**Avoidance mechanisms in adolescents:**

**behavioral, peripheral and central correlates**

**Introduction**

Anxiety disorders are highly prevalent mental disorders in humans, especially in children and youths (e.g., Penninx et al., 2021). They often develop in childhood or adolescence (e.g., Costello et al., 2005; De Lijster et al., 2017) and have a high risk of chronification if left untreated (Broeren et al., 2013). Exposure therapy, the first-line treatment for anxiety disorders (Bandelow et al., 2021) is highly effective across age (James et al., 2020; Bandelow et al., 2021). However, some studies suggest that exposure therapy might be less effective for younger clients compared to adults (e.g. Rapee et al., 2009). Consequently, recent research increasingly focusses on understanding the mechanisms involved in the development and maintenance of anxiety disorders in children and youths, aiming at enhancing treatment efficacy (Roesmann et al., 2022).

One core feature in the development and maintenance of anxiety disorders is *avoidance* (Craske et al., 2009). While *avoidance* *behavior* mostly reduces anxiety in the short-term, it reinforces long-term anxiety and hinders recovery. Despite its importance, there are few studies which examine the acquisition of avoidance behavior, i.e., avoidance learning, in children and adolescents (see e.g., Scheveneels et al., 2021). The few existing studies hint at that children and youths show increased avoidance behavior compared to adults (e.g., Klein et al., 2021; for review see Pittig et al., 2020) and at that aberrant avoidance learning might constitute a risk factor for later psychopathology (Klein et al., 2021). Given the crucial role of avoidance in anxiety disorders and the general effectiveness of exposure therapy, expanding research in this area seems essential. As an overarching goal, the present study therefore aims at advancing the understanding of avoidance mechanisms in children and adolescents, taking into consideration behavioral and psychophysiological information. In detail, one overarching study addressing three separate research aims is proposed:

1. Gain a better understanding of avoidance behavior in adolescents, and of its modulation by different outcomes (e.g., costly or no-cost avoidance) or individual differences
2. Gain insight into a possible association of *motivated attention* (i.e., the enhanced perceptual processing of motivationally relevant stimuli) and avoidance behavior in adolescents
3. Gain a better understanding of the influence of the *threat context* on motivated attention in adolescents and how this links to avoidance behavior

In the following, the rationale for each of the three research aims will be introduced. Subsequently, the general study procedure will be presented and a more detailed description of the experimental tasks is provided.

*Rationale Aim One: Gain a better understanding of avoidance behavior in adolescents, and of its modulation by different outcomes (e.g., costly or no-cost avoidance) or individual differences*

To understand the functionality of behavioral avoidance, it is important to consider the outcome of avoidance behavior, more specifically, costs and benefits of avoidance (Pittig et al., 2018; Pittig & Wong, 2022). In the decision of an individual to avoid or approach feared stimuli, costs and rewards always conflict with each other. Research suggests that this conflict is associated with the behavioral activation and behavioral inhibition system of individuals (Aupperle et al., 2011; Gray, 1981). An imbalance between approach and avoidance drives, coupled with impaired decision-making, is hypothesized to contribute to the development of psychopathology, particularly anxiety disorders (Aupperle & Paulus, 2010). For instance, if individuals with generally increased behavioral inhibition choose to regularly avoid parties or social get-togethers, they might experience reduced anxiety in the short run, but social insecurities could manifest and result in heightened social anxiety in the long run.

Having in mind that adolescence is a critical time for the onset of social anxiety as well as other mental disorders (Kessler et al., 2005), being able to engage in adaptive approach-avoidance behavior seems especially important in this age group. Adaptive approach-avoidance behavior includes weighing possible costs and rewards that could result from the chosen behavior against each other and going through with the behavioral option that maximizes reward and minimizes costs (Letkiewicz et al., 2023). Despite the importance of adaptive approach-avoidance behavior in adolescence, little research has specifically investigated approach-avoidance conflicts in this age group. Therefore, the *first* aim of the study is to advance the understanding of approach and particularly avoidance behavior towards aversive and neutral stimuli in adolescents compared to adults, when avoidance behavior is associated with different rewards or costs. To investigate avoidance behavior in adolescence, an approach-avoidance conflict (AAC) task will be used, based on the design introduced by Aupperle et al. (2011). In the study, participants were asked to choose a likelihood with which they would experience an appetitive or aversive outcome. Outcomes were indicated by specific cues, i.e., a sun representing appetitive and a rainy cloud representing aversive outcomes. If participants chose a high likelihood for the aversive outcome (i.e., they expressed less avoidance behavior), they increased their chances to win reward points. If participants chose a low likelihood for the aversive outcome (i.e., they expressed more avoidance behavior), they decreased their chance to win reward points. Since possible benefits of avoidance (i.e., avoid the experience of an aversive outcome) conflicted with possible costs of avoidance (i.e., decrease chance to win reward points), participants were faced with an approach-avoidance conflict. Additionally, the amount of cost was manipulated, as possible reward points varied. As outcomes, appetitive and aversive pictures from the International Affective Picture System [IAPS] coupled with a matching sound from free source websites were used. Aupperle et al. (2011a) also measured self-report questionnaires, particularly the BIS/ BAS scale by Carver & White (1994) and the Anxiety Sensitivity Index (ASI) by Peterson & Heilbronner (1987). The researchers were interested (1) in the effect of different levels of reward on approach behavior, (2) gender differences in approach and avoidance behavior and (3) associations to self-report measures. As main results, they found that greater possible rewards led to increased approach behavior. Moreover, they found significant gender differences, as males showed more approach behavior than females. Regarding self-report questionnaires, ASI (Physical subscale) scores related negatively to approach behavior for males, while the BAS (Fun Seeking subscale) scores related positively to approach behavior for females. Also, approach behavior was related to self-reported motivation to gain reward.

