experiments showed that we can aptly make use of social cues in giving meaning to ambiguous social scenes regardless of whether we are anxious or not. It might be the case that more automatic perceptual processes might reveal a different picture, something that future research should look into. Furthermore, no consistent differences in visual exploration patterns over areas containing contextual cues is apparent between safety and anxiety states. Taken together, this supports the conclusion shared at the beginning of this paragraph, suggesting that both extraction (visual exploration of cues) and usage of priors seem intact during states of anxiety.

Strengths and potential practical implications

One of the main goals of this thesis was always to transpose more fundamental research concerning visual perception during anxiety into more practical (i.e., life-like) paradigms. Specifically, the studies investigating sensory-perceptual processes and use of priors in anxiety had almost entirely been done with EEG measures and with basic paradigms (e.g., measuring MMN processes to deviant sounds). The goal here was to try and capture these same processes using experimental paradigms that more closely reflect real-life scenarios. As such, social scenes involving approaching strangers, aggressive gestures towards the viewer and others and simple interactions between two people were used. Although still detached from truly real-life examples (e.g., conducted in a lab and depicted in video), these scenarios are more representative of such real-life social encounters. For instance, we may find ourselves trying to assess if an individual walking in a dark alley is approaching or going away from us (Study 1). Another example might be when we try to assess if a person is preparing to display aggressive behaviors by means of body gestures and actions (Study 4), or how to interpret (e.g., "is this a real threat or are they playing around?") two individuals acting aggressively towards each other based on other group members (Study 3). Lastly, Study 2 showed an example of how we gather contextual cues from other people's behavior to anticipate and give meaning to other's actions. Of course, trying to investigate such phenomena with these more "realistic" paradigms brings about its own difficulties (e.g., representativity of the gestures, unknown confounders in the actions), some of which were, as mentioned in the topic below, not fully controlled for. Nonetheless, these efforts, I believe, are surely useful in bringing more elementary findings (e.g., increased MMN under anxiety Cornwell et al., 2007, 2017) outside of the lab (or at least "closer to the door").

Another strength of the research depicted here concerns how it addresses transitory (i.e., normative) states of anxiety, a feature that, as shown in Chapter I, is still markedly understudied compared to pathological and even high-trait anxiety (Robinson, Vytal, et al., 2013). Given how frequent anxiety is experienced in the overall population, trying to measure its effects over social perception was also a fundamental goal of this thesis. These effects could range from beneficial effects (e.g., "are we more capable of quickly detecting threat in our visual environment?") to impairments (e.g., "are there difficulties in using contextual cues?" or "do we more erroneously perceive the more threat-related outcome?"). Indeed, very little, to no, research has been done on these questions, even when more basic research suggests such potential consequences.

Lastly, one important aspect of this project was to try and steer way from using only faces, a typical norm when assessing social perception, and using other social stimuli that also carry a wealthy portion of socially-relevant information – i.e., body gestures/actions. It is clear, by the amount of research surrounding it, that the vast majority of the scientific literature related to social perception is predominantly dependent on facial expressions (e.g., Little et al., 2011; Todorov, 2012). Furthermore, these are often simply used as static stimuli, lacking the critical feature of motion, making this stimulus even less real and life-like (Calvo et al., 2016; Krumhuber et al., 2013; Mayes et al., 2009). Here, we used body gestures and facial expressions, relying on dynamic motion transmitted via PLDs. It can be argued that using real videos (e.g., actors or even real-life situations) might have proven to be a better way to properly assess how we behave in our daily lives, making our findings more ecologically valid. Regardless, it is obvious that the amount of potential confounds (e.g., certain clothes, body types, attractive features of the individuals) could easily contaminate the results. The intent with this project was always to, as mentioned before, study perceptual processes elicited from anxiety using more realistic examples/paradigms. Nevertheless, it is still up to future studies to continue to evaluate this using more representative and real-life situations, bridging the fundamental and translational sides of psychology and discovering more tangible real-life consequences of anxiety.

The aforementioned strengths alongside our findings allow some more direct, even if brief, practical implications to be discussed here. Specifically, the picture painted in this project helps to show, in alignment with previous studies, that anxiety carries beneficial changes, allowing us to more aptly detect and isolate threat-related actions/gestures. Indeed, this attests to the benefits of normative anxiety states during potentially dangerous social situations, where being able to quickly identify threat is of utmost importance. Thus, we demonstrate how feelings of anxiety, albeit a negative experience, are a valuable tool even in social settings where threat is possible. Furthermore, we show that under anxiety we still appear not to be subject to increased tendencies to perceive threat in an exaggerated manner, nor do we experience any impairments in using contextual cues to infer meaning and anticipate behavior. Ultimately, this hints at how states of anxiety by themselves carry no clear hindrances towards social perception. Nonetheless, since these constitute null findings, it is still early to reach such conclusions. Moreover, other side effects of anxiety (e.g., worry about a specific threat or a potential panic attack) might still affect perception by disrupting one's attention over the social scene (Verkuil et al., 2009).

Limitations and future studies

Aside from the individual limitations raised in each specific study, it is also important to highlight more general limitations that cover all (or most) studies presented here. A first limitation concerns how anticipatory threat and safety were induced, particularly, in how (and if) these two distinct states were truly separated and not, to put it more directly, slightly overlapping. Put simply, it is possible that safe blocks might not have been a) entirely viewed by the participant as safe and b) not experienced without some threatening anticipation in regard to expected upcoming threat blocks. Concerning the former (a), it is possible that the experiments that used threat of shock (Study 1c, 2, 3 and 4) might have led participants to feel that they might be at risk of shock even during safe blocks, despite being told so otherwise. This could be due to the fact that, although informed that no shock would be delivered, they remained connected to the device used to deliver the electric shocks during these safe blocks (i.e., electrodes remained placed in their arm and were not removed). Indeed, at least one study has come to shed some potential caution regarding such practice (Grillon & Ameli, 1998). Nevertheless, having the electrodes connected to the participant across the whole experiment was still proven to be advantageous since repeatedly disconnecting and reconnecting the participant would require some additional time, the implementation of safety checks and possibly moving the participant (a problem for experiments using eye tracker). Moreover, this decision was based on the vast majority of other studies who, in the same manner, did not disconnect the electrodes from the participant during safe blocks (e.g., Cornwell et al., 2017; de Voogd et al., 2022; Robinson et al., 2011). To the best of my knowledge, only one study did, in fact, remove any connection between the participant and the device responsible for the electric shocks during safe blocks (Shackman et al., 2011). Despite this possibility, in the experiments reported here that used threat of shock, the anxiety subjective ratings at the end of each block indicated that feelings of anxiety were always vastly lower than during than those felt during threat blocks. However, the overall average anxiety ratings across all experiments during safety blocks were still above 0, which, although partially expected, does support the concern discussed here. It is worth pointing out that this (above 0 anxiety rating given to safe blocks) was also seen in Experiment 1b (Chapter II), where anxiety was induced via screaming sounds, even though, since the headphones were removed during the safety blocks, we were able to confirm that participants were assured that no aversive outcome would happen. Notwithstanding if this concern was, or was not, an impactful negative influence over our experiments, this matter should be of consideration in future experiments.

