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The curvature effect: Approach-avoidance tendencies in response to interior design stimuli

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ABSTRACT

Previous research suggests that curved vs. angular interior environments trigger affective (e.g., preference) and behavioural (e.g., approach-avoidance) responses. Yet, behavioural responses have mainly been assessed through explicit evaluations, such as self-reports. We aimed to investigate this phenomenon more 'implicitly' using a battery of reaction time (RT) paradigms, particularly focusing on approach-avoidance tendencies.

Online participants (initial N = 219) undertook four randomized tasks involving 20 photo-realistic living room images matched for contours (angular vs. curved) and styles (modern vs. classic). We intended to capture attentional (Dot Probe Task [DPT]), motoric (Approach Avoidance Task [AAT]), as well as associative-semantic (Implicit Association Task [IAT]) and -motoric (Stimulus Response Compatibility Task [SRCT]) biases towards contours.

The DPT and AAT showed no significant effects. However, we observed a significant congruency effect in the IAT ($F(1,192) = 97.51$, $p < .001$, $\eta^2 = 0.074$), whereby images were assigned faster into categories when those were curved-approach and angular-avoid (instead of curved-avoid, angular-approach). Additionally, we found a significant direction x contour interaction ($F(1,179) = 7.08$, $p = .009$, $\eta^2 = 0.004$) in the SRCT, attributable to within-curvature differences (faster approach compared to avoidance). Moreover, within-directions comparisons revealed a faster avoidance of angular than curved conditions.

Our findings confirmed an effect of contours on approach-avoidance tendencies using RT paradigms. We identified semantic associations between curvature and approach and angularity and avoidance behaviour. Furthermore, we demonstrated differential approach (faster) – avoidance (slower) representations in relation to curvature rather than an avoidance of angularity. These findings may hint towards (partially) automatic responses to contours in interior design, which in addition to self-reports, should be further researched concerning criterion validity, such as in correlation with physiological and psychological reactions to built spaces.

1. Introduction

As we navigate through our modern habitat, the built environment, we continuously perceive its physical properties and make judgments about them. While this process can be conscious or intentional, it appears that automatic response tendencies might generally govern one's behaviour in physical surroundings (Sussman & Hollander, 2014). Most stimuli, including environments, elicit immediate and unintentional affective responses (e.g., like vs. dislike) and behaviours (e.g., approach vs. avoidance) that are crucial to our general physiological and psychological state and wellbeing (Appleton, 1996; Elliot, 2008; Phaf, Mohr, Rotteveel, & Wicherts, 2014; Ulrich, 1983). Indeed, research has shown that the design of physical spaces can affect human emotions, cognition, and behaviour, subsequently influencing general mood states, mental health, and wellbeing (Burton, Cooper, & Cooper, 2014; Coburn et al., 2020; Evans, 2003; Evans & McCoy, 1998). While research has mainly relied upon explicit responses to design features such as via self-reports, the more immediate automatic responses they possibly induce are still understudied (Higuera-Trujillo, Llinares, & Macagno, 2021).

Among the influential features of design, curvature has been claimed as a "biophilic" parameter (Browning, Ryan, & Clancy, 2014; Kellert & Calabrese, 2015; Salingaros, 2015) that can have positive psychological and physiological effects on human beings (Coburn et al., 2020;

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Salingaros, 2019). Generally, the angular (or edgy/rectilinear) versus curved (or round/curvilinear) dichotomies have been extensively studied in many disciplines, repetitively demonstrating positive effects of curves. A variety of stimuli was tested, including abstract shapes and lines (Bertamini, Palumbo, Gheorghes, & Galatsidas, 2016; Gordon, 1909; Lundholm, 1921; Palumbo, Ruta, & Bertamini, 2015, 2021; Poffenberger & Barrows, 1924; Silvia & Barona, 2009), artwork such as typeface (Kastl & Child, 1968; Velasco, Woods, Hyndman, & Spence, 2015) and paintings (Ruta et al., 2021), as well as everyday objects (Bar & Neta, 2007; Chuquichambi, Palumbo, Rey, & Munar, 2021; Sinico, Bertamini, & Soranzo, 2021), commercial products (Carbon, 2010; Leder & Carbon, 2005; Pombo & Velasco, 2021; Westerman et al., 2012), and exterior (Ruta, Mastandrea, Penacchio, Lamaddalena, & Bove, 2019) and interior environments (Hesselgren, 1987; Küller, 1980; Madani Nejad, 2007; Tawil, Ascone, & Kühn, 2022; Vartanian et al., 2013, 2019). Everyday human-made artifacts (e.g., objects, built environments) were typically presented as line drawings (Chuquichambi, Palumbo, et al., 2021; Madani Nejad, 2007), photographs (Bar & Neta, 2006; Vartanian et al., 2013, 2019), three dimensional renders (Dazkir & Read, 2012; van Oel & van den Berkhof, 2013), and recently in Virtual Reality (Banaei, Hatami, Yazdanfar, & Gramann, 2017; Formiga, Rebelo, Cruz Pinto, & Gomes, 2022; Tawil, Sztuka, Pohlmann, Sudimac, & Kühn, 2021). However, most of the previously tested interior design image stimuli were either not matched or not realistically representative of a real-life scenario (e.g., greyscale, drawings).