As the paradigm by Aupperle et al. (2011a) provides the possibility to manipulate costs and benefits of avoidance behavior and seems sensitive to individual differences, we will use it to investigate avoidance behavior in adolescents. However, in the present form, the paradigm compares avoidance behavior towards aversive with approach behavior towards appetitive stimuli, so that different behavioral outcomes could be attributed either to a difference in avoidance (i.e., evaluation of and behavior towards aversive stimuli) or a difference in approach behavior (i.e., evaluation of and behavior towards appetitive stimuli). Therefore, we will adapt the paradigm to provide a measure of behavior towards aversive stimuli, only. More specifically, participants will now not choose the likelihood for aversive and appetitive outcomes (i.e., cloud vs. sun), but choose the likelihood for aversive and neutral outcomes. Additionally, we will not use symbolic cues to represent outcomes, but outcomes will be represented by face stimuli. Faces represent stimuli relevant in everyday life, playing an important role in human perception of threat and emotion in general as well as processes of behavioral avoidance, which renders them especially useful for our research goal (Willis & Todorov, 2006). Several studies show that angry faces are more frequently avoided than happy or neutral faces (Heuer et al., 2007; Lau & Viding, 2007). Participants will therefore choose a likelihood for aversive or neutral cues (i.e., angry and neutral faces). The angry face will predict a possible aversive **outcome** (screaming angry audiovisual face). However, choosing high probabilities of the aversive outcome will also be associated with a higher probability of winning different amounts of reward points, which renders it a considerable choice (i.e., an approach-avoidance conflict). With this adapted paradigm, we will investigate the influence of age (adolescents vs. adults), varying cost (or reward) and individual differences (i.e., BIS scores) on avoidance behavior towards negative outcomes.

*Rationale Aim Two: Gain insight into a possible association of motivated attention (i.e., the enhanced perceptual processing of motivationally relevant stimuli) and avoidance behavior in adolescents*

Different neurocognitive processes might be associated with avoidance responses towards threatening stimuli. Multiple studies (Carretié et al., 2003; Hajcak & Dennis, 2009; Junghöfer et al., 2001; Schupp et al., 2003; Wessing et al., 2011) using electroencephalography (EEG) or magnetoencephalography (MEG) have shown that emotionally arousing stimuli (e.g., aversive emotional scenes, faces) typically induce stronger electrophysiological responses compared to emotionally less salient stimuli (e.g. neutral scenes, faces), a phenomenon called motivated attention (Lang, Bradley, & Cuthbert, 1997). More specifically, emotionally arousing stimuli frequently induce enhanced negative going amplitudes in posterior EEG sensors during mid-latency time-intervals (around 120 to 300 ms post-stimulus presentation) and enhanced positive going amplitudes in central EEG sensors during later time-intervals (starting around 300 ms post-stimulus presentation). Such enhanced negative going potentials during mid-latency time-intervals and enhanced positive going potentials during later time-intervals have been termed Early Posterior Negativity (EPN) and Late Positive Potential (LPP) (e.g. Junghöfer et al., 2001; Lang & Bradley, 2010; Schupp et al., 2004). With regard to neural processing of facial expressions, research also shows that angry faces elicit stronger electrophysiological responses compared to friendly or neutral faces (Schupp et al., 2004). More specifically, Schupp et al. (2004) observed facilitated processing in EPN amplitudes, emerging approximately 200 ms post-stimulus presentation and peaking between 240 and 280 ms at temporo-occipital sensors. In LPP amplitudes, a facilitated processing was found in the time interval between 400 to 500 ms post-stimulus presentation at centro-parietal sensors. As stated above, these findings are linked to processes of motivated attention, i.e., enhanced sensory processing of motivationally relevant stimuli. Lang et al. (1997) proposed that emotionally relevant stimuli guide or motivate attention in a “natural”, automatic way, since it is of biological importance to utilize attentional resources for potentially threatening stimuli. Several studies found evidence for this hypothesis, in adults as well as in children and adolescents (Hajcak & Dennis, 2009; Wessing et al., 2011)

While motivated attention is a natural and typically adaptive neurocognitive process, attentional biases and altered processing of threat-related stimuli are assumed to be a pathogenic factor in anxiety disorders (Mathews & MacLeod, 2005). Several studies indicate that people with high trait anxiety or anxiety disorder show an attentional bias towards angry faces, as they detect angry faces faster and more frequently compared to healthy controls (Ashwin et al., 2006; Bradley et al., 1999). An oversensitive behavioral inhibition system (BIS) has been found to be associated with trait anxiety and attentional biases (Gray & McNaughton, 2000; Kimbrel, 2008). Furthermore, the relationship between attentional biases and anxiety appears to be complex, as these biases seem to vary, depending on the stage of processing (i.e., early vs. later stimulus processing). Indeed, according to the hypervigilance-avoidance hypothesis, anxious individuals initially orient faster to highly arousing and potentially threatening cues, while they later redirect their attention away from aversive stimuli (Mogg et al., 2004). So far, most evidence for the hypervigilance-avoidance hypothesis is provided in adults, using EEG, MEG or eye tracking (e.g. Pflugshaupt et al., 2005; Walentowska & Wronka, 2012; Weinberg and Hajcak, 2011; Wieser et al., 2009). In children and adolescent populations, findings are fewer and less clear. For instance, Dodd et al. (2015) or Price et al. (2013) found an enhanced vigilance towards angry or fearful faces, respectively, in children and youth with *and* without anxiety disorder, possibly indicating a pattern of hypervigilance towards threatening stimuli in this age group in general. Moreover, while a pattern of hypervigilance towards threatening stimuli is also quite consistently found in anxious children and youth (e.g. Hogan et al., 2007; Seefeldt et al., 2014), support for the avoidance pattern is more limited (for review see Rosen et al., 2019). One MEG study supporting the hypervigilance-avoidance hypothesis in anxious children was conducted by Wessing et al. (2017), who found enhanced amplitudes in early stages of event-related potentials (ERP’s) for aversive versus neutral images, indicating initial hypervigilance, yet diminished differences in later processing stages, suggesting avoidance (Wessing et al., 2017).

(Price et al., 2016) argue that one reason for the mixed findings regarding the pattern of avoidance in children and youth could be that most studies rely on measures of *perceptual avoidance* in the laboratory, i.e.,a relatively automatic and fast form of avoidance, occurring seconds after stimulus onset. This automatic form of avoidance may not be fully developed in youth, indicating the need to look further into measures of avoidance behavior*,* i.e., amore voluntary, planned form of avoidance. Taking this into consideration, the authors used Ecological Momentary Assessment (EMA) to study avoidance behavior, next to an fMRI paradigm to study the pattern of (hyper)vigilance, and could find support for the hypervigilance-avoidance pattern (Price et al., 2016).

To summarize, there are still limited and mixed findings regarding the association of attentional biases and perceptual and behavioral avoidance in children and adolescents. Additionally, the influence of related psychological constructs such as the BIS/BAS system is not yet well studied.