This brings us to the second point (b), where I argue that it is plausible that some threat anticipation was experienced during safe blocks. Following the vast majority of studies using threat of shock (e.g., Grillon et al., 2017; Robinson et al., 2011), our experiments were divided between 6 (Study 2 and 3) to 8 (Study 1c) alternating safe and threat blocks (with the exception of Study 4). This, however, could have led to some participants performing safe blocks while consciously anticipating upcoming threat blocks. As a result, they could have experienced some anticipatory anxiety, even though they were not, at that exact moment, at risk of receiving electric shocks. Indeed, some experiments induce anxiety by means of informing the participant of an upcoming oral evaluation or presentation that they must perform after the main task (e.g., Starcke et al., 2008; Wieser et al., 2010). This exact principle could be said to be applicable in our case, leading to safe blocks being associated with feelings of anxiety, even if to a lesser extent than those experienced during threat blocks. It is possible that having just one big safety and threat block would have helped to mitigate the potential problems raised in this and in the previous paragraph. Regardless, this would entail its own problems (e.g., habituation effects). A more ideal solution would thus be to use a between-subjects design, making half of the participants only experience safe blocks and the other half experience only threat blocks. Despite being considered in the initial planning phase of this thesis, this would entail the necessity of bigger sample sizes (see Brysbaert, 2019), a difficult endeavor considering the anxiety-inducing nature of the task.

Other shared limitations, which were already briefly mentioned in some studies, should be further acknowledged in this section. One of such limitations entails the power analyses surrounding the expected effect sizes from the perceptual phenomena we were exploring. Given the absence of similar research investigating perceptual effects when under anxiety, we chose (estimated) our minimum sample size (given a power of .8) with either 1) reference tables (Brysbaert, 2019) or simulations based on expected means and standard deviations (Lakens & Caldwell, 2021). Both methods were adjusted to be able to capture medium to high effect sizes ($d \sim 0.4$ and/or partial η^2 between 0.9 and 1.9), but not necessarily low effect sizes. Although possibly missing smaller effects (even medium ones in certain experiments) these effect sizes, and subsequent minimum samples, were adopted considering the nature of the task (use of electric shocks), which led to difficulties in recruitment. This latter justification, however, does not invalidate this limiting factor, which should be considered when interpreting our final conclusions.

Importantly, the limited stimuli availability might also have posed a significant contribution to a less than ideal statistical power of some of the studies presented here. This was a reflection of two specific factors. Firstly, the reduced number of stimuli used overall (and per condition). Secondly, in some experiments (Study 2, 3 and 4), each stimulus was uniquely bound to one condition, without the possibility of adapting such stimulus to be present in both condition (e.g., saying hello in a neutral and in an aggressive manner). Taken together, this results in a less than optimal design, with a potentially significant reduction to the true statistical power of the experiments (see Westfall et al., 2014 for a more thorough explanation). Nonetheless, stimuli availability was a constraint without a viable workaround (given time and budget limitations), and efforts were made to, at least, add some variability to each stimulus (different noise and limited life-time technique versions), as well as to provide a sufficient number of trials (whilst also accounting for possible fatigue effects).

Considering the above-mentioned limitations and the examples concerning future studies highlighted in each study and in this discussion, I would like to add a few more general, as well as concrete, ideas for future work. When inducing anticipatory anxiety, future studies should strive to understand if safe conditions were truly experienced as safe, aside from mere subjective anxiety ratings. One way to achieve this might be through the use of electrophysiological data (such as from electrodermal activity), which provides a more objective way to assure that threat of shock and safe blocks were experienced differently in terms of physiological arousal. Ideally, to ensure that no anticipation of upcoming shock is felt, perhaps the researcher could opt for a between-subjects design, where one group would be exposed to shock, whilst the other would always remain safe (no shocks). This would require an increased sample size (a potentially difficult achievement given the anxiety-inducing nature of the task), but might provide more pure control counterparts (i.e., truly safe scenarios). Adding to this, sample size and, particularly, variety of stimuli, should be increased in future studies for the purposes of more robust generalizations and better statistical power. Future studies should also account for how different response time-windows might better capture perceptual shifts (i.e., favored sensory-input over expectations) present during states of anxiety. For this, they could manipulate how quick decisions or accuracy is valued in a task, as well as limiting the time given towards decisions. Using clinical populations, such as individuals with GAD or PD, and comparing those to healthy individuals under threat of shock and safe conditions, might also help to show if the findings described here are also present in pathological states. Lastly, using clearer contextual cues, such as video backgrounds, could also be a viable alternative in determining the use of expectations during threat. For example, both FTV biases (Study 1) as well as the identification of aggressive behaviors (Study 3 and 4), could be coupled with more threat-related (e.g., dark street alley, boxing ring) or more neutral backgrounds (e.g., busy street, coffee shop).

Final remarks

To sum up, our objective was to shed light on the possible consequences of anxiety, both positive and negative, regarding how visual perception takes place in different social settings. Ultimately, our findings showed an overall positive picture, with anxiety creating a facilitatory effect in the form of increased perceptual sensitivity towards the identification of threats in social settings. This finding aligns with, and expands on, previous, more elementary research, transferring and capturing the effects of enhanced sensory-perceptual mechanisms seen during anxiety over into tasks that are closer reflections of our daily experiences. Although during anxiety certain negative consequences were also expected to be observed, either taking the form of exaggerated threat biases or inability to properly integrate external cues during perception, no such effects were observed. Some explanations were brought forward when interpreting these unexpected results, but the overarching conclusion was that more research is needed before we can safely generalize these findings. Overall, considering the strengths and limitations of this project, it is fair to say that these findings and conclusions broaden our understanding of anxiety but should, crucially, prompt future studies to expand on them whilst also mending their potential weaknesses.

CHAPTER VII

References

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CHAPTER VIII

Appendix

Supporting material for Study 1

Appendix A – PLW pilot study

A pilot study (N = 29) was conducted where participants were asked to identify the direction PLWs across multiple videos. Participants had the full pool of depth levels (25) available to them (ranging from -12 to +12). Each participant started with level 0 and based on their answer, the task automatically showed the next level on the list (staircase procedure). In this case, if they selected "approaching" the next level would be one where more cues towards receding motion were present (i.e. level -1). The reverse was seen if they selected "receding" as their answer. The task ended after 75 trials had been completed.