Despite the extensive replication of the contour effect across different stimulus categories, consensus on its origins remains elusive (Corradi & Munar, 2019). An evolutionary perspective was proposed, as effects were observed in different cultures, e.g., western and non-western (Gómez-Puerto et al., 2018; Munar, Gómez-Puerto, & Gomila, 2014) although not in Japanese (Maezawa, Tanda, & Kawahara, 2020) and Chinese (Dai, Zou, Wang, Ding, & Fukuda, 2022) observers, however again across age groups (Fantz & Miranda, 1975; Hopkins, Kagan, Brachfeld, Hans, & Linn, 1976; Jadva, Hines, & Golombok, 2010), and even in non-human primates (Munar, Gómez-Puerto, Call, & Nadal, 2015; Schneirla, 1966). One view, the “threat hypothesis”, attributes these effects to appraisal mechanisms, possibly developed to quickly detect and behaviourally avoid potentially threatening edges (Bar & Neta, 2006, 2007), suggesting an association with avoidance behaviour. Other explanations proposed a “curvature effect”, attributable to an inherently attractive and pleasant appeal of curves (Bertamini et al., 2016),that are assumed to cause specific activations of sensorimotor mechanisms (Amir, Biederman, & Hayworth, 2011; Fantz & Miranda, 1975), including approach behaviour in particular (Palumbo et al., 2015). A third perspective argues that, although possibly pre-shaped by evolution, the preference for curves could be learnt as it was found to be modulated by a so-called “Zeitgeist effect” denoting time-related societal trends (Carbon, 2010). At least for more complex domains such as human-made objects, and using explicit ratings, cars with curved features were favoured only when the design belonged to an epoch in which curvature was trendy. However, further research is needed to address particularly the behavioural accounts using appropriate experimental paradigms that can inform specifically on the approach-avoidance reactions that have been discussed.

Generally, the literature reports effects of angular vs. curved everyday human-made artifacts onto multiple psychological domains. Using explicit rating formats, spaces, furniture, and objects with curved features were evaluated more positively compared to those with angular ones. These evaluations encompass multiple affective dimensions, including preference (Bar & Neta, 2006; Carbon, 2010; Tawil et al., 2022), pleasantness (Banaei et al., 2017; Dazkir & Read, 2012; Formiga et al., 2022; Hesselgren, 1987; Küller, 1980; Madani Nejad, 2007; Vartanian et al., 2013), attractiveness (Leder & Carbon, 2005), beauty (Tawil et al., 2022; Vartanian et al., 2013, 2019), safety (Madani Nejad, 2007), and stress responses (Madani Nejad, 2007; Tawil et al., 2022). On the behavioural level, approach vs. avoidance explicit decisions have been reported (Dazkir & Read, 2012; Vartanian et al., 2019). The scarce neuroimaging studies observed a consistent preference for curves, however, correlated with different brain activation patterns. In one study, edgy everyday objects activated stress-related regions (Bar & Neta, 2007), while in another, curvilinear spaces activated regions related to pleasantness and reward (Vartanian et al., 2013). Yet, to date, most research has mainly relied on explicit measures to study responses to angular vs. curved interiors, and the behavioural reaction tendencies they elicit remain understudied.

Reaction time (RT) experimental paradigms are utilized in social and cognitive psychology to assess hypothetical links. These paradigms strive to assess responses that are less influenced by conscious processes, reducing the impact of social desirability or other expectancy biases, including experimenter bias. They find utility in clinical studies aimed at examining response biases in individuals suffering from psychological disorders like addiction, phobias, or suicidality (Nock et al., 2010; Wiers, Eberl, Rinck, Becker, & Lindenmeyer, 2011). Hereby, participants typically respond to stimuli presented on a computer screen through mouse, joystick movements, or button presses. Hypothetical “automatic” response biases with respect to the feature of investigation can be detected, reflected in differential RTs or errors made in response to the stimuli of interest vs. suited control stimuli. Such paradigms have shown efficacy in testing the effects of environmental image stimuli, for instance in a study demonstrating a tendency in humans to approach nature and avoid cities (Schiebel, Gallinat, & Kühn, 2022). Research investigating contours has employed these paradigms, although exclusively with abstract shapes and patterns, demonstrating automatic effects concerning semantic (Palumbo et al., 2015), hedonic (Chuquichambi, Corradi, Munar, & Rosselló-Mir, 2021), and motoric, i.e., approach-avoidance (Bertamini et al., 2016; Palumbo et al., 2015) associations. Using an updated version of the implicit association task (IAT) (Greenwald, McGhee, & Schwartz, 1998), curved abstract shapes were associated with semantic concepts of positive valence and safety, and angular ones were related to opposite concepts (Palumbo et al., 2015). More recently, an affective stimulus-response compatibility (aSRC) task (Eder, Elliot, & Harmon-Jones, 2013) with non-verbal content (i.e., schematic faces instead of words) detected the compatibility of curved and symmetric patterns with positive hedonic tones (Chuquichambi, Corradi, et al., 2021). Furthermore, associations between contour shapes and approach-avoidance movements were demonstrated using adapted versions of the stimulus-response compatibility task (SRCT; De Houwer, Thomas, & Baeyens, 2001). These associations were driven by an approach tendency towards curved polygons rather than an avoidance of angular ones (Bertamini et al., 2016; Palumbo et al., 2015).

