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Loneliness, personality, and attention to AI-generated images depicting social threat: An eye-tracking study

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ABSTRACT

Attention bias towards social threat has been linked to loneliness and anxiety, though findings are mixed and concerns about measurement reliability persist. This study examined whether state and trait loneliness, along with personality, self-esteem, social anxiety, and life satisfaction, are associated with attention bias towards social threat images (indicating rejection or exclusion) in young adults ($N = 241$). AI-generated images were used to enhance control over stimulus content and category distinctions. Participants completed an eye-tracking free-viewing task comprising 40 image matrices (four images per matrix, displayed for 6000 ms). We then computed attention bias (dwell time percentage, total fixation duration percentage, and fixation count percentage) and initial orientation of attention (first fixation percentage). The attention bias measures showed adequate-to-good internal consistency ($\alpha = 0.61$–0.86). No significant associations emerged between loneliness and attention to socially threatening stimuli, suggesting that heightened vigilance to social threat may not be a feature of loneliness in non-clinical young adults. However, it was found that females exhibited greater attention to social positive images, and baseline pupil diameter was associated with social anxiety. Future research should assess whether loneliness-specific attention bias is a replicable phenomenon, ideally by using an extreme-sampling approach with very lonely individuals.

1. Introduction

Loneliness, defined as the discrepancy between desired and actual relationships (Perlman & Peplau, 1981), is an important societal issue, with purported long-term effects on physical and mental health (Heinrich & Gullone, 2006). Several models have been proposed to explain how loneliness develops and persists. The evolutionary model (Cacioppo et al., 2006; Cacioppo & Hawkley, 2009) views loneliness as an adaptive signal, much like hunger, which motivates individuals to reconnect with others to improve chances of survival. Building on this, the re-affiliation motive model (Qualter et al., 2015) suggests that loneliness initially triggers social withdrawal, allowing individuals to assess the social environment. During this period of withdrawal, cognitive processes shift to prioritise social cues, particularly those signalling threat or rejection. When adaptive, this monitoring facilitates reconnection, but over time, it can become maladaptive, reinforcing attention to social threat while neglecting signs of inclusion (Cacioppo & Hawkley, 2009).

To better understand how loneliness influences social cognition, Spithoven et al. (2017) integrated these models into the Social Information Processing (SIP) framework (Crick & Dodge, 1994), identifying how loneliness biases attention, interpretation, memory, and behaviour towards socially threatening information. Of particular relevance is the perceptual encoding stage, where lonely individuals show heightened attention to social threats, such as rejection or exclusion cues, hypothetically leading to faster and more efficient processing of negative social stimuli compared to non-lonely individuals. This attention bias has been proposed as an important mechanism for maintaining loneliness and a potential target for intervention (Qualter et al., 2015).

In order to operationalise this attention bias, eye-tracking is potentially a valuable tool for the measurement of attention in this context, offering continuous data and improved reliability over traditional reaction-time tasks like dot-probe or emotional Stroop (MacLeod et al., 2019). It enables fine-grained analysis of both initial orienting (i.e., first fixation) and sustained attention (i.e., total dwell time, including fixations and saccades), making it suitable and reliable to measure attention biases (Skinner et al., 2018).

Findings on attention bias in relation to loneliness remain mixed.

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Bangee et al. (2014) found that lonely adolescents spent a greater proportion of time looking at negative social interactions in playground videos within the first 2 s of viewing, while Qualter et al. (2013) observed a similar bias in lonely children, although over a longer time frame (first 15 s of 20-s video clips). With a static image paradigm, where participants freely viewed × 2 matrices of images, Bangee and Qualter (2018) reported that lonely individuals spent a greater proportion of viewing time on social negative stimuli compared to non-lonely peers, whereas Lodder et al. (2015) found no significant group differences in total fixation duration or count on social negative content.

These inconsistencies may reflect a number of methodological differences. For example, variability in sample size (43 to 140), participant age (children vs. students), and how loneliness is measured or categorised may impact statistical power and generalisability of the findings. Moreover, studies differ in the stimuli used, ranging from dynamic playground videos (Bangee et al., 2014; Qualter et al., 2013) to static images from the International Affective Picture System (IAPS) or private sources (Bangee & Qualter, 2018; Lodder et al., 2015), and in how they define 'social threat', from explicit rejection to more ambiguous cues like a lack of smiling or physical danger involving other persons (e.g., robbery). Attention bias is also operationalised in diverse ways, such as first fixation probability, fixation count, total fixation duration or proportion of dwell time, further complicating comparisons.

Beyond loneliness, attention biases to social threat have been more widely studied in related conditions like social anxiety and depression (Lazarov et al., 2016; Peckham et al., 2010; Shamai-Leshem et al., 2023), though with variable effect sizes (Clauss et al., 2022) and replication failures (Byrne et al., 2024), underscoring the need for larger, well-powered studies. Personality traits have shown tentative links to attention: for example, neuroticism has been associated with greater threat sensitivity (Perlman et al., 2009; Reed & Derryberry, 1995), extraversion with positive social cues (Ellingsen et al., 2019) and low self-esteem with greater interference from rejection-related words (Dandeneau & Baldwin, 2004). Extraversion and agreeableness predict more gaze to others' eyes in social scenes, while openness predicts less (Wu et al., 2014), suggesting personality may shape social attention. However, findings are often limited by small samples, low or unreported reliability, minimal eye-tracking, and a lack of studies directly linking personality to attention bias towards social threat.