When computing means and establishing data distributions, only the data after the first reversal was accounted for. Based on number of visits per level, as well as number of reversals in each level, we established the most ambiguous set of levels, which were used in the task described in this study (see Figure 7 below).

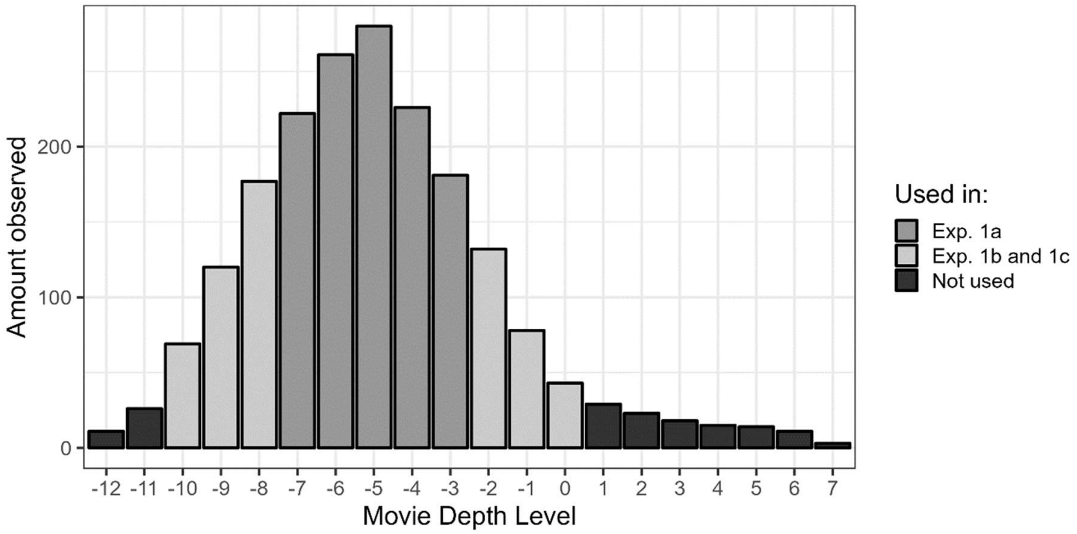

Figure 7. Distribution of "visits" to each level by all participants. The fill color of each bar shows the levels that were selected either for Experiment 1a, 1b and 1c. The darker levels were not selected/used in any Experiment.

Appendix B – Vignettes

The vignettes used in this study were validated as part of a bigger data set that comprised different types of contexts (animal and social) and different threat levels (threat and safe). The safe version of the vignettes was created by replacing the potentially threatening event with a neutral one. In this study, only vignettes related to social scenarios were used (N = 24). The vignettes were validated on a sample of 54 participants (39 men), with each participant rating only 16 (randomly selected) vignettes. These vignettes were rated on their threat level, with participants using a 0-100 slider to report their imagined threat level in each scenario (non-threatening to threatening; see Figure 8 below).

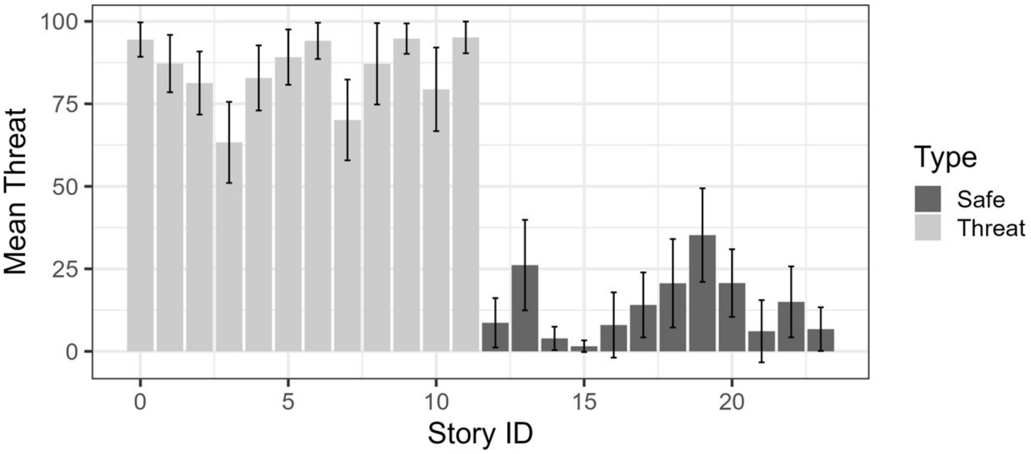

Figure 8. Mean threat rating for each story according to the type of story (threatening vs neutral/safe story). Error bars represent ±1 SD.

Appendix C – Bayesian analyses

We performed additional Bayesian analyses in all of our experiments to further elaborate on the level of support given by our data (and priors) to the null hypothesis. These analyses were performed in R with the brms package (Bürkner, 2017). Our prior choice was a Cauchy distribution ($x_0 = 0$, $\gamma = 0.2$), with a sensitivity analysis supporting the robustness of this prior choice. A total of 2000 iterations, with a 1000 iterations burn-in period, was used. The convergence of the chains was assessed visually (trace plot inspection) and by calculating the Gelman-Rubin statistic. Bayes factors were computed using the bayestestR package for R (Makowski et al., 2019). Below we present the estimates for each model (regarding each individual experiment), alongside the bayes factors (BF).

Table 1. Bayesian analysis' population-level effects for Experiment 1a.

Parameter	Est.	Est. Error	95% CI	Rhat	BulkESS	TailESS	BF_{01}
Intercept	0.48	0.25	[0.01, 0.96]	1.01	947	1780	0.33
Vignette	0.03	0.21	[-0.39, 0.45]	1.00	2331	2260	2.95

Table 2. Bayesian analysis' population-level effects for Experiment 1b.

Parameter	Est.	Est. Error	95% CI	Rhat	BulkESS	TailESS	BF_{01}
Intercept	-0.08	0.08	[-0.24, 0.09]	1.00	1204	1466	3.82
Block	0.11	0.07	[-0.04, 0.25]	1.00	2801	2842	2.57

Table 3. Bayesian analysis' population-level effects for Experiment 1c.

Parameter	Est.	Est. Error	95% CI	Rhat	BulkESS	TailESS	BF_{01}
Intercept	0.08	0.09	[-0.1, 0.27]	1.00	605	1244	3.98
Block	0.06	0.07	[-0.08, 0.19]	1.00	2078	2290	6.54

Appendix D – Anxiety scores in Experiment 1a

Below are the distributions of anxiety scores obtained in Experiment 1a. Additionally, scatter plots are presented to graphically depict the relation between these and adjusted PLW level as well as FTV bias scores.