In order to improve research in this area, it is important to look at the general, underlying mechanisms of neural processing of emotional stimuli (i.e., motivated attention) in combination with avoidance. Furthermore, in accordance with (Price et al., 2016), a special asset seems to be the combination of psychophysiological measures with behavioral measures. **Based on the stated research, one could assume that enhanced neural processing of potentially threatening stimuli (i.e., motivated attention) is associated with a** vigilance towards these stimuli. Enhanced vigilance might facilitate the perception of danger, which might lead to an increase in expressed **avoidance** behavior to escape or avoid the perceived threats. Thus, with this research aim, we will investigate the relationship between motivated attention, as assessed by ERPs in the electroencephalogram (EEG), and avoidance behavior, as assessed using the individual avoidance tendencies of the AAC-task described in research aim one. To be able to compare different age groups, we will recruit adults as well as adolescent samples.

*Rationale Aim Three: Gain a better understanding of the influence of the threat context on motivated attention in adolescents and how this links to avoidance behavior*

As stated before, the concept of motivated attention describes the finding that emotional stimuli are preferentially processed compared to neutral stimuli, independent of the *context* in which stimuli occur (Lang, Bradley, & Cuthbert, 1997; Schupp et al., 2006; Vuilleumier, 2005). However, research suggests that the contextin which emotional stimuli are presented additionally influences the neural processing of these stimuli (e.g. Grillon et al., 2004; Klinkenberg et al., 2016). The NPU-task (Grillon et al., 2004; Schmitz & Grillon, 2012) and its adaptations provide a good framework to study the influence of *context* on perceptual processing.

The original NPU-task includes three types of threat contexts (or conditions): a *neutral* context (N-condition), in which participants do not expect a threat; a *predictable* threat context (P-condition), in which a threat, for instance an electric shock, is predicted by a warning cue; and an *unpredictable* threat context (U-condition), in which a threat appears without warning (Grillon et al., 2004; Schmitz & Grillon, 2012).

Predictable threats are assumed to activate *phasic fear,* a short-term, direct response to an *actual present* threat, while unpredictable threats activate *sustained fear*, a longer lasting response towards *anticipated* threat (Alvarez et al., 2011). These fear responses correspond to different phases in the threat imminence model(Hamm et al., 2016). The sustained fear response is associated with the *pre-encounter phase*, in which threat is anticipated, yet not actually present. This phase is associated with heightened vigilance towards our environment and increased physiological arousal, enabling the detection of possible threats (Abend, 2023). The phasic fear response is associated with the *encounter phase*, in which a possible threat is not only anticipated but actually detected, enabling rapid threat evaluation and, if required, consequent defensive behaviors (Abend, 2023). To get back to the topic of avoidance, the encounter phase may regulate approach-avoidance conflicts by evaluating potential threats and ultimately guide defensive behavior (Alvarez et al., 2011). In contrast, the *pre-encounter phase,* which is associated with heightened vigilance in possible threatening contexts (unpredictable threat), is thought to guide more generalized avoidance responses towards these possibly threatening contexts.

A substantial amount of research shows that unpredictable threats induce stronger aversive responses compared to predictable threats in individuals (e.g. Alvarez et al., 2011; Grillon et al., 2004). Additionally, adults with high trait anxiety and especially adults with anxiety disorders show increased sustained fear responses compared to healthy individuals in according experimental conditions (Grillon et al., 2004). With regard to children and adolescents, Schmitz et al. (2011) aimed to study the NPU-paradigm in this age group, adapting their often-used electric shock as a threat with a picture of a screaming lady combined with an air blast, to adjust the threat to this age group. They found elevated startle responses to cues in both the predictable and unpredictable threat condition, yet only girls showed stronger responses in the unpredictable condition, indicating sex differences of sustained fear responses. Building on the study of Schmitz et al. (2011), Nelson & Hajcak (2017) also found that symptoms of social phobia, negative mood and negative self-esteem were related to stronger aversive responses in unpredictable compared to predictable threats in 8 to 14 year-old girls.

Shifting focus back to motivated attention (the enhanced perceptual processing of motivationally relevant stimuli), recent research aimed to examine the perceptual processing of emotional stimuli under NPU-conditions that are *threat-irrelevant*. Indeed, emotional stimuli were used that occurred independently of the concrete threat, which enables a broader view on contextual perceptual processing of emotional stimuli (Klinkenberg et al., 2016). In an MEG study, Klinkenberg et al. (2016), for example, presented neutral and fearful face stimuli in all three NPU-conditions to participants, next to the actual threats in the P- and U-condition. As threat, a short clip of a monster was shown, which occurred independently of the presented neutral and fearful faces. Thus, the focus on perceptual processing of threat-irrelevant emotional stimuli was ensured. The authors found that processing of both negative and neutral stimuli was enhanced during the U-condition compared to the P- or the N-condition, yet, they did not find an interaction between threat context and motivated attention. That is, the enhanced processing of the negative relative to the neutral faces was independent of the context in which the faces were presented. In contrast, Grillon & Charney (2011) as well as Wieser et al. (2010), for example, found an enhanced processing of negative compared to neutral faces in the U-condition compared to the P- and N-condition. With regard to children and adolescent populations, no study so far investigated this adapted version of the NPU-task in this age group. These aspects demonstrate that there are still mixed findings and a general existing research gap regarding the association between motivated attention and threat contexts in both, adult and adolescent populations.

To summarize, the NPU-task is greatly suited to study different fear states, namely phasic fear and sustained fear, and their relation to motivated attention. As both fear states and motivated attention have implications on avoidance behavior (see threat imminence model), the application of the paradigm bears high importance also in the context of avoidance research. So far, research specifically examining the link between emotional stimulus perception in different threat contexts and *avoidance behavior* is missing. Additionally, to the best of our knowledge, there has not been a single study examining this potential link in underage participants, i.e., in *adolescents*. Thus, we aim to investigate emotional stimulus perception under phasic and sustained fear contexts in adolescents and adults using behavioral and central measures. To achieve this, the described study design of the NPU-task by Klinkenberg et al. (2016) will be adapted. Furthermore, we aim to extend knowledge on related concepts of defensive responding, specifically the threat imminence model, by exploring the link to individual behavioral tendencies of avoidant and non-avoidant responding.

**Materials and methods**

The overall methods will be introduced first, followed by a more detailed description of the different experimental tasks. Subsequently, the planned data analyses corresponding to each of the three research aims will be presented.

***Participants***

Healthy adolescents (14-17 years) and adults (25-39 years) will be recruited for the study. In research, there is no clear consensus regarding the end of the adolescent period (Defoe et al., 2015). Some researchers define the onset of adulthood at the typical age of 18 or 19, while others argue that brain development continues until the mid-twenties and consequently define adulthood starting around this age range (Defoe et al., 2015; Giedd, 2010; Mummaneni et al., 2023). To enable a clear distinction between age groups, we have decided to define adulthood as beginning at age 25, which is one of the higher thresholds used in research. To avoid including an overly broad age range of adults compared to adolescents, we will recruit participants no older than 39, an age often referred to in research as young adults (Berk, 2011).