A further limitation in this area is the lack of standardised, ecologically valid stimuli to assess responses to real-world social threats. Most studies rely on facial expressions to represent social cues (i.e., anger, sadness), yet these lack the complexity of actual social situations. While scenarios of exclusion or inclusion may better capture the psychological experience of loneliness (Bangee & Qualter, 2018), open-source image databases for such stimuli are rare. To our knowledge, only the ISIEA dataset (Zheng et al., 2022) includes images of social inclusion and exclusion, but it is limited to Asian young adults.

To address this gap, we created a novel set of AI-generated images using Midjourney, featuring realistic depictions of social inclusion, exclusion and other relevant categories. These images allow for the creation of nuanced scenes, such as one person being excluded from a group, that are difficult to stage in real life. Prior research suggests that such images are perceived as highly photo-realistic and often indistinguishable from real photographs (e.g., Lu et al., 2023; Shen et al., 2021). Moreover, the use of AI-generated content is a new and promising approach, with validation studies demonstrating the benchmarking of experimental stimuli for advertising research (Van Berlo et al., 2024; Zamudio et al., 2025) and in psychological research to probe social and emotional perception of images (Becker & Laycock, 2023; Lu et al., 2025) and videos (Vijay et al., 2021).

In the present study, we used this new stimulus set in a free-viewing eye-tracking paradigm, with a large sample of young adults ($n = 241$) to examine attention biases towards social threat. We measured attention with multiple indicators (first fixation percentage, total fixation duration percentage, fixation count percentage, and dwell time percentage) and evaluated their internal consistency. We incorporated self-report measures of both state and trait loneliness, social anxiety, life satisfaction, self-esteem, and personality, to examine whether loneliness and broader affective traits are linked to attention allocation to positive vs. negative and social vs. non-social stimuli.

Based on prior literature (Bangee et al., 2014; Bangee & Qualter, 2018; Qualter et al., 2013; Spithoven et al., 2017), we hypothesised that loneliness (both state and trait) and social anxiety would be associated with attention bias (looking more) towards socially negative stimuli, and that measures associated with positive affect (i.e., extraversion, self-esteem, life satisfaction) would be associated with attention bias (looking more) towards social and non-social positive stimuli.

2. Methods

2.1. Participants

Participants were 255 MSc engineering students, recruited from our university's MSc course 'Human-Robot Interaction' (20–34 years old). Participants were excluded if data quality was poor (more than 25% of eye-tracking data was missing, $n = 12$), if the participant failed to understand the experiment instructions[1] ($n = 1$), or if they did not answer the self-report questionnaire ($n = 1$). The remaining 241 participants[2] were 184 males and 56 females (1 person did not identify with a gender), with a mean age of 23.5 years ($SD = 1.9$) (based on 240 participants, one participant did not report a valid age). The final sample was predominantly Dutch ($n = 169$), with seven of those participants reporting a mixed national background. The remaining participants were from various nationalities, including Indian ($n = 12$), Greek ($n = 7$), Belgian ($n = 6$), Spanish ($n = 5$), Italian ($n = 5$), Portuguese ($n = 4$), and Romanian ($n = 4$), alongs with others in smaller numbers. 14 of 241 participants wore glasses during the experiment. The research was approved by the Human Research Ethics Committee of our university (approval number 4742) and all participants provided their written informed consent.

2.2. Image generation, selection and validation

Images were generated with an API using the Imagine feature of Midjourney v6.1 (see Supplementary Fig. 1 for an example and prompt). Four categories were created: social positive, social negative, non-social positive, and non-social negative. Social images featured human interaction and non-social images did not. Contexts within each category were informed by affective databases (i.e., OASIS, Kurdi et al., 2017; IAPS, Lang et al., 1999) such as "children playing" (social positive), "exclusion in high school hallway" (social negative), "kittens" (non-social positive), "garbage dump" (non-social negative). Arousal and camera settings were varied via prompt instructions. After removing images with artefacts per manual inspection, 1398 images were retained.

The social positive category depicted social and collaborative activities (e.g., gardening, cooking, games, sitting at a cafe). The social negative category depicted social exclusion, loneliness, or interpersonal confrontation in school or public settings (e.g., people arguing, a person being excluded from a group). The social images contained children, younger adults, and/or older adults. The non-social positive category represented natural and leisure contexts (e.g., sunsets, forests, amusement rides, baby animals, etc.). The non-social negative category represented death, disaster, and decay (e.g., skulls, floods, rotting food, pollution, cockroaches). All images were drawn from contemporary Western cultural contexts, mostly reflecting urban, middle-class social

[1] They looked at the centre of the screen (cross) for the entire duration of the task.

[2] One participant had a missing response on the agreeableness scale, and another on the life satisfaction scale.

life in Anglophone or Northern European societies. The individuals in the images reflected diverse cultural and ethnic backgrounds.

These 1398 images were rated by OpenAI's GPT-4o on ten dimensions (e.g., valence, arousal, social exclusion, salience) and objective dimensions (brightness, contrast, colouration, saturation, and entropy) were computed per image (see Supplementary material and Supplementary Table 1). Images with AI-generated or Artefact scores > 25 and/or in black and white were excluded. Images were then filtered by valence to match category definitions, and outliers were removed (1.5 × IQR below Q1 or 1.5 × IQR above Q3). Finally, 2 to 5 images per context were randomly sampled to ensure variety within each category.