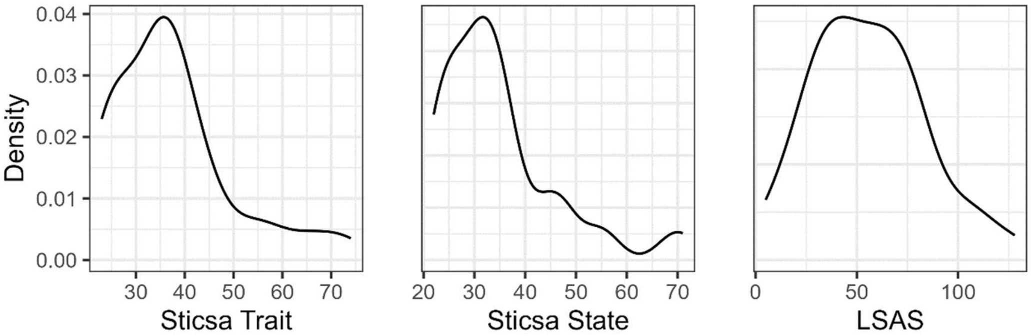

Figure 9. Distributions of the several anxiety measures (STICSA-Trait, STICSA-State and LSAS) in the sample of Experiment 1a.

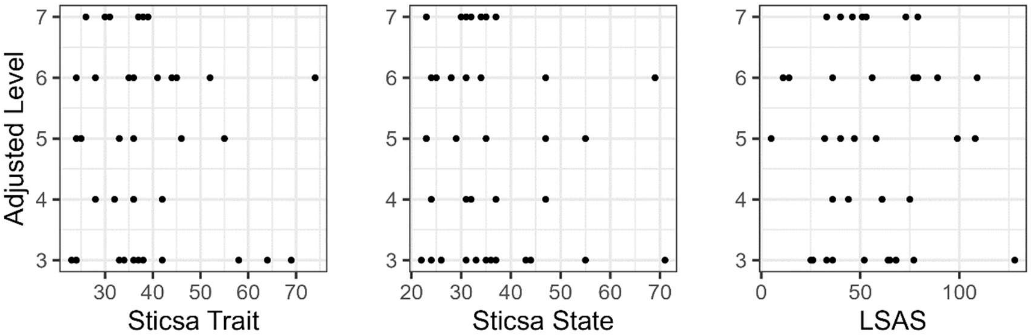

Figure 10. Scatter plot between adjusted level (based on the initial calibration task) and the several anxiety measures (STICSA-Trait, STICSA-State and LSAS) in Experiment 1a. No correlation was statistically significant (p > .05).

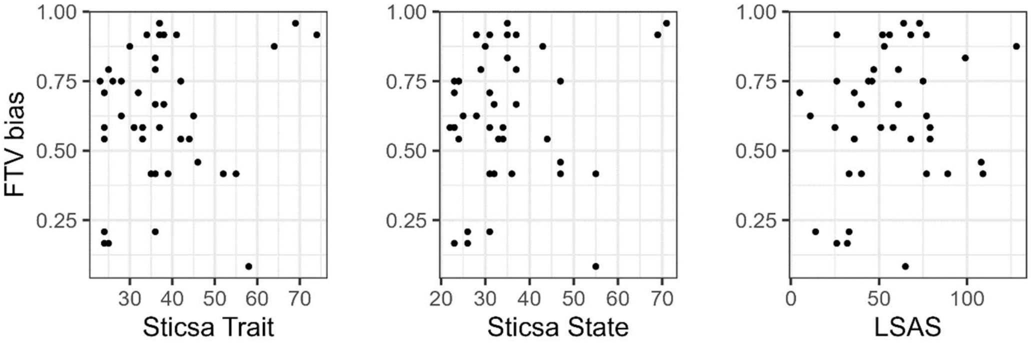

Figure 11. Scatter plot between observed FTV bias (across all conditions) and the several anxiety measures (STICSA-Trait, STICSA-State and LSAS) in experiment 1a. No correlation was statistically significant (p > .05).

Appendix E – Anxiety scores in Experiment 1b

Below are the distributions of anxiety scores obtained in Experiment 1b. Again, scatter plots are presented to graphically depict the relation between these and adjusted PLW level as well as FTV bias scores.

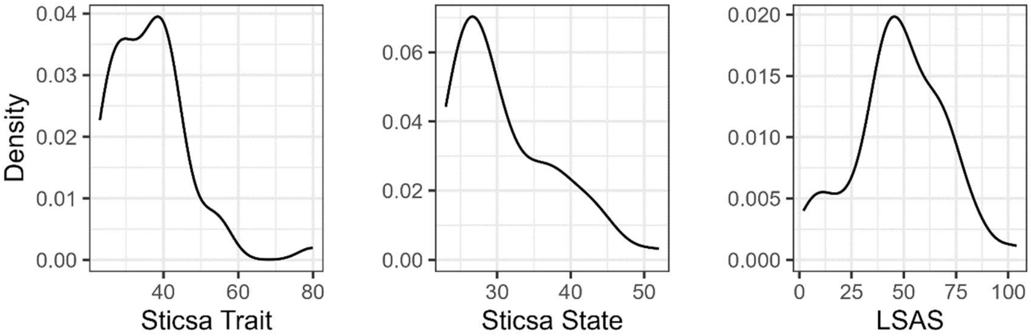

Figure 12. Distributions of the several anxiety measures (STICSA-Trait, STICSA-State and LSAS) in the sample of Experiment 1b.

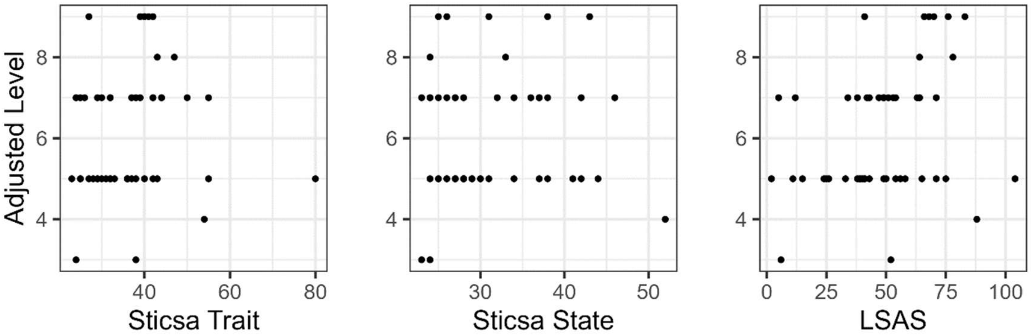

Figure 13. Scatter plot between adjusted level (based on the calibration task) and the several anxiety measures (STICSA-Trait, STICSA-State and LSAS) in Experiment 1b. No correlation was statistically significant (p > .05).