In this study, we investigated behavioural response tendencies towards contours using a set of photo-realistic living room images featuring varying contours (angular vs. curved) and styles (modern vs. classic). Explicit responses to the same images previously showed that curvature positively impacted aesthetic preference, while angularity was related to higher self-reported stress (Tawil et al., 2022). Here, we adopted an experimental testing strategy with RT tasks that can detect associations between mental representations and action/response tendencies. The ad-hoc test battery selection comprised the dot probe task (DPT; MacLeod, Soong, Rutherford, & Campbell, 2007), the approach-avoidance task in stimulus-irrelevant format (AAT; Wiers et al., 2011), the implicit association task (IAT; Greenwald et al., 1998), and the stimulus-response compatibility task (SRCT; De Houwer et al., 2001). These tests were selected based on previous studies focusing on abstract contours (SRCT, IAT) as well as a prior study on (city vs. natural landscape) environmental stimuli (DPT, AAT, and IAT), which identified response tendencies suggesting attentional and approach biases towards nature (Schiebel et al., 2022). Our particular focus was on approach-avoidance tendencies since these may best align with the different theories explaining the source of the contour effect (i.e., threat hypothesis vs. curvature appeal). To the best of our knowledge, implicit

RT paradigms have not yet been employed to evaluate responses to contours related to interior environments. Our primary goal was to mirror the contour effect with implicit paradigms (pre-registration can be retrieved from https://aspredicted.org/B65_HP6) and thus to tap into less aware responses (in contrast to self-reports), representing the 'behavioural component of emotional responding' (see Krieglmeyer & Deutsch, 2010). Furthermore, we explored whether other contextual (i.e., style) and individual (i.e., self-reported sex) factors affected the results, as previously observed for explicit measures (Tawil et al., 2022). Such findings could contribute to the understanding of (more) automatic responses to contours, facilitating a cost-effective, yet objective exploration of human reactions to interior design and architectural stimuli. Unravelling such tendencies in the long run could also inform design strategies aimed at considering immediate human responses, which may be particularly relevant to spaces intended to promote mental health and wellbeing, but also everyday environments.

2. Materials and methods

2.1. Participants

A total of N = 219 participants enrolled in the study via the crowdsourcing platform Prolific.[1] We determined the sample size based on results from an unpublished forerunner pilot of the AAT using similar stimuli (for detailed sample size calculations, see Tawil et al., 2022). To be included, participants had to confirm age (between 18 and 69 years old), absence of neurological/mental disorder requiring medication, no psychotic disorder, acute suicidal thoughts or tendencies, and no regular drug intake, no visual impairment unless appropriately corrected, German language proficiency, and the availability of an external computer mouse (for the AAT). The study was approved by the local psychological ethics board of the University Medical Center Hamburg-Eppendorf (LPEK-0215). The experiment lasted 1 hour on average and participants were compensated with approximately 10€.

2.2. Stimulus material

The stimulus material originated from a previous Virtual Reality study (Tawil et al., 2021). Four different living rooms were created and implemented in the gaming software Unity[2] (version 2019.2.1f1, 64-bit). Each of the four rooms included objects matched in their bounding sizes, materials, and colours, and contrasted exclusively according to the respective combination of the two study design factors "contours" and interior design "style". Rooms within the same pair were matched in all design features, except with respect to their contours (angular vs. curved). The contrast between pairs was style (modern vs. classic). We generated 80 images, with 20 images per room. Out of the respective 20 images, only those that showed insignificant differences in low-level image properties across the design factors were selected, resulting in five images per room (for more details, see Tawil et al., 2022). In total, 20 images were included in the final stimulus set (10 pairs of modern [5 angular, 5 curved], 10 pairs of classic [5 angular, 5 curved] stimuli). Stimulus examples are shown in Fig. 1a.

2.3. Experimental tasks and randomization

2.3.1. Dot probe task (DPT)

A keyboard input DPT was used (adapted from Schiebel et al., 2022). Each trial began with a 500ms central fixation cross, followed by a pair of matched images with angular vs. curved features, randomly presented on the right or left side. After a 500ms presentation, a probe ("X") appeared behind either the angular (hereafter defined as "congruent" condition) or the curved (hereafter defined as "incongruent" condition) stimulus (Fig. 1b). Participants had up to 1.000ms to identify the side on which the probe appeared by pressing the keyboard letters "E" (located on the left side of the keyboard) or "I" (right side). If no response was given, a red error message ("Fehler") would centrally show for 400ms. Trials were fully randomized, with 40 trials in total, therefore, each stimulus was presented four times (2 [left/right] x 2 [with/without probe appearing behind it]). Ten practice trials were conducted prior to the main trials, showing probes behind grey rectangles matching the size and positions of the stimulus pairs.

This paradigm resulted in two RT parameters of interest per participant: median RTs for the "congruent" and "incongruent" trials. Since the DPT is considered 'a gold standard in the field for investigating attentional bias to threat' (Kappenman, Farrens, Luck, & Proudfit, 2014), the label "congruent" was assigned to angular conditions in line with the threat hypothesis, which posits that attention is automatically drawn to angular compared to curved stimuli. Therefore, faster RTs could be expected for congruent conditions.