A human validation study involving 749 participants was conducted on a subset of the current image set. Participants were asked to rate 74 images on a 7-point Likert scale on positivity ("Please rate how positive this image is on a scale from Very negative to Very positive."). As detailed in the supplementary material, this validation revealed that the ratings for OASIS and AI-generated images were highly similar (Supplementary Fig. 3). The median valence ratings for OASIS and Midjourney images (where the rating for each image is the mean score from all participants) were 6.25 and 6.24 for social positive, 2.46 and 3.04 for social negative, 5.98 and 6.11 for non-social positive, and 2.24 and 2.70 for non-social negative, respectively. For the social negative category, the OASIS stimuli (e.g., crying baby) were rated as somewhat more negative than AI-generated stimuli (e.g., social exclusion), an expected difference since AI-generated social exclusion content was not available in the OASIS dataset.

2.3. Apparatus and software

The experiment was programmed in the SR Research Experiment Builder (version 2.3.38), with additional custom randomisation coded using Python. All stimuli were presented on a 64-bit Windows 7 Professional operating system. Binocular eye movements ($n = 17$) were recorded at 1000 Hz, and monocular eye movements ($n = 224$) from the right eye were recorded at 2000 Hz using the SR Research EyeLink 1000 Plus.[3] For binocular recording, x, y coordinates were averaged from both eyes. Participants positioned their heads on a head support on the edge of a table. The monitor was positioned 100 cm from the edge of the table and at a horizontal distance of about 96 cm from the participants' eyes. The eye-tracking camera was positioned 59 cm from the table's edge, with a horizontal distance of 55 cm between the camera lens and the participants' eyes. The stimuli were presented on a 24-inch BenQ monitor (XL2420) with a resolution of 1920 × 1080 pixels and a refresh rate of 60 Hz. The monitor subtended horizontal and vertical viewing angles of approximately 30.9° and 17.7°, respectively. Participants wore closed-back headphones (Beyerdynamic DT-770 PRO) to block out ambient noise.

The illuminance, measured with a Konica Minolta T-10MA from the position of the head support, was 410–430 lx when pointed in the direction of the ceiling, and 279–304 lx when pointed towards the monitor. Luminance, measured with a Konica Minolta LS-150 at 100 cm from the screen, was 69.76 cd/m^2 for a grey surface [RGB: 127, 127, 127] (range: 3.109 cd/m^2 for a black surface [RGB: 0, 0, 0] to 344.6 cd/m^2 for a white surface [RGB: 255, 255, 255]). There was no natural light in the room.[4]

2.4. Experiment procedure

At the start of the experiment, participants were asked to read and sign the consent form. They then completed EyeLink's standard calibration followed by validation, both using a 9-point grid. Next, participants were presented with the following instructions: "During this task, you will be presented with 40 image matrices. The images will be displayed for several seconds. Please view these images however you wish; there is no instruction to focus on anything particular. In between each image matrix, a cross will be presented at the centre of the screen. Please look at this. If you have any questions, please ask them now. Press any key to proceed with the task."

Each trial began with a central fixation cross (700 ms), followed by a 4-image matrix displayed for 6000 ms, with one image from each category (social positive, social negative, non-social positive, non-social negative) (Fig. 1). Image locations and combinations were randomised. A total of 160 images were shown once per participant. After this task, participants completed an AI discrimination task (De Winter et al., 2025) and viewed a video for separate studies. Finally, they completed a questionnaire (via Qualtrics) on a separate computer.

2.5. Data processing

Periods where vertical gaze data were unavailable, including eye blinks, were classified as data gaps. A 100-ms margin was added before and after each gap to account for eyelid closure and reopening (Caffier et al., 2003). Missing data in the horizontal (x) and vertical (y) gaze coordinates were linearly interpolated. The x and y coordinates were then filtered using a median filter with a 100-ms window. Trials in which more than 50% of the data (i.e., more than 3000 ms) consisted of data gaps were not included in further analyses. In total, 32 trials originating from 11 participants were excluded from further analyses for this reason, which constitutes 0.3% of the total 9640 (241 participants × 40 trials per participant) trials.

Following this, gaze data were segmented into fixations and saccades. A custom fixation filter, based on Nyström and Holmqvist (2010) and used in previous studies (De Winter et al., 2023), was applied. Gaze speed, measured in degrees per second, was filtered using a second-order Savitzky-Golay filter. Saccades were identified when gaze speed exceeded 30°/s, with durations constrained between 10 and 150 ms. Fixations were defined as stable gaze for at least 100 ms. Fixations that overlapped with a data gap (blink) were not included in this calculation. Moreover, if the gaze point fell within the centre of the screen (a circle with a radius of 100 pixels, or 1.65°), it was not counted as part of an AOI (Fig. 1).

2.6. Dependent variables: eye-tracking metrics

For image category/AOI (social positive, social negative, non-social positive, non-social negative), the following eye-gaze measures were computed:

(1) Dwell time percentage (DTP): sum of gaze data (all x, y coordinates sampled, i.e., fixations and saccades) per AOI divided by sum of all gaze data on the four AOIs, multiplied by 100%.
(2) Number of fixations percentage (NFP): sum of fixation counts per AOI divided by sum of all fixation counts on the four AOIs, multiplied by 100%.
(3) Total fixation duration percentage (TFDP): sum of fixation durations per AOI divided by sum of all fixation durations on the four AOIs, multiplied by 100%.
(4) First fixation percentage (FFP): percentage of trials in which first fixation is on the AOI.

The variables DTP, NFP and TFDP are averaged across the included trials per participant, whereas FFP represents the percentage of included

[3] Eye-tracking was switched to monocular because an initial inspection of the binocular recordings revealed too much missing data. This change also allowed for recording at a higher frequency (2000 Hz).

[4] Due to logistical and accessibility reasons, for four participants the experiment was conducted using an eye-tracker of the same brand and model as the primary eye-tracker, but it was a different unit in a different room where some daylight was present. Pupil diameter data for these participants were omitted from the analysis.