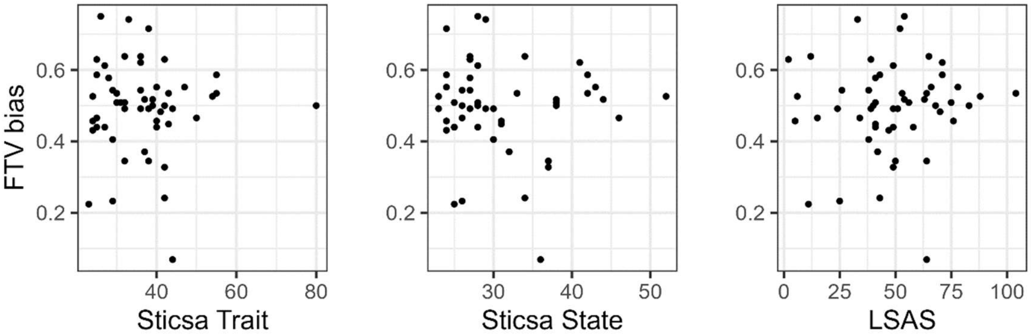

Figure 14. Scatter plot between observed FTV bias (across all conditions) and the several anxiety measures (STICSA-Trait, STICSA-State and LSAS) in Experiment 1b. No correlation was statistically significant (p > .05).

Appendix F – Anxiety scores in Experiment 1c

Below are the distributions of anxiety scores obtained in Experiment 1c. Again, scatter plots are presented to graphically depict the relation between the FTV bias scores. No adjusted FTV is presented given that no calibration (depth level adjustment of the PLW) was performed in this final experiment.

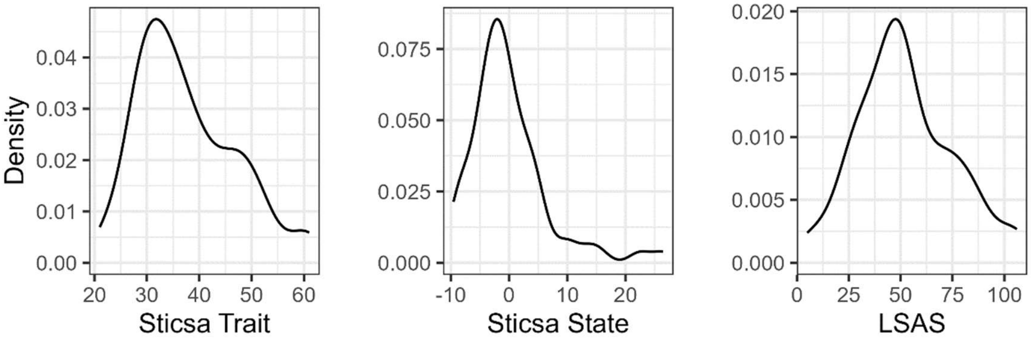

Figure 15. Distributions of the several anxiety measures (STICSA-Trait, STICSA-State and LSAS) in the sample of Experiment 1c.

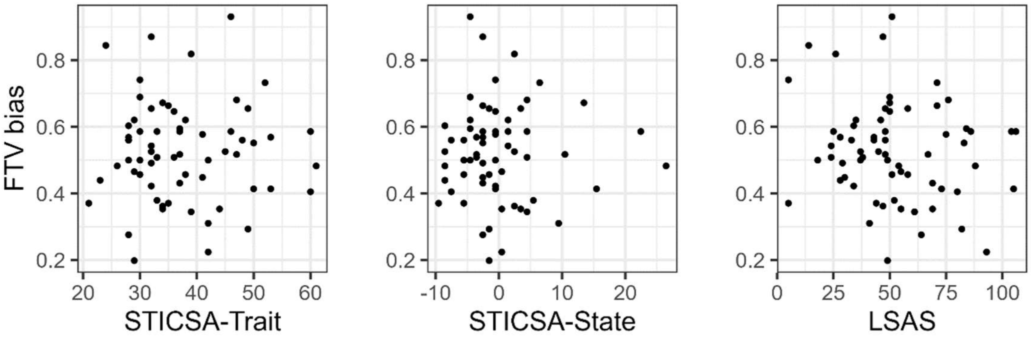

Figure 16. Scatter plot between observed FTV bias (across all conditions) and the several anxiety measures (STICSA-Trait, STICSA-State and LSAS) in Experiment 1c. No correlation was statistically significant (p > .05).

Supporting material for Study 2

Appendix A – End questions

A graphical exploration (Figure 7) of the questions asked at the end of the experimental task regarding 1) to what extent the participant used cues from agent A to infer the presence of agent B (0 – "Not at all" to 100 – "A lot") and 2) how much the participant thought agent A and B's actions were related (0 – "Not at all" to 100 – "A lot"), is shown below.

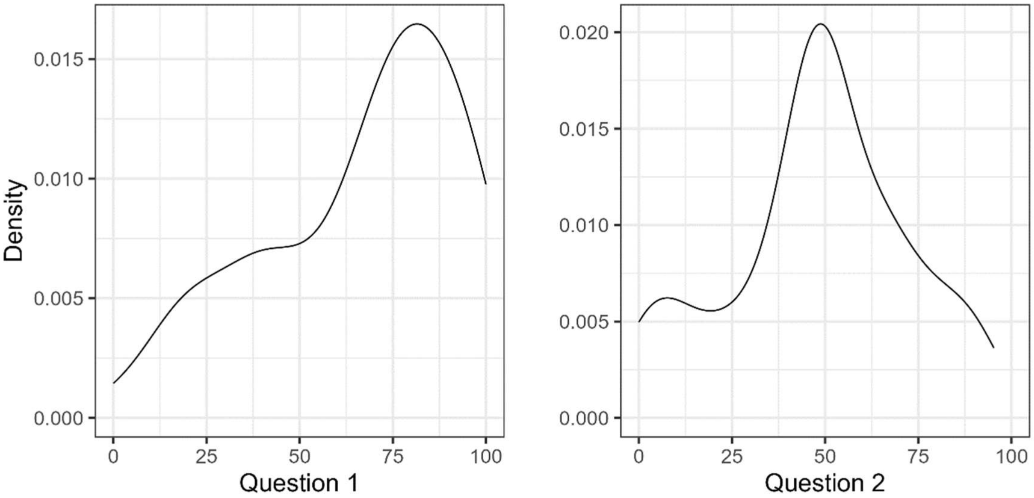

Figure 7. Density distributions of all responses in the last two questions. The left plot represents the first question regarding the extent to which participants used cues from agent A to infer the presence of agent B. The right plot shows the second question concerning how much the participants though agent A and B's actions were related.