2.3.2. Approach Avoidance Task (AAT)

A stimulus-irrelevant AAT with mouse input was used (adapted from Schiebel et al., 2022), in which participants responded to the image orientation (Cousijn, Goudriaan, & Wiers, 2011). Each room image appeared four times, twice tilted to the left and twice to the right by 2° (see Fig. 1b). Participants completed 20 practice trials (with grey rectangles) then 80 main trials (with room images). In each trial, participants clicked on a central fixation cross before stimulus presentation to ensure a central initial position of the cursor. Using the mouse, they were instructed to pull the stimuli towards themselves (approach; whereby the image enlarges [zoom in until filling up nearly the entire screen]) or push it away (avoid; whereby the image shrinks to only a fraction of its original size [zoom out]), depending on its orientation (tilt), as quickly as possible. The stimulus disappeared after reaching its maximum (approach) or minimum (avoid) size, by the mouse cursor reaching the screen's upper or lower bound. The zoom feature mimics the stimulus moving towards or away from the self/participant (Fig. 1b). Incorrect cursor movements triggered a 400ms central red error message ("Fehler"). Instructions were randomized between participants (PULL--if-tilted-right & PUSH-if-tilted-left vs. PULL-if-tilted-left & PUSH-if-tilted-right). We evaluated two different AAT outcomes as typically done: initial (stimulus onset until mouse movement initiation) and movement (start of mouse movement until stimulus disappearance) RTs.

The paradigm results in four RT parameters of interest per participant, by means of which an interaction of [2] direction (approach vs. avoidance) and [2] contour (angular vs. curved) can be computed, and reflects the main analysis of interest. Significant interactions could manifest as between- and/or within-contour differences. Faster approach RTs towards curved vs. angular stimuli (between-difference) could be detected. Approach (vs. avoidance reactions) towards curved stimuli (within-difference) should be faster. Conversely, faster avoidance RTs of angular vs. curved stimuli (between-difference) could be observed. Avoidance (vs. approach) reactions towards angular stimuli (within-difference) should be faster.

2.3.3. Implicit association task (IAT)

The IAT (adapted from Schiebel et al., 2022) comprised 7 blocks. In the first (categorization) block, participants quickly assigned each centrally presented stimulus to either "angular" ("Eckig") or "curved" ("Rund") categories (shown on the screen's upper left and right sides) by pressing a left ("E) vs. right ("I") button on the keyboard [block 1; 20 trials]. In the second (attribute practice) block [block 2; 20 trials], five "approach", e.g., "to touch" ("berühren") and five "avoidance" words, e.g., "to dodge" ("ausweichen") were each centrally presented (twice), and participants sorted them into their respective categories ("Annäherung" and "Vermeidung" which respectively translate as

[1] www.prolific.co.

[2] www.unity.com.