Fig. 1. Sample image matrix presented during the experiment, with eye-tracking overlaid for Participant 90, Trial 6. Top left: Non-social negative, Top right: Non-social positive, Bottom left: Social positive, Bottom right: Social negative. The yellow circle (centre 960,540) with a radius 100 pixels (1.65°) represents the centre of the screen. Eye-gaze coordinates of saccades are displayed in magenta, and eye-gaze coordinates of fixations are displayed in white. Eye-gaze coordinates outside the areas of interest or in the centre of the screen are displayed in yellow and excluded from the analysis.

trials.

2.7. Independent variables: individual measures

Loneliness. Trait loneliness was measured with the short version (Hughes et al., 2004) of the UCLA Loneliness Scale (Russell, 1996), which consists of 3 items (e.g., "How often do you feel left out?"). Participants rated every item on a 3-point Likert scale (1 = *Hardly ever* to 3 = *Often*). Reliability was acceptable (α = 0.69). State loneliness was measured with a single item asking participants to indicate the extent to which the statement "I feel lonely right now" applied to them (adapted from Burgin et al., 2012). Participants rated this on a 5-point Likert scale (1 = *Not at all* to 5 = *Very much*).
Social anxiety. Social anxiety was measured with the Interaction Anxiousness Scale (IAS-3; Nichols & Webster, 2015), which consists of 3 items (e.g., "I wish I had more confidence in social situations"). Participants rated every item on a 5-point Likert scale (1 = *Not at all characteristic of me* to 5 = *Extremely characteristic of me*). Reliability was good (α = 0.83).
Personality: The Big Five Personality traits were measured with the Big Five Inventory (BFI-10; Rammstedt & John, 2007), which consists of 10 items measuring agreeableness, conscientiousness, extraversion, openness to experience, and neuroticism. Participants rated every item on a 5-point Likert scale (1 = *Disagree strongly* to 5 = *Agree strongly*, with 5 items reverse-coded). Reliability ranged from not acceptable (openness to experience α = 0.14, agreeableness α = 0.49, and conscientiousness α = 0.43), to acceptable (extraversion α = 0.73, and neuroticism α = 0.72).
Self-esteem: Self-esteem was measured with the Brief Rosenberg Self-Esteem Scale (RSE), a 5-item scale proposed by Monteiro et al. (2022) based on the original RSE (Rosenberg, 1965) (e.g., "On the whole, I am satisfied with myself"). Participants rated every item on a 5-point Likert scale (1 = *Disagree strongly* to 5 = *Agree strongly*, with 2 items reverse-coded). Reliability was good (α = 0.81).
Life satisfaction: Life satisfaction was measured with the Mini Quality of Life Enjoyment and Satisfaction Questionnaire (Rush et al., 2019), which consists of 7 items (e.g., "Taking everything into consideration, during the past week how satisfied have you been with your … household activities?"). Participants rated every item on a 5-point Likert scale (1 = *Very poor* to 5 = *Very good*). Reliability was good (α = 0.76).

In addition to the above personality-related measures, baseline pupil diameter, measured at the start of the trials and subsequently averaged across trials, was included as an independent physiological variable. Baseline pupil diameter is known to reflect individual differences in autonomic arousal and cognitive processing (Unsworth & Robison, 2017), which have previously been associated with attentional biases towards emotional stimuli (Bradley et al., 2008; Duque et al., 2014). Its inclusion enables exploration of potential physiological correlates of attentional bias beyond subjective self-report measures.

2.8. Data analysis

Descriptive statistics of all variables and Spearman rank correlations between all of the individual measures and eye-tracking metrics were computed. For analyses for 4 stimuli types x 4 attention measures x 12 independent variables, a strict Bonferroni correction, taking into account all 12 independent variables, was applied. Because the dependent variables were often strongly correlated and mathematically dependent (i.e., looking at one AOI implies a lower probability of looking at another), no separate significance level adjustment was made to account for them. Reliability of all measures, where applicable, was calculated using Cronbach's alpha (α). All analyses were conducted in MATLAB (version 2024b).

3. Results

3.1. Descriptive statistics

On a scale of 3 to 9, the mean score for trait loneliness was 4.47 (*SD* = 1.40), with 55 people classified as "lonely" (Score 6: 32, Score 7: 16, Score 8: 5, Score 9: 2) and 186 as "non-lonely" (Score of 3, 4, or 5). On a scale of 1 to 5, the mean score for state loneliness was 1.70 (*SD* = 0.92).

On a scale of 2 to 10, the mean (*SD*) scores for extraversion, agreeableness, conscientiousness, neuroticism and openness were 6.74 ($SD = 2.01$), 7.42 ($SD = 1.66$), 7.00 ($SD = 1.69$), 5.54 ($SD = 2.15$), and 7.02 ($SD = 1.72$), respectively. On a scale of 5 to 25, the mean score for self-esteem was 19.58 ($SD = 3.97$). On a scale of 3 to 15, the mean score for social anxiety was 6.91 ($SD = 2.86$). On a scale of 7 to 35, the mean score for life satisfaction was 25.27 ($SD = 4.26$). In arbitrary units, the mean for baseline pupil diameter was 4266 ($SD = 611$). Descriptive statistics for the eye-tracking dependent variables can be found in Table 1.

3.2. Relationship between attention measures, loneliness and personality

The hypothesis that loneliness (state or trait) shows a statistically significant positive correlation with the dwell time percentage on socially negative stimuli was not confirmed (state loneliness: $\rho = -0.01$, $p = 0.870$, trait loneliness: $\rho = 0.01$, $p = 0.899$, Fig. 2).