To continue, there should be an approximately equal number of participants for each age group. Both age groups will be balanced for gender and educational background. All participants as well as parental guardians of adolescents need to provide written consent. Afterwards, a telephone screening of participants, and in case of adolescents also of their parents, will be conducted to realize inclusion and exclusion criteria. Exclusion criteria include a current or past mental disorder, (psycho)pharmacological treatment, current or past psychotherapy, neurological or severe somatic diseases and EEG-related exclusion criteria. Furthermore, an IQ-screening or measure of general intelligence will be conducted to ensure an overall matching of cognitive capacities of both age groups. After power calculation using G-Power, a total number of minimum 150 participants (75 adults, 75 adolescents) is required (calculation based on the AAC-task: F-tests, ANCOVA: fixed effects, main effects, interactions, Power 0.8.).

***Overall materials***

**Stimuli.**

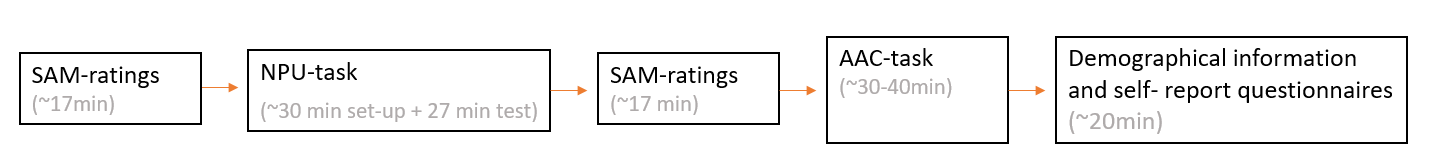
***Face Cues*.** In theAAC-task, 18 neutral and 18 angry faces will be employed as visual stimuli during the decision phase, summing up to 36 faces (18 face identities). In the NPU-task, 28 neutral and 28 angry faces will be included in each of the N-, P- and U-condition, summing up to 168 faces. Ideally, different face identities for all pictures will be used in the NPU-task. Additionally, 20 filler faces (angry and neutral) will be included in each of the U- and P-conditions (see section EEG-assessment for details), summing up to 40 faces (40 face identities). The face identities used in the NPU-task will be different from the ones used in the AAC-task. Overall, a total number of 244 (36 + 168 + 40) face stimuli will be used. Half of the faces will be female, the other male. All faces will be selected from pre-validated data bases (e.g., Karolinska Directed Emotional Faces, KDEF). All pictures will be converted to grayscale and aligned in brightness and size with the remaining pictures.

***Aversive outcome and threat*.** One additional angry face in combination with a scream will be used as aversive outcome in the AAC-task and as threat stimulus in the NPU-task. The angry face and the scream will be selected from pre-validated data bases for faces (e.g., KDEF) or sounds (e.g., International Affective Digitized Sounds, IADS). Individual hearing threshold will be assessed to assure comparable perceived loudness of the audio-visual-stimulus between participants.

***Rewards*.** In the AAC-task, reward points to be earned per trial (0, 2, 4 or 6 points) will be displayed on the starting screen of each trial to manipulate approach-avoidance conflicts. Additionally, the current total score (sum of earned rewards) will be displayed in the reward phase after each trial. If participants earned points in a trial, they will see the newly won points being added to their total score, leading to a new total score. Depending on the total score by the end of the experiment, participants will receive a certain reinforcement (e.g., a gold medal).

***Overall procedure***

Participants will arrive at the lab and give informed consent. Then, self-assessment manikin ratings (**SAM-ratings)** of the 168 face cues used in the NPU (excluding filler faces) will be obtained. This will take approximately 20 minutes (assuming ~5 second duration for valence and arousal ratings per each face and ~5 minute instruction/practice time). Next, the **NPU-task**attentive viewing task will be conducted, while EEG and SCR will be acquired. First, EEG electrodes will be set-up (~30 minutes). Next, electrodes for measurement of skin conductance responses will be placed on the non-dominant hand. Then, the measurement will be performed (total duration ~27 minutes, ~9 minute per condition). Participants will be asked to minimize movement during the task. Subsequently, EEG as well as SCR electrodes will be removed and **SAM-ratings** will be repeated (~20 minutes). After a short break, participants will perform the **AAC-task**. Electrodes for measurement of skin conductance responses will again be placed on the non-dominant hand before the task. Participants will receive an instruction and complete three practice trials, before performance of the actual task (total duration ~40 minutes, ~20 minutes for set-up, instruction and practice, ~20 minutes for completion of the task). Lastly, participants will complete the self-report questionnaires and answer a questionnaire on relevant demographical information. In total, participants will spend around three hours in the lab.

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**Figure 1**: Overview of the overall study procedure. The NPU-task includes EEG and SCR as psychophysiological measures, the AAC-task includes measures of SCR.

***Experimental tasks***

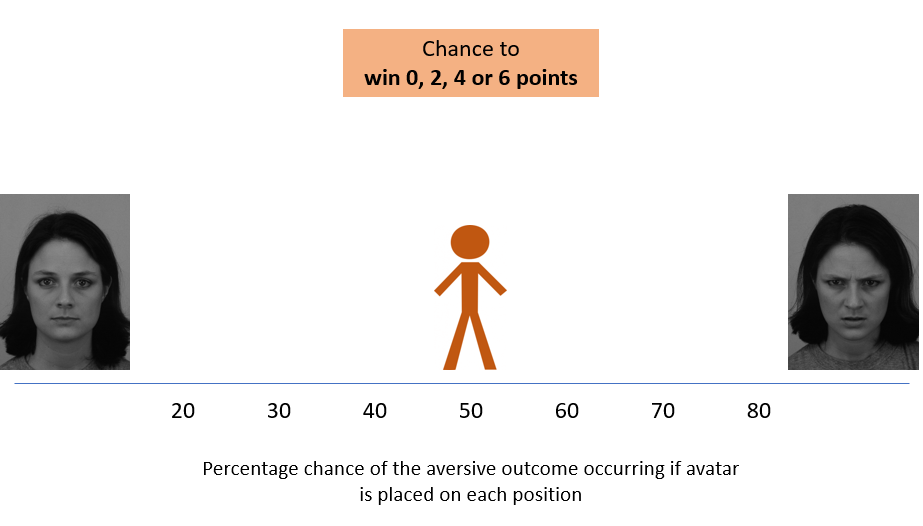
**AAC-task (relevant for Aim One).** In the AAC-task, behavioral avoidance of aversive outcomes is assessed, with the refraining from avoidance behavior (i.e., the execution of approach behavior) being reinforced with varying reward points. Four different reward levels will be experimentally introduced (within-subject factor **reward condition**: 0, 2, 4 or 6 reward points). **Avoidance behavior is defined as a behavioral choice associated with a low likelihood of the aversive negative outcome** to occur (i.e., tendency to choose the neutral facial cues instead of the angry facial cue). By contrast, **approach behavior is defined as a behavioral choice associated with a high likelihood of the aversive negative outcome to occur** (i.e., tendency to choose the angry facial cue instead of the neutral facial cue).