Appendix B – Bayes Factor analysis over criterion and sensitivity

We conducted Bayesian analyses over our criterion and sensitivity measures, independently. We used the brms package (Bürkner, 2017) in R. For each, block type and action type were used as predictors. We chose non-informative priors for intercepts (Cauchy distribution with $x_0 = 0$ and $\gamma = 0.2$) and betas (Cauchy distribution with $x_0 = 0$ and $\gamma = 0.5$), with a sensitivity analysis supporting the robustness of this prior choice. We used 2000 iterations with a burn-in period of 1000 iterations. The convergence of the chains was assessed visually, through a trace plot inspection, and by calculating the Gelman-Rubin statistic. Bayes factors were computed using the bayestestR package for R (Makowski et al., 2019). Below the estimates and other statistics from both models (criterion and sensitivity) alongside the Bayes Factors are presented.

Table 1. Bayesian analysis for the criterion data. Each line represents each parameter of the final model.

Parameter	Est.	Est. Error	l-95% CI	u-95% CI	Rhat	BulkESS	TailESS	BF_{01}
Intercept	0.17	0.07	0.012	0.31	1.00	2935	3208	0.97
Block	0.03	0.10	-0.18	0.22	1.00	2686	2799	6.25
Action Type	0.31	0.10	0.11	0.51	1.00	2652	2727	0.08
Block * Action Type	-0.03	0.14	-0.31	0.24	1.00	2345	2541	4.9

Table 2. Bayesian analysis for the sensitivity data. Each line represents each parameter of the final model.

Parameter	Est.	Est. Error	l-95% CI	u-95% CI	Rhat	BulkESS	TailESS	BF_{01}
Intercept	0.53	0.1	0.33	0.73	1.00	3171	3013	0.001
Block	0.04	0.14	-0.22	0.31	1.00	2797	2709	4.425
Action Type	0.11	0.14	-0.16	0.4	1.00	2839	2927	3.413
Block * Action Type	0	0.18	-0.38	0.36	1.00	2434	2628	3.718

Appendix C – Time spent on agent A

The image below (Figure 8) represents the distribution of time spent looking at agent A during the first two seconds of every trial across participants.

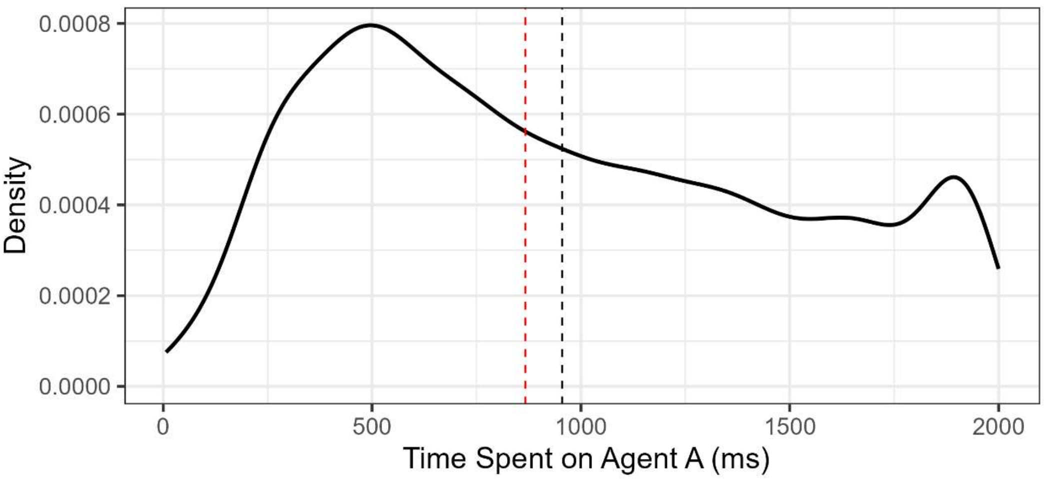

Figure 8. Distribution of time spent gazing at agent A during the first two seconds. Data represents all trials and all participants. The red line represents the median and the black line represents the mean.

Supporting material for Study 3

Appendix A – Bayesian analyses

Below we display the full result for the Bayesian analyses conducted for sensitivity, criterion, and response time measures. These analyses were performed in R with the brms package (Bürkner, 2017). We chose non-informative priors for intercepts (Cauchy distribution with $x_0 = 0$ and $\gamma = 0.2$) and betas (Cauchy distribution with $x_0 = 0$ and $\gamma = 0.5$). A total of 2000 iterations (1000 burn-in period) were used in each model. The convergence of the chains was assessed visually (trace plot inspection) and by calculating the Gelman-Rubin statistic. Bayes factors were computed using the bayestestR package for R (Makowski et al., 2019).

Table 3. Bayesian analysis of sensitivity.

Parameter	Est.	Est. Error	l-95% CI	u-95% CI	Rhat	BulkESS	TailESS	BF_{01}
Intercept	0.65	0.09	0.48	0.82	1	3228	3236	<0.001
Block	0.05	0.12	-0.18	0.31	1	2526	2598	5.1
Face Emotion	-0.02	0.12	-0.25	0.21	1	2808	2830	5.21
Block * Face Emotion	0.03	0.17	-0.31	0.35	1	2366	2633	3.66

Table 4. Bayesian analysis of criterion.

Parameter	Est.	Est. Error	l-95% CI	u-95% CI	Rhat	BulkESS	TailESS	BF_{01}
Intercept	-0.17	0.06	-0.29	-0.05	1	2650	2982	0.282
Block	-0.03	0.08	-0.20	0.48	1	2478	2943	6.17
Face Emotion	0.32	0.08	0.16	0.48	1	2304	3163	0.014
Block * Face Emotion	0.07	0.12	-0.16	0.29	1	2050	2812	4.69

Table 5. Bayesian analysis of response times.