High and low lonely individuals also did not differ in their dwell time over the length of a trial (Fig. 3). More specifically, there were no statistically significant correlations between trait loneliness and mean dwell time percentage for time windows (0–500 ms, 500–1000 ms, 1000–1500 ms, 1500–2000 ms, 2000–2500 ms, 2500–3000 ms, 3000–3500 ms, 3500–4000 ms, 4000–4500 ms, 4500–5000 ms, 5000–5500 ms, 5500–6000 ms) ($p > 0.04$ for all 48 correlations). With the exception of gender, additional analyses for the remaining 11 independent variables across the 4 stimuli types and 4 attention measures revealed no other statistically significant associations ($p > 0.05/12$, Fig. 2).

3.3. Additional observations

Gender was a significant predictor of social positive DTP, TFDP and NFP, with males less likely to look at these images than females (DTP: $\rho = -0.25$, $p < 0.001$, TFDP: $\rho = -0.22$, $p < 0.001$, NFP: $\rho = -0.19$, $p = 0.004$), and non-social negative FFP ($\rho = 0.20$, $p = 0.002$), with males more likely to look first at these images than females. Moreover, overall participants were more likely to look at social positive images compared to social negative images (Table 1, Fig. 4), and non-social positive images compared to non-social negative images (Table 1, Fig. 5). Over time, participants looked more at non-social positive images and less at social negative images (see Supplementary Fig. 4). Finally, 66% of participants' first fixations were on the top-left image.See Supplementary Fig. 5 for a time-based graph depicting dwell time percentages for the four quadrants.

The three eye-tracking metrics for attention bias were strongly correlated with one another. Taking attention bias to social negative images as an example, social negative DTP was correlated with social negative NFP ($\rho = 0.80$, $p < 0.001$) and social negative TFDP ($\rho = 0.92$, $p < 0.001$). Moreover, social negative NFP was correlated with social negative TFDP ($\rho = 0.88$, $p < 0.001$).

Fig. 2 shows that baseline pupil diameter was not significantly related to the dependent variables. However, an interesting observation was that respondents with a larger baseline pupil diameter showed significantly higher social anxiety scores ($\rho = 0.23$, $p < 0.001$).

4. Discussion

This study examined whether loneliness and related traits are associated with attention bias towards socially negative stimuli (e.g., rejection or exclusion) in a large non-clinical sample of young adults, using a free-viewing eye-tracking task with AI-generated images. Contrary to previous findings in smaller samples, loneliness was not statistically associated with either initial orientation (first fixation percentage) or sustained attention (dwell time percentage, total fixation duration percentage, fixation count percentage) towards socially negative stimuli. We also did not find evidence of an attentional avoidance of such stimuli or a preferential gaze or avoidance towards social positive stimuli. This suggests that, in a generally healthy young adult population, loneliness may not manifest through a measurable shift in visual attention towards or away from social threat or positive social content. Our attention bias measures showed moderate to good internal consistency ($\alpha = 0.61$–0.86), which is important given concerns about the reliability of traditional attention bias tasks (MacLeod et al., 2019). Our use of longer image presentation times, a large trial count, and well-defined stimuli may have contributed to this reliability.

While loneliness was associated with known correlates, namely lower self-esteem, extraversion and agreeableness, and higher social anxiety (Buecker et al., 2020; Szcześniak et al., 2020), none of these traits predicted visual attention bias to social threat. This suggests that visual attention bias towards social threat images is likely not a cognitive indicator of loneliness in young adults, particularly in the absence of extreme symptoms or clinical disorders.

Our results are consistent with Lodder et al. (2015), who found no attention bias in lonely participants. While earlier research using more immersive stimuli (e.g., videos of playground interactions; Bangee et al., 2014) reported attention biases in extremely lonely individuals, our study did not replicate these effects using comparable still-image scenes. This may reflect differences in ecological validity, stimulus complexity, or participant engagement. The strong top-left viewing preference observed in our data (see also Ossandón et al., 2014) confirms the importance of randomising image location, while casting doubt on first fixation as a reliable marker of initial threat vigilance (Skinner et al., 2018). Yet, a significant association between first fixation to non-social negative content and gender suggests the measure can still reflect meaningful individual differences.

Table 1
Descriptive statistics for dependent variables ($n = 241$).

Dependent variable	Stimulus type	Mean	*SD*	95% CI	Cronbach's α
Dwell time percentage (DTP) (%)	Social positive	27.10	4.51	[26.52, 27.67]	0.80
	Social negative	22.67	3.55	[22.21, 23.12]	0.76
	Non-social positive	26.99	5.94	[26.24, 27.75]	0.86
	Non-social negative	23.24	4.26	[22.70, 23.78]	0.78
Number of fixations percentage (NFP) (%)	Social positive	27.81	3.77	[27.33, 28.28]	0.70
	Social negative	24.39	2.99	[24.01, 24.77]	0.61
	Non-social positive	24.73	4.43	[24.17, 25.30]	0.78
	Non-social negative	23.07	3.60	[22.61, 23.52]	0.70
Total fixation duration percentage (TFDP) (%)	Social positive	27.52	4.57	[26.94, 28.10]	0.77
	Social negative	23.18	3.58	[22.72, 23.63]	0.69
	Non-social positive	26.10	5.68	[25.38, 26.82]	0.82
	Non-social negative	23.21	4.30	[22.66, 23.75]	0.75
First fixation percentage (FFP) (%)	Social positive	30.08	8.51	[29.00, 31.16]	N/A
	Social negative	23.01	7.43	[22.07, 23.95]	N/A
	Non-social positive	25.16	7.35	[24.23, 26.09]	N/A
	Non-social negative	21.74	7.03	[20.85, 22.64]	N/A