In the beginning of each separate trial, participants will be asked to place an avatar on a position on a runway, with which they can control the likelihood for an aversive outcome (i.e., screaming angry face) to occur or to not occur. The potential aversive (i.e., screaming angry face) or neutral (i.e., absence of screaming angry face) outcomes will be indicated by an angry face or a neutral face, positioned on both ends of the runway, respectively. The angry and the neutral face will correspond to the angry and neutral expression of the same face identity (see figure 2 and 3). The position on which the participants place the avatar will determine the relative probability of the aversive outcome to occur (from left to right: 20% probability of the angry face, 30%, 40%, 50%, 60%, 70% and 80%), corresponding to the seven potential avatar positions ranging from −3 to +3). The avatar will start out at different locations on the runway to control for different levels of effort that participants will put into moving the avatar. The aversive outcome (i.e., screaming angry face) will be the same in each trial.

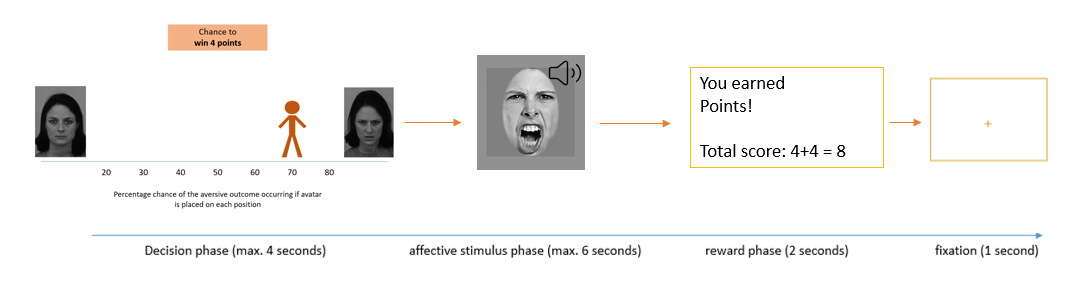
The AAC-task will include a baseline phase and a conflict phase.The baseline phase, including 18 trials, will measure avoidance tendencies, when avoidance is not associated with any costs. In this phase, approach behavior will not be associated with a reward. Thus, it can be considered adaptive to show avoidance behavior, because no costs are associated with it (no-cost avoidance).

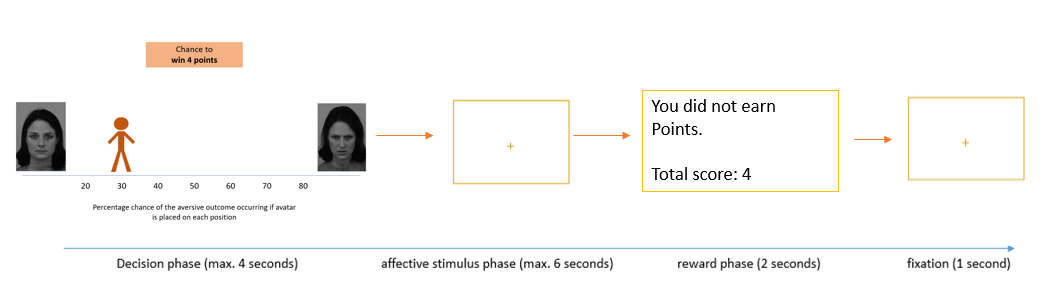
Next, the conflict phase will be administered, in which approach behavior will be reinforced with varying amounts of reward points are presented (54 trials; 18 trials per each of three reward conditions). As in the conflict phase the execution of avoidance behavior will result in a loss of reward points, avoidance behavior can here be considered costly, and thus less adaptive (costly avoidance). The order of trials corresponding to the different reward conditions (2, 4, 6 points) will be randomized within and across participants to counteract mere exposure and learning effects as well as response tendencies. Participants will be informed beforehand that they can win a gold, silver, or bronze medal based on the total number of points they accumulate (see figure 4). After completing the task, participants will see their total points and, if applicable, they will receive their medal.

The total duration of the task will be approximately 15 to 20 minutes. In accordance with Aupperle and coworkers (2011), an additional post-task questionnaire will be administered in which participants will be asked on a 1–7 Likert scale (1) how upsetting the task was, (2) how difficult it was for them to make decisions during the task, (3) how motivated they were to get reward points, (4) how motivated they were to avoid aversive outcomes and (5) how anxious or uncomfortable they felt in response to the aversive outcomes.



**Figure 2***:* Decisional conditions included within the approach-avoidance conflict (AAC) paradigm.



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**Figure 3***:* Example trials with four-points-reward condition



**Figure 4***:* Picture of won gold medal if e.g., 100 points are earned

**NPU-task (relevant for Aims Two and Three).** To assess perceptual processing of emotional stimuli under different conditions, participants will perform an adapted version of the **NPU-task** (design based on Klinkenberg et al., 2016) during which EEG will be acquired. The task will include three different threat context conditions, of which the first context condition (**N**eutral context condition) will provide a baseline assessment of motivated attention via attentive viewing (relevant for Aim Two). The second and third context conditions will assess the perceptual processing of emotional stimuli in different threat contexts (**P**redictable threat and **U**npredictable threat context; relevant for Aim Three). For an overview of the paradigm see figure 5.