Parameter	Est.	Est. Error	l-95% CI	u-95% CI	Rhat	BulkESS	TailESS	BF_{01}
Intercept	2.36	0.07	2.22	2.50	1	2785	3059	<0.001
Block	-0.03	0.10	-0.22	0.16	1	2434	2526	7.19
Face Emotion	0.12	0.10	-0.07	0.31	1	2373	2690	2.9
Action Emotion	0.25	0.10	0.06	0.44	1	2411	2731	0.167
Block * Face Emotion	0.03	0.13	-0.21	0.28	1	2233	2671	4.24
Block * Action Emotion	0.06	0.13	-0.20	0.32	1	2252	2845	4.63
Face Emotion * Action Emotion	-0.08	0.13	-0.34	0.16	1	2288	2765	4.76
Three-way interaction	-0.04	0.17	-0.38	0.29	1	2267	2683	3.65

Appendix B – Final questions

Below we show some graphical analyses of all three final questions. The first (Figure 10) demonstrates the emotion identification rating for each type of facial expression. Each value was averaged across the two viewing positions/sides (left and right). The second graphic (Figure 11) shows the accuracy distribution regarding the identification (aggressive *vs* non-aggressive) of each action observed during the experimental task. Lastly, the last graph (Figure 12) shows the participant's judgement on how the relationship between observer (facial expression) and main action was, or was not, dependent on the type of block.

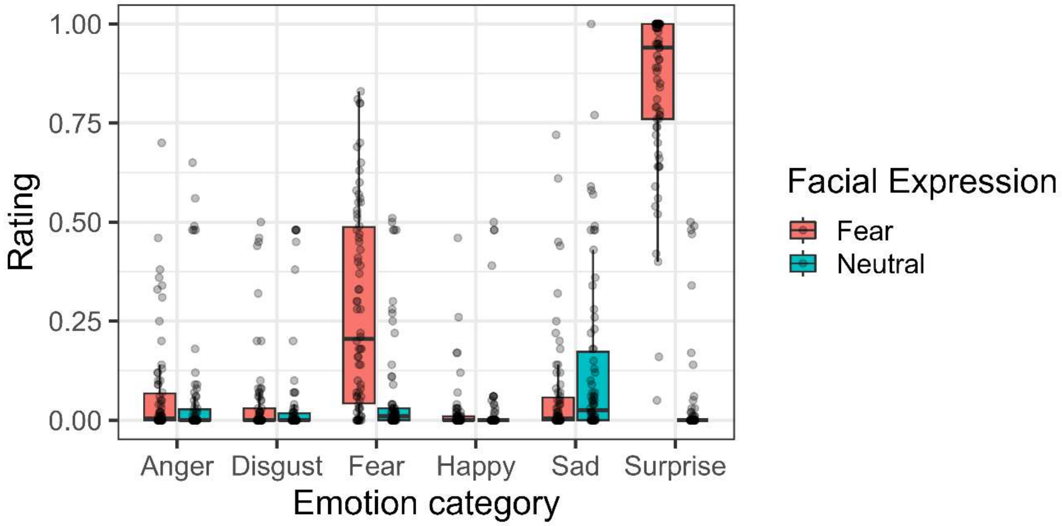

Figure 10. Distribution of ratings across facial expressions (averaged across left/right variants) across six different possible emotions.

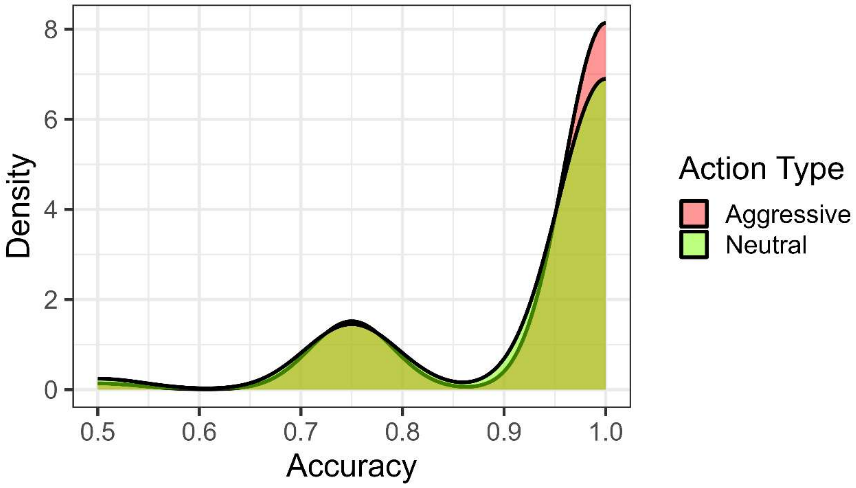

Figure 11. Emotion identification (aggressive vs neutral) accuracy distribution per Action Type.

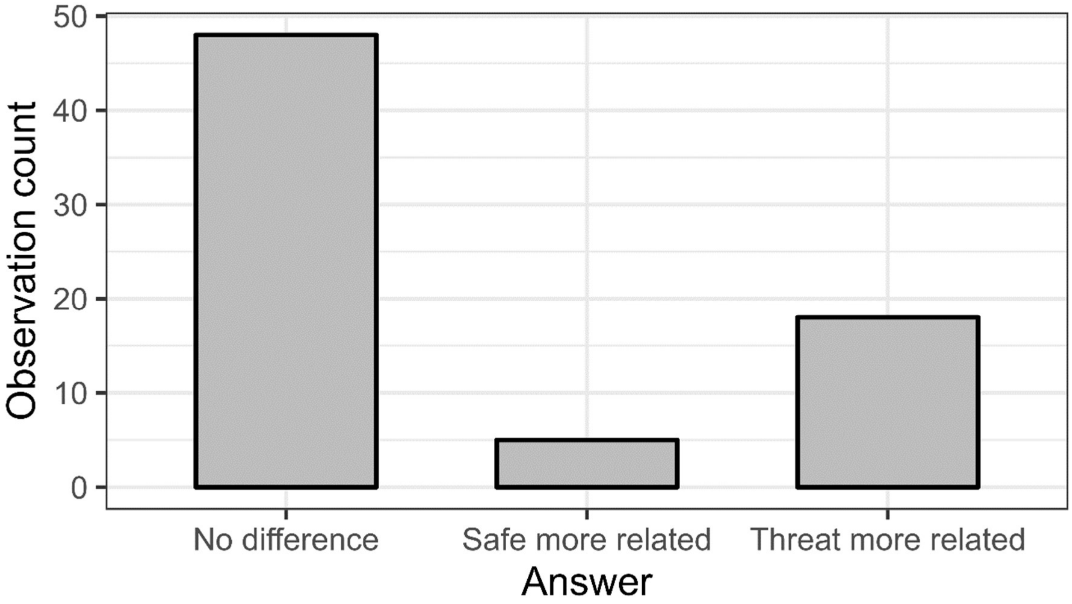

Figure 12. Count of all answers regarding how the observer and main action were related. Participants could either indicate "no difference" meaning the association between observer and main action was the same across conditions, or "safe more related"/ "threat more related" if the actions were more associated in the safe/threat block, respectively.