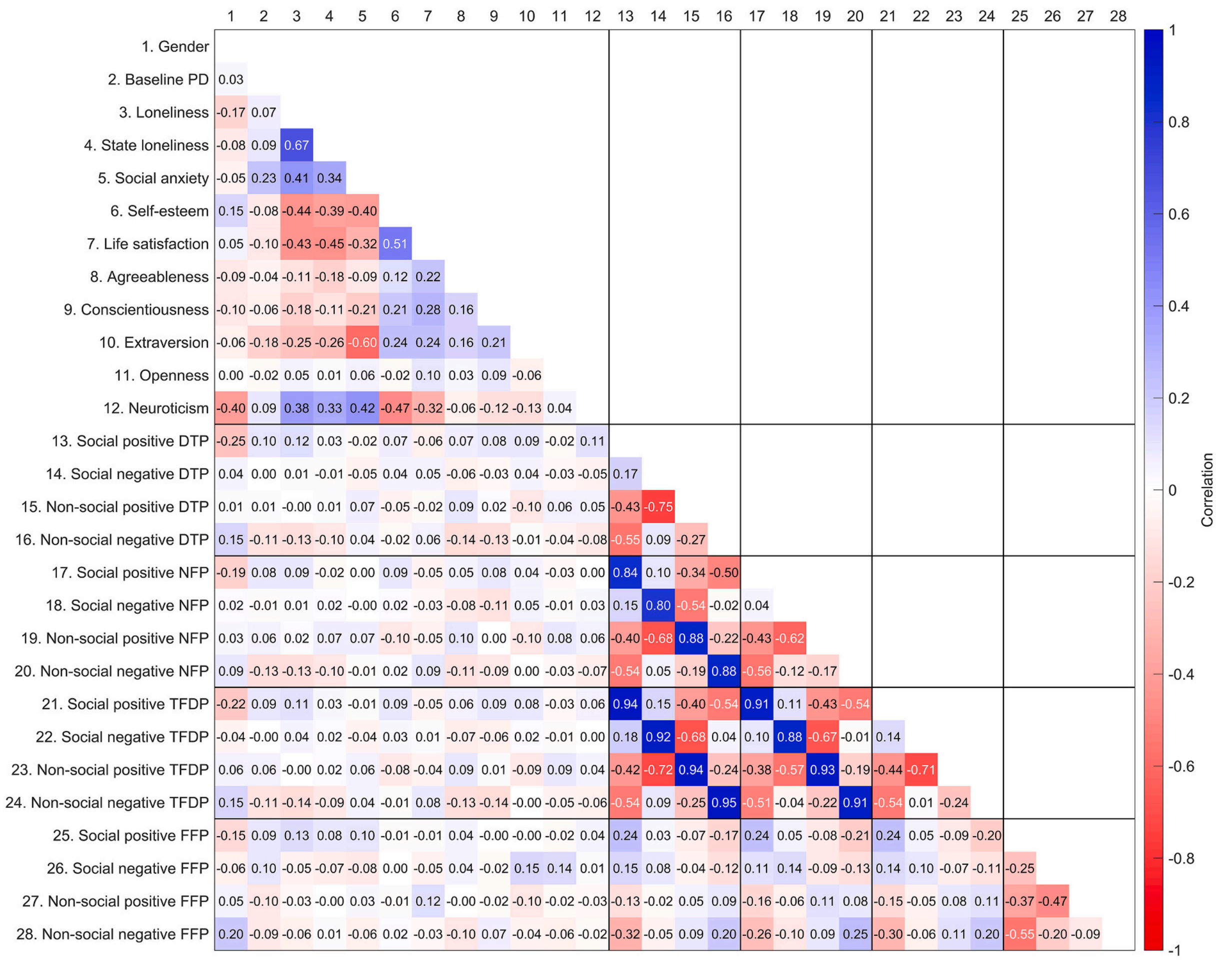

Fig. 2. Correlation matrix. Spearman rank-order correlation coefficients between all independent variables (individual difference measures, labelled 1–12) and dependent variables (eye-tracking metrics for four different areas of interest, labelled 13–28). Correlations of 0.184 or stronger are statistically significant ($p < 0.05/12$). Linearly-scaled colour coding is applied from -1 (red) to 0 (white) to 1 (blue). Abbreviations: PD: pupil diameter, DTP: dwell time percentage, NFP: number of fixations percentage, TFDP: total fixation duration percentage, FFP: first fixation percentage. Gender was coded as 1: Female, 2: Male. $n = 241$, except for Variables 1, 7 and 8 where $n = 240$, and Variable 2 where $n = 237$.

We also did not observe a link between social anxiety and attention bias. Prior research suggests that attention bias is more reliably observed in clinical or high-anxiety populations (Lazarov et al., 2016), though even in these groups, findings remain inconsistent (Byrne et al., 2024; Clauss et al., 2022). Studies show individuals with trait anxiety or anxiety disorders may also display attention avoidance of threat, while others do not show attention bias or avoidance (Clauss et al., 2022; Mogg & Bradley, 2016; Zvielli et al., 2014).

Despite the lack of loneliness-related bias, we found significant gender differences in attention patterns. Females had a longer dwell time, fixation duration and fixation count percentage on social positive images, while men were more likely to fixate first on non-social negative images. This aligns with some previous findings, suggesting that women may be more attuned to social and emotional cues (Kret & De Gelder, 2012) and men to action-oriented threats (Sulikowski & Burke, 2014), possibly due to evolutionary or socialisation differences (Cross et al., 2013), but not all studies find such differences (Pintzinger et al., 2016). Gender should therefore be taken into consideration in future studies on attention bias.