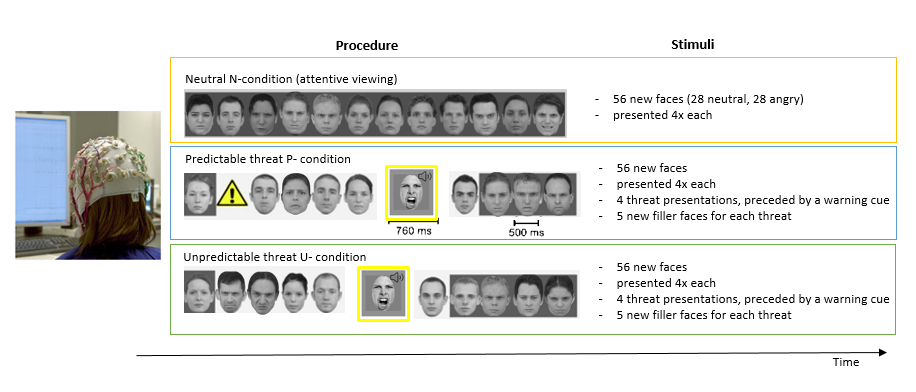
After preparation of the EEG and skin conductance electrodes, participants will be familiarized with the procedure. Then, they will first be asked to attentively view different face identities with neutral and angry expressions, while EEG will be recorded (Neutral context condition). Here, 56 new faces with neutral and angry expression will be presented four times, summing up to a total of 224 (4 x 56) faces in this condition. After participants have finished the neutral context condition, they will be asked to rate their stress level using two subscales of the German mood-questionnaire *MDBF (Mehrdimensionaler Befindlichkeitsfragebogen,* Form A, subscales tranquility – agitation and good mood – bad mood, Steyer et al., 1997). Subsequently, they will complete the P-condition and the U-condition (fear conditions), the order of which will be randomized across participants. In the P-condition (predictable threat), participants will again attentively view face identities with neutral and angry expressions. However, in this condition also threats will be presented, signaled (=predicted) by a yellow triangle and a beep. Participants will be instructed accordingly. In the U-condition, threats are again presented next to neutral and angry faces, however they will not be signaled by a warning cue but appear unannounced (=unpredicted). Participants are instructed accordingly.

The threats will be presented four times during each fear-condition. The threat will be the same screaming angry faces as used in the AAC-task. Loudness and size of the threat will increase from the first to the fourth presentation within each of the fear conditions to counteract mere expose and habituation effects (loudness: 51, 54, 57, 60 db above individual hearing threshold).

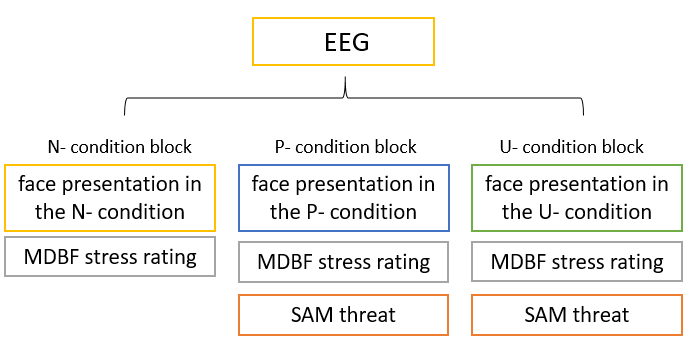
Moreover, around each threat, five new filler faces with angry or neutral facial expressions will be presented (four faces presented before the threat, one face presented after the threat). Assuming that the stimuli presented around the threat will be considered threat-relevant, they will not be included in later analyses as to enable an unbiased assessment of perceptual processing of threat-irrelevant emotional stimuli (i.e., the angry and neutral faces not associated with the threat).

After the P- and after the U-condition, respectively, participants will be asked again to rate their stress level using the subscales of the *MDBF.* Additionally,they will be asked to evaluate the threat regarding hedonic valence and emotional arousal using the SAM-scales (for an outline of the procedure see figure 6).

In alliance with the study design of Klinkenberg and colleagues (2016), each face will be presented for 500 ms with an interstimulus interval (ISI) ranging between 1750 ± 500 ms. This applies to filler faces as well. The warning triangle will also be presented 500 ms, the treat will be presented 760 ms. This will sum up to an approximate overall duration of around 25 minutes of the experimental task.



**Figure 5***:* Illustration of the three NPU-conditions in the EEG (adapted from Klinkenberg et al., 2016)



**Figure 6**: Procedure within the EEG-paradigm (P- and U-condition will be randomized)

**SAM-ratings of hedonic valence and emotional arousal (relevant for Aims Two and Three).** To obtain ratings of valence and arousal regarding the angry and neutral face cues in the NPU-task, SAM-ratings for all face identities but the filler face identities will be obtained before and after the experimental task (for an overview see figure 1). This leads to a total number of 168 faces.

To obtain ratings of valence and arousal of the threat cues, SAM-ratings regarding the threat are obtained after each fear-condition (for an overview see figure 6).

**MDBF stress rating (relevant for Aims Two and Three).**

To obtain stress levels of participants after each NPU-condition, three subscales of the German mood-questionnaire *MDBF (Mehrdimensionaler Befindlichkeitsfragebogen),* Form A, are administered, namely the subscales tranquility, agitation and good mood – bad mood (Steyer et al., 1997).

***Self-report questionnaires***

To enable analyses on the relationship between avoidance tendencies observed in the experiment and individual differences in the behavioral inhibition system (Gray, 1981), an adapted version for adolescents of the German BIS/BAS scale (Strobel et al., 2006) will be administered. For this specific research only the BIS scale will be relevant.

Additionally, the following questionnaires will be applied: the German version of the Anxiety Sensitivity Index-3 (ASI-3; Kemper et al., 2011), the German version of the Screen for Child Anxiety Related Emotional Disorders (SCARED; Essau et al., 2002), both as self-report and parent-report versions, the German questionnaire *Allgemeine Depressionsskala* (ADS-K; Hautzinger et al., 2012), the German version of the Intolerance of Uncertainty Scale – long form (IU; Gerlach et al., 2008), the German Need inventory of sensation seeking (NISS; Roth et al., 2014), as well as the German *Fragebogen zur Erhebung der Emotionsregulation bei Kindern und Jugendlichen* (FEEL-KJ; Grob & Smolenski, 2005). Lastly, a short questionnaire will be administered to collect important demographic information.

***Overall data analyses***

Here, we present the planned data analyses associated with the different aims. In general, data analyses will be selected based on the assumption that data meet the requirements for parametric tests. In case these requirements are not met, non-parametric alternatives will be used (but not presented here).