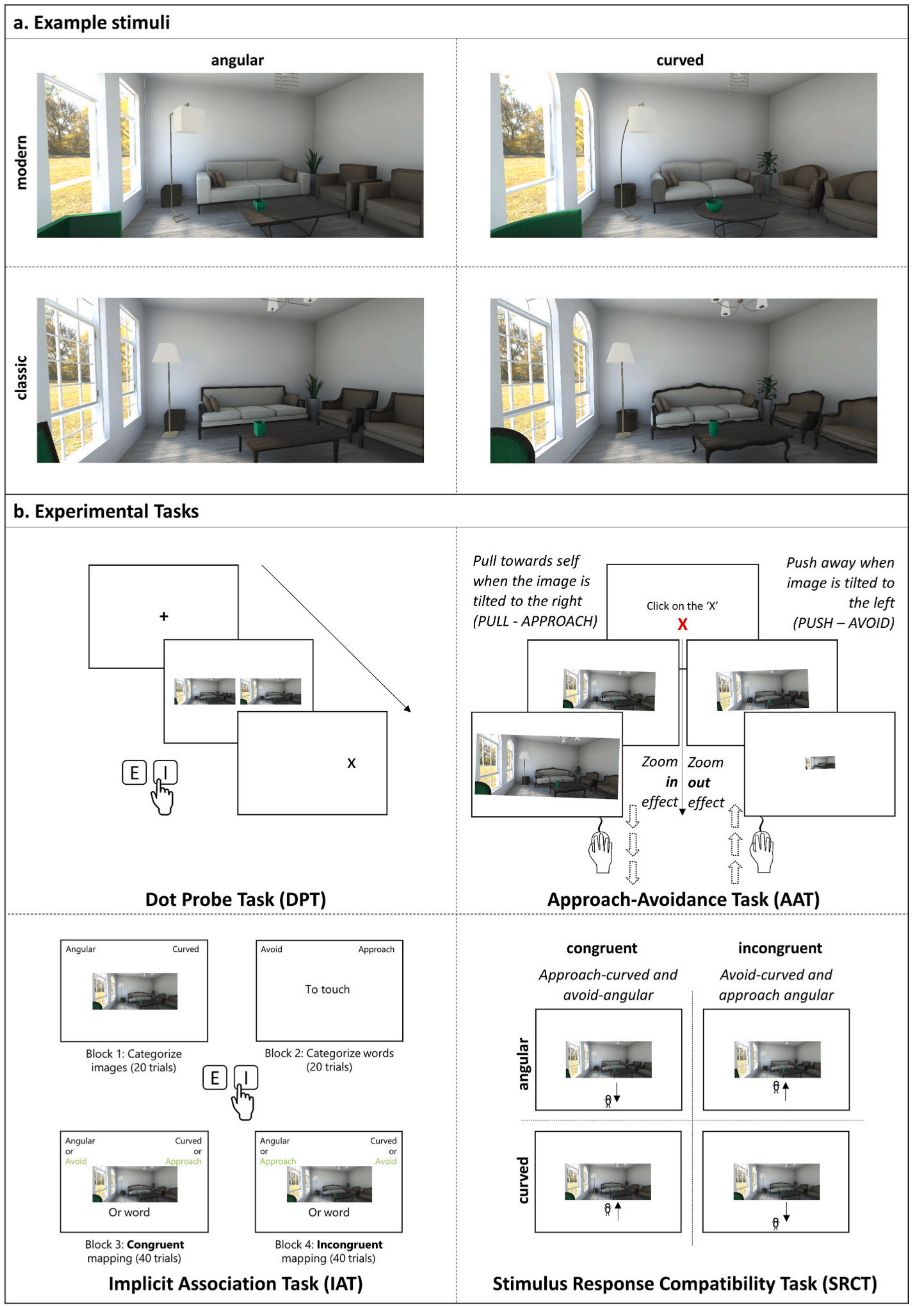

Fig. 1. Stimuli and experimental tasks. **a.** Example stimuli showing the same view according to the design factors contour (angular vs. curved) and style (modern vs. classic). The generated image size was set to 5075 × 2160 pixels, 4 K resolution with ratio 21:9. **b.** Example slides showing the four experimental tasks.

"approach" and "avoidance"). During the next two blocks [3–4; 40 trials each], participants assigned the 20 images (each once) and ten words (each twice), alternately displayed, into the combined categories in an "incongruent" ("curved-avoid", "angular-approach") or "congruent" ("curved-approach", "angular-avoid") pairing (see Fig. 1b). Next, they repeated the categorization task from block 1, but with the sides of "angular" and "curved" categories switched [block 5; 20 trials]. The remaining pairings (opposite to block 3–4) were then presented in the last two blocks [6–7; 40 trials each]. A 200ms red error message appeared if participants pressed the wrong button, requiring correction. The intertrial interval was 250ms. The total number of trials was n = 220. The main outcomes were RTs for "congruent" vs. "incongruent" pairings across blocks 3–4 and 6–7. Only RTs related to image stimuli were evaluated.

This paradigm results in two RT parameters of interest per participant: the "congruent" and "incongruent" median RTs forming the "congruency" factor. The congruent condition is hypothesized to match participants' semantic associations (curved conditions with the approach category and angular conditions with the avoidance category), and thus faster responses can be expected.

2.3.4. *Stimulus response-compatibility task (SRCT)*

A keyboard input SRCT was utilized (adapted from the millisecond download library[3]). Participants initially viewed a black screen for 1000ms, followed by a randomly selected stimulus with a manikin placed (randomly) above or beneath it. Depending on the manikin location, they pressed the "up" or "down" (arrow) keyboard buttons to

[3] https://www.millisecond.com/download/library.

make the manikin approach or avoid the stimulus based on its depicted contour content (Fig. 1b). Two main blocks were presented in random order, in which participants were instructed to approach images of curved interiors and avoid those of angular ones in one block (20 trials, each stimulus presented once), and vice versa in the other block (20 trials). Two distractor blocks (each with 20 trials) were randomly presented either before or after the main blocks, where participants had to move the manikin to the left or right (curved-move-right, angular-move-left vs. curved-move-left, angular-move-right). Errors (moving the manikin into the wrong direction) were flagged with a 1000ms message ("Fehler"). Each block had 10 practice trials (images from the same rooms, not included in the main experiment).

This paradigm results in four RT parameters of interest per participant: two median RTs respectively for [2] direction (approach vs. avoidance) and [2] contour (angular vs. curved). The interaction between direction and contour was the focus of the analysis, which in the post-hoc tests could plausibly manifest within-contours (faster approach & slower avoidance of curvature; slower approach & faster avoidance towards angularity) or within-directions (faster approach towards curvature vs. angularity; faster avoidance of angularity vs. curvature), or both.

2.4. Procedure

The experiment was conducted online using Inquisit 6 software.[4] Participants were recruited via Prolific. First, they were informed about the aims (examining perception of different interior designs) and provided informed consent. Eligibility criteria were later checked, before administration of the four tasks, which were presented in quasi-random order. The DPT and AAT were always introduced first, and the IAT and SRCT thereafter, as the latter two tasks included explicit instructions regarding how to respond to curved vs. angular stimuli. Hence, showing IAT and SRCT first would have enhanced awareness concerning the stimuli classification (curved vs. angular) which could have interfered with the DPT and AAT, in which participants were unaware of the stimulus type concerning contours. Upon completing the tasks, participants filled out a sociodemographic survey (age, biological sex, school degree, net income, and occupational status), including questions about environmental exposure (nature vs. urban exposure and landscape preferences, home environment and preferences), expertise in arts and architecture through part A of the Vienna Art Interest and Art Knowledge Questionnaire (VAIAK; Specker et al., 2020) and another version adapted to architecture, psychopathology levels with the depression, anxiety, and stress scale (DASS-21; Lovibond & Lovibond, 1995), as well as personality traits (BFI-10; Rammstedt & John, 2007). In the last section, participants rated the stimuli on different visual analogue scales concerning aesthetics and stress response evaluations (for details and results see Tawil et al., 2022).