Across the entire sample, positive stimuli (social and non-social) received the most attention, in line with previous work demonstrating healthy participants have longer dwell times on positive stimuli than threatening or sad stimuli (Eizenman et al., 2003; Guy et al., 2024; Sears et al., 2019), although this pattern is not always consistent, as in youth, the opposite effect is found (Byrne et al., 2024). In our sample, few individuals had extreme loneliness or social anxiety scores, which could explain this tendency. It should be noted that this may not necessarily be a causal effect and could be due to low-level salient features of the images such as colouration (see Supplementary Table 1).

Several limitations warrant consideration. First, although AI-generated images allow for tighter experimental control and standardisation, they may contain subtle artefacts affecting authenticity. Second, our sample included few individuals with high loneliness or social anxiety, limiting the ability to detect effects that may only emerge at extreme levels. The sample consisted of engineering students who were predominantly male and Dutch, limiting generalisability to the broader young adult population. Moreover, the images used were not tailored specifically to this group. Additionally, we used short-form measures of all self-report scales, which, while efficient, showed mixed reliability; scales for loneliness and social anxiety were adequate, but several for personality traits were not.

Future work could explore attention in clinically lonely individuals or subgroups with more specific vulnerability profiles and conduct group comparisons with healthy controls (ideally matched for gender, age and other known confounders). Given the variability in attention bias across time, context, and task (MacLeod et al., 2019; Zvielli et al., 2015), future studies should also examine intra-individual fluctuations in mood and state loneliness under controlled social stress conditions. Our findings are consistent with previous research showing that individuals with high trait anxiety exhibit larger pupillary responses than

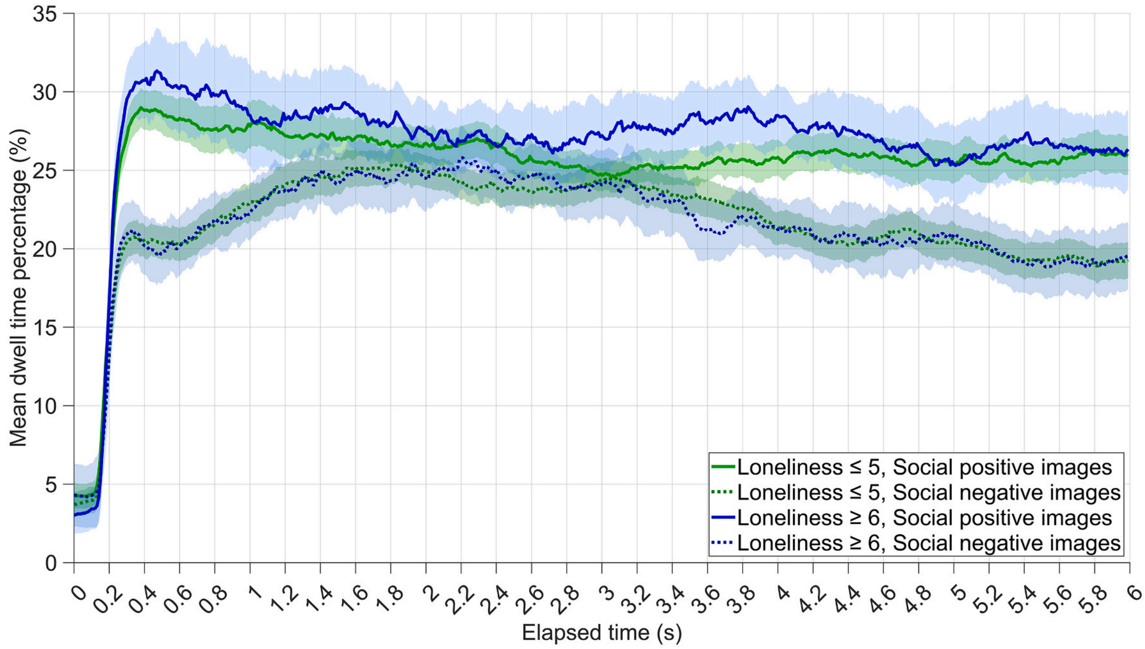

Fig. 3. Time course of visual attention to social images based on loneliness, with 95% confidence intervals. The graph shows the mean percentage of dwell time within the area of interest corresponding to social positive (solid lines) and social negative (dotted lines) images across the 6-s trial duration. Data are averaged across trials and presented separately for participants with low loneliness (scores ≤ 5, green lines) and high loneliness (scores ≥ 6, blue lines). The shaded regions surrounding each mean line represent the 95% confidence intervals.