***Data analysis: Aim One***

**Main dependent variables**.

* Mean avoidance behavior: Mean avoidance behavior in the 0,2,4 and 6 reward condition (the avatar’s end position on the runway in relation to the positive affective outcome (range of −3 to +3), averaged across trials separately for each reward condition)
* No-cost avoidance: Mean avoidance behavior in the 0-conflict condition, that is, when avoidance behavior is not associated with any costs (= the avatar’s end position on the runway in relation to the positive affective outcome (range of −3 to +3), averaged across trials)
* Costly avoidance (mean): Mean avoidance behavior in the 2, 4, 6 conflict condition (the avatar’s end position on the runway in relation to the positive affective outcome (range of −3 to +3), averaged across trials separately for each conflict condition)
* Costly avoidance (slope): Change in avoidance behavior with increasing reward, calculated by using the slope for avoidance behavior from 2-point to 4-point to 6-point conflict ((6pt–2pt) + (4pt–2pt)) (Aupperle et al., 2011)
* Effort: the average number of steps participants move the avatar from the starting position to their goal position (this outcome is not a main interest in this study but will additionally be analyzed for reasons of comparison with Aupperle and colleagues, 2011)
* Response time: time used for button press averaged across valid trials per participant (this outcome is not a main interest in this study but will additionally be analyzed for reasons of comparison with Aupperle and colleagues, 2011)
* Skin conductance responses (SCRs): Mean SCRs for the 0, 2, 4, 6 conflict condition, measured during the affective stimulus phase. We will only consider the first four presentations of the aversive stimulus per condition for calculation of SCR scores. This restriction is based on the fact that the final number of presentations of aversive outcome stimuli depend on individual avoidance behavior (the more participants avoid, the less aversive outcomes they will receive). As the end positions of the runway during the decision phase correspond either to a 20% or 80% chance to receive the aversive outcome, each screaming angry face will be presented at least three to four times per reward condition in every participant (20% of 18 trials). To guarantee that effects of reward condition are not confounded by the rate of expressed avoidance behavior or potential habituation effects due to repeated exposure to the aversive stimulus, we will program the experiment to present the screaming face at least four times per participant and calculate the averaged SCRs to the first four repetitions of the aversive audiovisual outcome stimulus only per participant and per reward condition.

**Main independent and correlational variables**.

* Experimental Condition: 0, 2, 4, or 6 reward condition
* Conflict Condition: 2, 4, or 6 reward condition (without the 0 reward condition, in which the avoidance behavior does not conflict with the reward condition)
* Age Group: adolescents, adults
* Behavioral inhibition: individual score in the BIS
* Gender: male, female, diverse (since Aupperle et al. (2011) found significant gender differences in the task, gender will additionally be included as a controlling factor for an exploratory analysis)

**Specific research questions and corresponding analyses**.

1. Did our manipulation in the AAC-task work (manipulation check)? Did the experimental conditions of the AAC-task modulate behavior in adolescents and adults?
   * ANOVA with the factor Experimental Condition (0, 2, 4, 6) on Mean Avoidance Behavior (avatar´s end position on the runway: -3 to 3), separately for adolescents and adults
2. Does avoidance behavior in the AAC-task differ between adolescents and adults? Are these differences observable in the no cost and costly avoidance condition or both?

* No cost avoidance: Compare means of no cost avoidance between Age Groups via *t*-test
* Costly avoidance (mean): ANOVA with the factors Age Group (adolescents, adults) and Conflict Condition (2,4,6)
* Costly avoidance (slope): Compare slopes in avoidance behavior (costly avoidance) between Age Groups via *t*-test

1. Does the experimental condition (0,2,4,6), in which the faces were presented during the AAC-task, have an effect on SCRs towards outcome stimuli? Does this effect depend on age (i.e., differs between adolescents and adults) or on the individual avoidance tendency during costly avoidance?
   * ANOVA with the factors Experimental Condition (0,2,4,6) and Age Group (adolescents, adults) on SCRs: Interest in Experimental Condition main effect and in Experimental Condition x Age Group interaction
   * ANCOVA with the factor Experimental Condition (0,2,4,6) and covariate Mean Costly Avoidance on dependent variable SCR, separately for adolescents and adults
   * ANCOVA with the factors Experimental Condition (0,2,4,6) and covariate Slope Costly Avoidance on dependent variable SCR, separately for adolescents and adults
2. Is no cost and costly avoidance positively associated with the behavioral inhibition system?
   * Correlation analysis: BIS ~ no cost avoidance
   * Correlation analysis: BIS ~ costly avoidance (mean)
   * Correlation analysis: BIS ~ costly avoidance (slope)

***Data analysis: Aim Two***

**Main dependent variables.**

* Event-related potentials (ERPs) towards angry and neutral faces in the N-condition of the NPU- task during early (0-100ms), mid-latency (100-200ms and 200-300ms) and later (300-600ms) time-intervals. Special interest will be directed to the EPN (~120-190ms and ~190-300ms) and LPP (~300-600ms), as indicators of motivated attention.

**Main independent and correlational variables.**

* Age Group: adolescents, adults
* Stimulus Category: angry, neutral
* Mean and slope of costly avoidance in the AAC-task, as indicators of the individual behavioral avoidance tendency
* Individual BIS scores, as indicators of individual differences in the behavioral inhibition and behavioral activation systems

**Specific research questions and corresponding analyses.**

1. Do we see differential responding towards angry and neutral faces in the N-condition of the NPU-task, especially during EPN and LPP time-intervals, reconcilable with typical effects of motivated attention? Do adolescents and adults differ in these differential responses?

* ANOVA with the factors Stimulus Category (angry, neutral) and Age Group (adolescents, adults) on neural activation in the above specified time intervals: Interest in Stimulus Category main effect (motivated attention) and Stimulus Category x Age Group interaction (developmental differences in motivated attention)

1. Do motivated attention effects (as assessed via difference amplitudes of angry *minus* neutral) depend on the individual avoidance tendency (as assessed via mean and slope of costly avoidance in the AAC-task)? Does this association differ between age groups?

* Significant difference amplitudes (angry *minus* neutral) from the previous analysis (research question 1, Aim Two) are extracted, as indicator of motivated attention
* Multiple linear regression with predictors Age group (adolescents, adults - coded as a dummy variable) and mean costly avoidance, dependent variable motivated attention
* Multiple linear regression with predictors Age group (adolescents, adults), coded as a dummy variable, and slope costly avoidance, dependent variable motivated attention

1. Do motivated attention effects (as assessed via difference amplitudes of angry *minus* neutral) depend on behavioral inhibition (assessed via self-report in the BIS)? Does this association differ between age groups?