2.5. Statistical analyses

We followed a data preparation and analysis approach similar to a prior study (Schiebel et al., 2022) for our four RT tasks results.

Mixed effects (repeated measures) ANOVA models were used with different factors (and their interactions) depending on the task and corresponding hypothesis (for more details, see respective descriptions of the experimental tasks above). Post hoc t-tests were conducted for significant effects of interest. *P*-values were checked for false discoveries using the False Discovery Rate method (FDR) (Benjamini & Hochberg, 1995), corrected according to the total number of relevant comparisons across each task. We considered this to be a good compromise given the explorative character of the study (i.e., little previous evidence and novelty of the stimulus material). As correction had no substantial impact on the significance, we report the uncorrected values within the manuscript and the corrected ones within the Supplementary Material (SM).

Data pre-processing was conducted in Python (version 3.8.3; see section 1 in SM for details). Data analysis was conducted with RStudio-v4.2.1 (RStudio, Boston, MA, USA). We fitted the models and produced inferential statistics using the function "ez_aov" from the package "afex" (Singmann et al., 2022). We used the packages "emmeans" (Lenth et al., 2022) for pairwise comparisons and "effectsize" (Ben-Shachar, Lüdecke, & Makowski, 2020) for effect sizes.

Moreover, in order to enhance the robustness and generalizability of our findings, we opted to conduct a sensitivity analysis. To that end, we complemented the ANOVA approach with a linear mixed-effects modelling (LME) approach. LME models effectively accommodate both the between-subject and within-subjects effects of the independent variable while also providing the capacity to consider random effects associated with subjects and stimuli (Baayen, Davidson, & Bates, 2008; Judd, Westfall, & Kenny, 2012). The raw, unaggregated data was used for the sensitivity analysis. We used the "lmer" function from the "lme4" package to fit the models (Bates, Mächler, Bolker, & Walker, 2015) and the package "emmeans" to produce the inferential statistics and *p*-values, as well as to obtain predicted means for the fixed effects.

3. Results

3.1. Descriptive sample data

The dataset contains information from 197 to 205 participants depending on the questionnaire. Table 1 describes the sample in terms of biological variables, education, knowledge and expertise in architecture, general (aesthetic) preferences, and psychopathology.

3.2. Experimental tasks

3.2.1. DPT

The $2 \times 2 \times 2$ ANOVA with factors "congruency" (congruent vs. incongruent), "contour" (angular vs. curved), and "style" (modern vs. classic) did not yield the expected significant congruency effect ($F(1,207) = 0.42$, $p = .52$, $n2 < 0.001$). For a more detailed analysis, including other main effects and interactions, see Supplementary Table 1 (inferential statistics) and 2 (descriptive statistics).

Similarly, another ANOVA on error rates with the same factors as reported above, revealed no significant main effects ($p > .05$).

3.2.2. AAT

The $2 \times 2 \times 2$ ANOVA with factors "direction" (approach vs. avoid), "contour" (angular vs. curved), and "style" (modern vs. classic) revealed that the main interaction of interest, namely contour x direction, was non-significant for both initial ($F(1,118) = 1.11$, $p = .30$, $n2 < 0.001$) and movement ($F(1,115) = 0.31$, $p = .58$, $n2 < 0.001$) RTs. No significant main or interaction effects were observed beyond the main effect of direction, that exclusively showed in movement RT ($F(1,115) = 8.87$, $p = .004$, $n2 = 0.004$), indicating participants were generally faster in avoiding than approaching stimuli. For further details, see Supplementary Tables 3 and 4 (inferential statistics), and 5 (descriptive statistics).

In line with the RT response, the analysis of the error rates also revealed an effect of direction, but no significant interaction of direction x contour.

3.2.3. IAT

The $2 \times 2 \times 2$ ANOVA including factors "congruency" (congruent vs. incongruent), "contour" (angular vs. curved), and "style" (modern vs. classic) revealed a significant main effect of congruency ($F(1, 192) = 97.51$, $p < .0001$, $n2 = 0.074$). Pairwise comparisons showed that, on average, RTs were faster during congruent ($M = 720.93 \pm 133.28$) compared to incongruent ($M = 809.38 \pm 151.00$) test blocks with

[4] www.millisecond.com.

Table 1
Sample characteristics.