Appendix C – Attention check

Below (Figure 13) depicts the distribution of accuracy shown by participants when asked to identify if the observer had performed any sort of facial expression, divided by block. These questions would be prompted at random moments during each block (3 per block, corresponding to around 9% of all trials). Participants had only to select "Z" to indicate that the previous shown observer did exhibit a facial expression (i.e., not a neutral face) or "M" to indicate that no facial expression was made by the observer (no time limit).

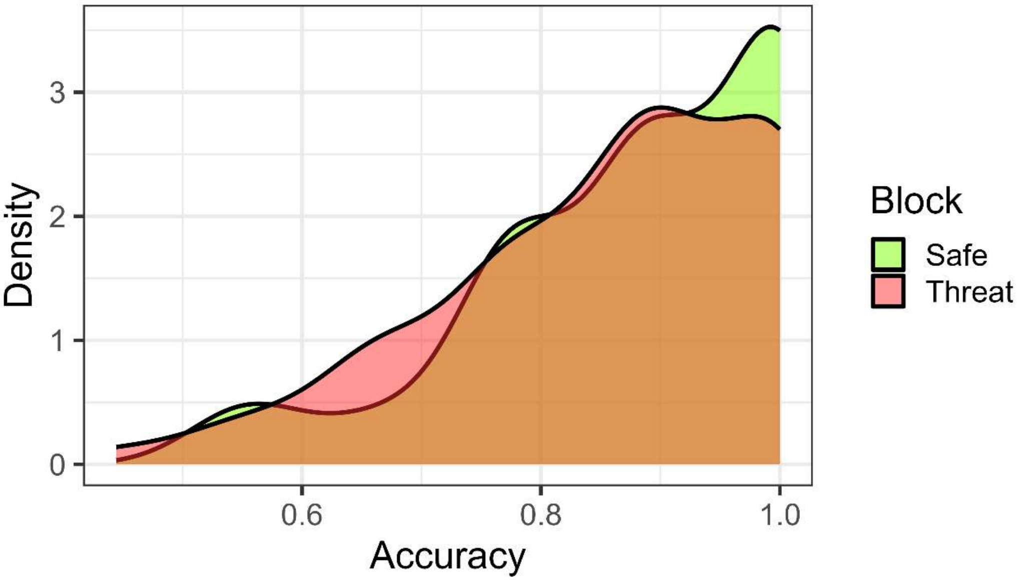

Figure 13. Accuracy distribution for the attention check task across both safe and threat blocks.

Supporting material for Study 4

Appendix A – Final questions

At the end of the task, participants had to indicate how much they thought their response was associated with the delivery of an electric shock, in both Threat R and Threat A blocks. The graphic below (Figure 4) shows the distribution of answers to each question.

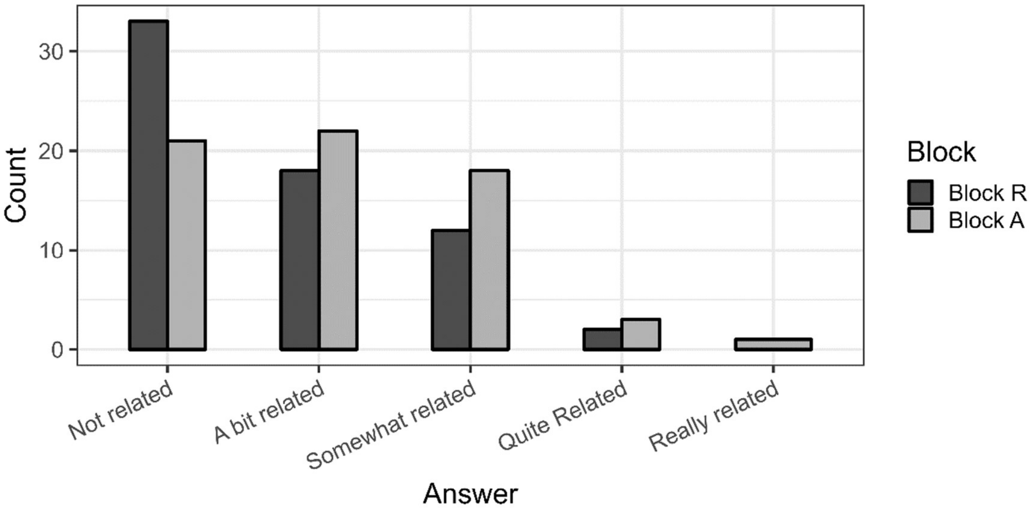

Figure 4. Response count for how participants thought their responses were associated with the delivery of an electric shock during threat blocks R and A.

Appendix B – Recognition task

In one last brief task, participants were asked to identify (as aggressive *vs* non-aggressive) all the actions displayed during the main task, this time without any type of noise. They showed an average accuracy in identifying aggressive actions of 93.8% (*SD* = 1.4%) and an average accuracy in identifying non-aggressive (neutral) actions of 81.9% (*SD* = 2.2%). Below, Figure 4 depicts the distribution of accuracies per type of action.

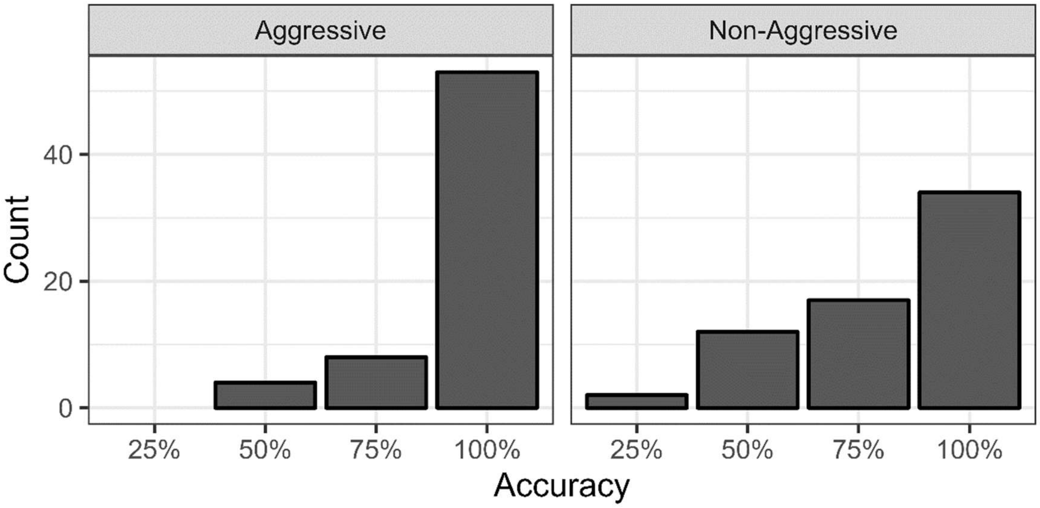

Figure 5. Accuracy distribution among participants per type of action (aggressive vs non-aggressive).