* Significant difference amplitudes (angry *minus* neutral) from the previous analysis (research question 1, Aim Two) are extracted, as indicator of motivated attention
* Multiple linear regression with predictors Age group (adolescents, adults - coded as a dummy variable) and BIS-scores, dependent variable motivated attention

***Data analysis: Aim Three***

**Main dependent variables.**

* SAM threat ratings of the threat, as assessed within the NPU-task after the Predictable and the Unpredictable context
* MDBF stress ratings, as assessed after each context within the NPU-task
* Hedonic valence and emotional arousal ratings of all faces, as assessed in the NPU-task before and after EEG measurement
* Event-related potentials (ERPs) towards angry and neutral faces in the NPU-task (all contexts) during early (0-100ms), mid-latency (100-200ms and 200-300ms) and later (300-600ms) time-intervals. Special interest will be directed to the EPN (~120-190ms and ~190-300ms) and LPP (~300-600ms), as indicators of motivated attention.
* SCR towards the threat in the P- and in the U-condition

**Main independent and correlational variables.**

* Session (pre, post)
* Context (N, P, U)
* Threat Context (P,U)
* Stimulus Category (angry, neutral)
* Age Group (adolescents, adults)
* Mean and slope of costly avoidance assessed in the AAC-task, as indicators of individual behavioral avoidance tendency
* Individual BIS scores, as indicators of individual differences in the behavioral inhibition and behavioral activation systems

**Specific research questions and corresponding analyses.**

1. Did our manipulation in the NPU-task work (manipulation check adapted from Klinkenberg et al., 2016)? Is the threat in the Unpredictable as compared to the Predictable context observed as less pleasant and more arousing? Are participants experiencing more stress in the U-, as compared to the P-, as compared to the N-condition?
   * *threat ratings:* Paired t-tests will compare the hedonic valence and emotional arousal ratings of the threat collected after the U- and P-conditions, to assess whether the threat was rated as significantly less pleasant and more arousing in the U-condition than in the P-condition.
   * *MDBF stress-rating:* A within-subject ANOVA with the factor Context (N, P, U) calculated on individual stress ratings will assess whether participants experienced more stress with decreasing threat predictability
2. Does the threat context (P- or U-condition) have an effect on SCRs towards outcome stimuli? Does this effect depend on age (i.e., differs between adolescents and adults)?
   * ANOVA with the factors Threat Context (P, U) and Age Group (adolescents, adults) on SCRs: Interest in Threat Context main effect and in Threat Context x Age Group interaction
3. Does the threat context have an effect on the subjective valence and arousal ratings of the faces? Does the effect of threat context on subjective ratings differ between age groups?
   * ANOVA with the factors Session (pre, post), Context (N, P, U), Stimulus Category (angry, neutral), and Age Group (adolescents, adults) on SAM valence and arousal ratings: Interest in Session x Context and Session x Context x Stimulus Category interactions as well as Session x Context x Age Group and Session x Context x Stimulus Category x Age Group interactions
4. Does the effect of threat context on the subjective valence and arousal ratings of the faces vary, depending on the individual avoidance tendency during costly avoidance?
   * ANCOVA with the factors Session (pre, post), Context (N, P, U), Stimulus Category (angry, neutral), Age Group (adolescents, adults) and covariate Mean Costly Avoidance on SAM ratings across all participants: Interest in Session x Context x Stimulus Category x Mean and Session x Context x Stimulus Category x Age Group x Mean interactions
   * ANCOVA with the factors Session (pre, post), Context (N, P, U), Stimulus Category (angry, neutral), Age Group (adolescents, adults) and covariate Slope Costly Avoidance on SAM ratings across all participants: Interest in Session x Context x Stimulus Category x Slope and Session x Context x Stimulus Category x Age Group x Slope interactions
5. Does the effect of threat context on the subjective valence and arousal ratings of the faces vary, depending on the behavioral inhibition system (as assesses using individual scores on the BIS scale)?
   * ANCOVA with the factors Session (pre, post), Context (N, P, U), Stimulus Category (angry, neutral), Age Group (adolescents, adults) and covariate BIS on SAM ratings across all participants: Interest in Session x Context x Stimulus Category x BIS and Session x Context x Stimulus Category x Age Group x BIS interactions
6. Does the threat context have an effect on the processing advantage of angry versus neutral faces (i.e., motivated attention)? Does the effect of threat context on emotional processing differ between age groups?
   * ANOVA with the factors Context (N, P, U), Stimulus Category (angry, neutral), and Age Group (adolescents, adults) on neural activation in the above specified time intervals: Interest in Context x Stimulus Category and Context x Stimulus Category x Age Group interactions.
7. Does the effect of threat context on emotional processing vary, depending on the individual avoidance tendency during costly avoidance?
   * ANCOVA with the factors Context (N, P, U), Stimulus Category (angry, neutral), Age Group (adolescents, adults) and covariate Mean Costly Avoidance on neural activation across all participants: Interest in Context x Stimulus Category x Mean and Context x Stimulus Category x Age Group x Mean interactions (At present, covariate analysis is yet to be integrated into the EEG data analysis program. In case covariate analysis is not available at the time of data analysis, we will use group analysis, with the groups “Avoiders/Non-Avoiders” being established via median split on the mean of the adolescent and the adult group, respectively).
   * ANCOVA with the factors Context (N, P, U), Stimulus Category (angry, neutral), Age Group (adolescents, adults) and covariate Slope Costly Avoidance on neural across all participants: Interest in Context x Stimulus Category x Slope and Context x Stimulus Category x Age Group x Slope interactions (At present, covariate analysis is yet to be integrated into the EEG data analysis program. In case covariate analysis is not available at the time of data analysis, we will use group analysis, with the groups “Avoiders/Non-Avoiders” being established via median split on the slope of the adolescent and the adult group, respectively).
8. Does the effect of threat context on emotional processing vary, depending on the behavioral inhibition system (as assesses using individual scores on the BIS scale)?
   * ANCOVA with the factors Context (N, P, U), Stimulus Category (angry, neutral), Age Group (adolescents, adults) and covariate BIS on neural activation across all participants: Interest in Context x Stimulus Category x BIS and Context x Stimulus Category x Age Group x BIS interactions

**Points to consider and think about; possible challenges**

* It is important to conduct a Pilot study (e.g., with students) to test if the stimuli are working as intended (e.g., are the angry faces aversive enough?; is the threat threatening enough?, do we achieve the intended manipulation with the reward contexts 2,4,6?)
* Gender differences: include a questionnaire concerning hormones?
* The German BIS/ BAS questionnaire is only validated for adults - it has to be adapted for adolescents. Pagliaccioet al. (2016) did a revision in English for children and adolescents, if possible, we will translate this into a German version.

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