	N	Range [a]	Median	SD	freq.	%
Biological Variables	*200*					
Age		18–69	28.0	10.83	–	–
Self-reported sex [b]						
Male		–	–	–	101	50.5
Female		–	–	–	99	49.5
Handedness						
Right		–	–	–	170	85.0
Left		–	–	–	25	12.5
Ambidextrous		–	–	–	5	2.5
Vision correction (yes/no)						
Yes		–	–	–	91	45.5
No		–	–	–	109	54.5
Education	*200*					
Years of education [c]		5–13	12	1.34	–	–
Nominal level of education [d]						
No school degree		–	–	–	1	0.5
Hauptschulabschluss (9)		–	–	–	2	1.0
Realschulabschluss (10)		–	–	–	14	7.0
Polytechnische Oberschule (10)		–	–	–	5	2.5
Fachhochschulreife, Abschluss Fachoberschule (12)		–	–	–	[e]2	11[f]0
Allgemene Hochschulreife/ Abitur (12–13)		–	–	–	156	78.0
Architectural/aesthetics knowledge	*205*					
Architecture/design related profession (yes)		–	–	–	5	2.4
VAIAK architecture [e]		0–41	7	7.42	–	–
Interior design – interest VAS [f]		0–100	61.0	27.3	–	–
Interior design – knowledge VAS [f]		0[d]100	23.0	23.66	–	[c]
General aesthetic preferences						
Preferred interior design style	*198*					
No preference		–	–	–	2	1.0
Classic/traditional		–	–	–	19	9.6
Modern		–	–	–	104	52.5
No predominant style/ mixed		–	–	–	69	34.9
Other		–	–	–	4	2.0
Green colour rating – VAS [g]	*197*	0–100	75	22.99	–	–
Psychopathology	*198*					
DASS21- stress [h]		0–36	10.0	7.21	22	11.1
DASS21 – anxiety [h]		0–28	4.0	5.30	39	19.7
DASS21 – depression [h]		0–42	8.0	7.91	48	24.2

[a] Observed value range.
[b] The terms "male" and "female" are used as grouping adjectives, as this was how participants were asked to (dichotomously) classify themselves.
[c] School and professional education.
[d] Based on German education system. Years of education for each qualification are mentioned in brackets.
[e] A 7-item version of the interest subscale of the VAIAK (Vienna Art Interest and Knowledge Questionnaire) adapted to focus on architecture and interior design.
[f] Visual analogue scale (0–100) to rate interest or knowledge concerning architecture and interior design.
[g] Visual analogue scale (0–100) to rate the green colour as the only non-neutral colour presented in the rooms.
[h] DASS21 = Depression, Anxiety and Stress Scale 21. Values under the frequency column are the number of subjects reaching a clinically meaningful cutoff (i.e., moderate severity).

medium effect size ($t(192) = -9.88$, $p < .0001$, $d = 0.71$); (see Fig. 2). No significant two- or three-way interactions with neither contour (e.g., congruency x contour: $F(1,192) = 0.35$, $p = .557$, $n2 < 0.001$) nor style were observed (see Supplementary Table 9). For further inferential and

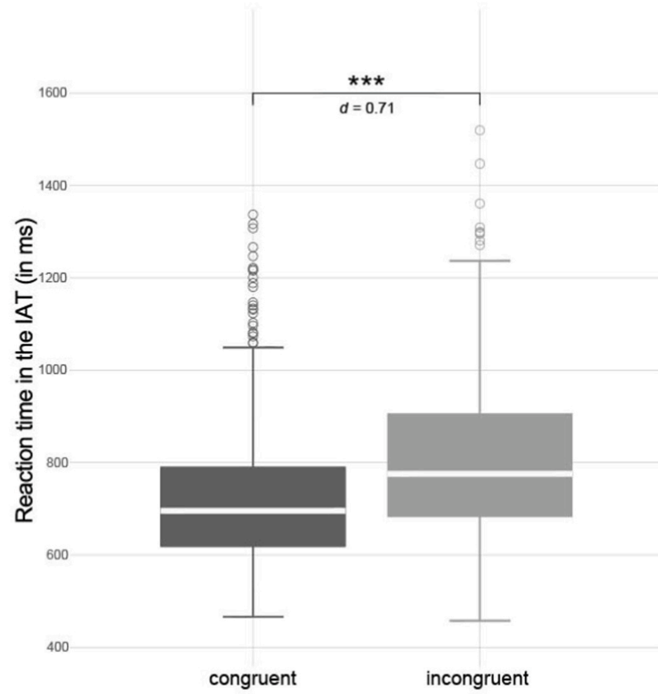

Fig. 2. Results of the IAT. Error bars represent standard errors.

descriptive statistics, see Supplementary Tables 9–11.

Patterns of error aligned with those of RTs, indicating that the number of errors was higher in incongruent than congruent trials.

3.2.4. SRCT

The 2 × 2 × 2 ANOVA, incorporating factors "direction" (approach vs. avoid), "contour" (angular vs. curved), and "style" (modern vs. classic), revealed a significant two-way interaction of direction x contour ($F(1,179) = 7.08$, $p = .009$, $n2 = 0.004$), as depicted in Fig. 3a. In terms of within-contour contrasts, pairwise comparisons showed that participants were faster approaching ($M = 937.93 \pm 246.68$) than avoiding ($M = 1027.33 \pm 252.88$) images showing curved interiors with small effect size ($t(179) = -5.42$, $p < .0001$, $d = 0.40$). Conversely, they were indifferent with respect to (approaching or avoiding) images with angular contours, as evident from the insignificant pairwise-comparison ($t(179) = -0.95$, $p = .35$, $d = 0.07$). Regarding the within-direction effects, while participants approached curvature descriptively faster than angularity, the effect was statistically insignificant. However, participants avoided angularity ($M = 974.73 \pm 223.11$) significantly faster than curvature ($M = 1027.33 \pm 252.88$), with small effect size ($t(179) = -3.09$, $p = .002$, $d = 0.23$); see Supplementary Tables 6–8 for more details.