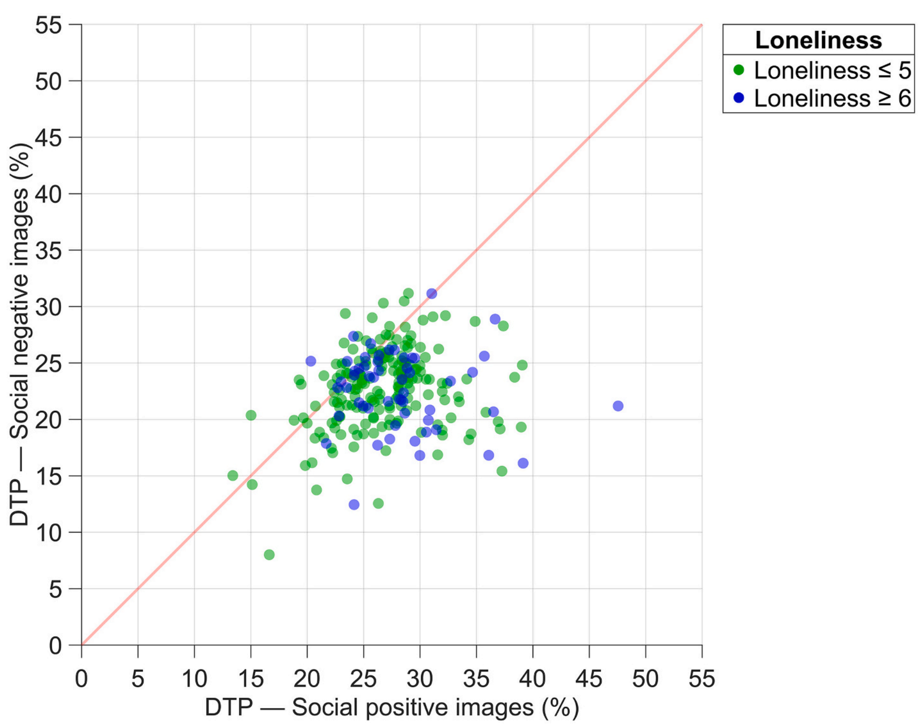

Fig. 4. Dwell time percentage (DTP) for social positive vs. social negative images, colour-coded for trait loneliness score. Each dot represents one participant's mean DTP across all included trials ($n = 241$).

those with low trait anxiety, and that individuals with diagnosed anxiety disorders such as PTSD show greater pupil dilation to emotional stimuli compared to controls (Cascardi et al., 2015; Felmingham et al., 2011; Hepsomali et al., 2017; Price et al., 2013; Shechner et al., 2017; Simpson & Molloy, 1971). A caveat is that, while a relatively strong correlation between pupil diameter and social anxiety was found, experimental control was limited. Baseline pupil diameter may have varied due to prior light exposure and adaptation over time, and glasses may have also affected measurements. Future studies should implement stricter control to better assess pupil-related effects. Additionally, incorporating richer social stimuli, such as virtual reality, AI-generated video or dynamic interpersonal interactions, may better capture attention differences in emotionally engaged contexts. It could be that attention bias only becomes evident when the individual themselves is emotionally invested,

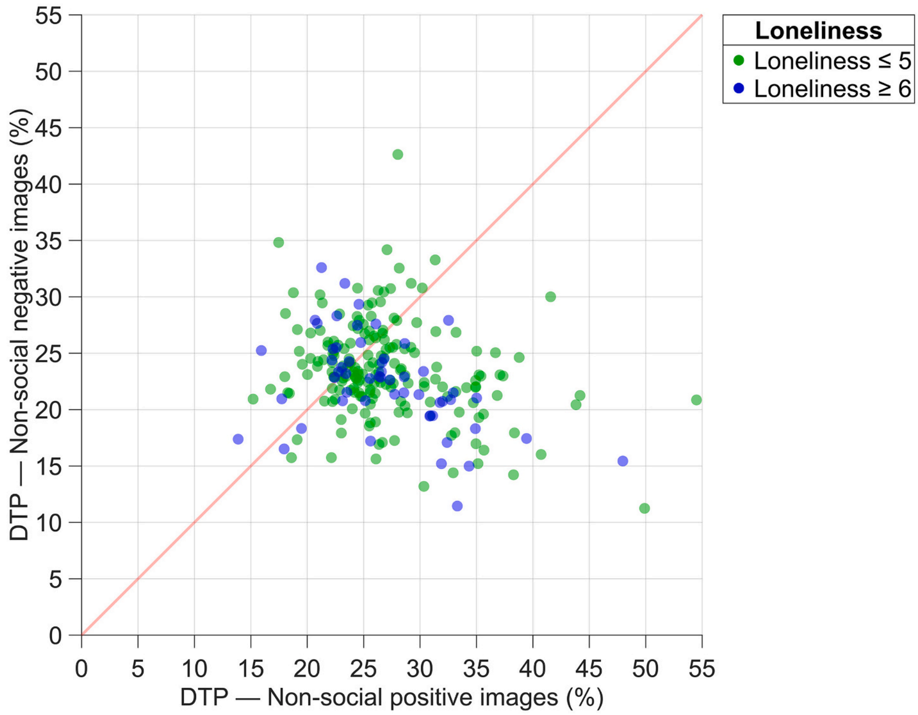

Fig. 5. Dwell time percentage (DTP) for non-social positive vs. non-social negative images, colour-coded for trait loneliness score. Each dot represents one participant's mean DTP across all included trials ($n = 241$).

involved in the social dynamic and the social stakes are high.

In conclusion, our study suggests that loneliness, self-esteem, life satisfaction, and personality are not statistically associated with attention bias towards social rejection or exclusion in static AI-generated images. However, a gender effect emerged, with females demonstrating attention bias towards social positive images and males exhibiting more first fixations to non-social negative images. Baseline pupil diameter was also statistically associated with social anxiety. Future research should explore gender and subgroup differences and contextual factors to clarify the relationship between loneliness and attention to social threat.

CRediT authorship contribution statement

Jenna Pfeifer: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Joost de Winter:** Writing – review & editing, Visualization, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Dimitra Dodou:** Writing – review & editing, Supervision, Resources, Project administration, Investigation, Funding acquisition. **Yke Bauke Eisma:** Writing – review & editing, Supervision, Software, Resources, Methodology, Funding acquisition.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.paid.2025.113415.

Data availability

Experimental stimuli, trial-level results, and analysis scripts can be found online at https://doi.org/10.4121/b02ace68-8e95-4355-bcea-f073c52e8a14.

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