The triple-interaction effect of direction x contour x style was also significant ($F(1,179) = 4.84$, $p = .03$, $n2 = 0.001$), as illustrated in Fig. 3b. Post-hoc comparisons revealed different patterns depending on the interior design style. While similar trends as those described above were observed within the classic style, the within-curvature difference (faster approach and slower avoidance) remained similarly significant within the modern style ($t(179) = -5.32$, $p < .0001$, $d = 0.40$), while the within-angularity indifference further descriptively increased ($t(179) = 0.04$, $p = .097$, $d < 0.0001$). This resulted in significantly both faster approach ($t(179) = 2.9$, $p = .004$, $d = 0.22$) and slower avoidance ($t(179) = -2.82$, $p = .005$, $d = 0.21$) of curved compared to angular interiors. For further details, see Supplementary Tables 6–8.

Error rates analyses mirrored the results above, revealing a significant two-way interaction effect of direction and contour on participants RT responses. Specifically, error rates were the highest when avoiding images of curved vs. angular interiors, as well as when compared to

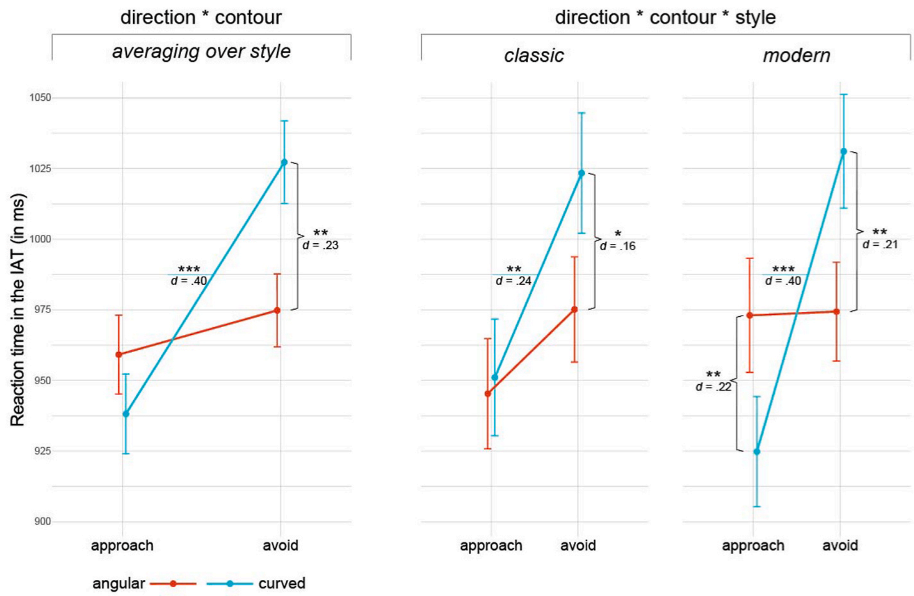

Fig. 3. Results of the SRCT. Error bars represent standard errors.

approaching them. The three-way interaction with style was also significant.

3.3. Interaction effects with self-reported sex

Interaction effects with "self-reported biological sex" (male vs. female; referred to hereafter as sex) were computed for exploratory purposes only when the main effect/interaction of interest was significant. This was the case for the IAT and the SRCT. Therefore, the two ANOVA models were updated by adding the factor "sex".

3.3.1. IAT

The 2 × 2 × 2 × 2 ANOVA revealed a significant main effect of "sex" on the IAT RTs ($F(1, 191) = 7.47$, $p = .007$, $n2 = 0.025$). Faster responses were generally observed in the female compared to male subgroup (see Supplementary Tables 13 and 14). There was a significant interaction effect of congruency x sex ($F(1, 191) = 8.88$, $p = .003$, $n2 = 0.007$). Pairwise comparisons indicated significant "congruency" effects within both groups, meaning, participants of both reported sexes were faster assigning images according to the congruent as opposed to incongruent instruction. When looking into between-group effects, RTs during congruent test blocks were faster for female ($M = 682.86 \pm 105.33$) compared to male ($M = 758.60 \pm 147.20$) participants with small effect size ($t(191) = 4.11$, $p = .0001$, $d = 0.30$). The groups did not differ in their response to incongruent trials ($t(191) = 1.08$, $p = .28$, $d = 0.08$). See Fig. 4 for a graphical depiction of the results, and Supplementary Tables 12–14 for more details on inferential and descriptive statistics.

No other significant two- or three-way interactions with neither contour nor style were observed (see Supplementary Table 12).

3.3.2. SRCT

When accounting for the effects of the factor sex on the SRCT RTs, we observed no main or interaction effects on any of our variables of interest, e.g., direction x contour x sex: $F(1, 177) = 1.16$, $p = .28$, $n2 < 0.001$ (see Supplementary Tables 15 and 16 for complete inferential and descriptive statistics).

3.4. Sensitivity analysis

For each of the four tasks, we estimated a model with the same ANOVA variables (experimental factors) and their interactions as fixed-

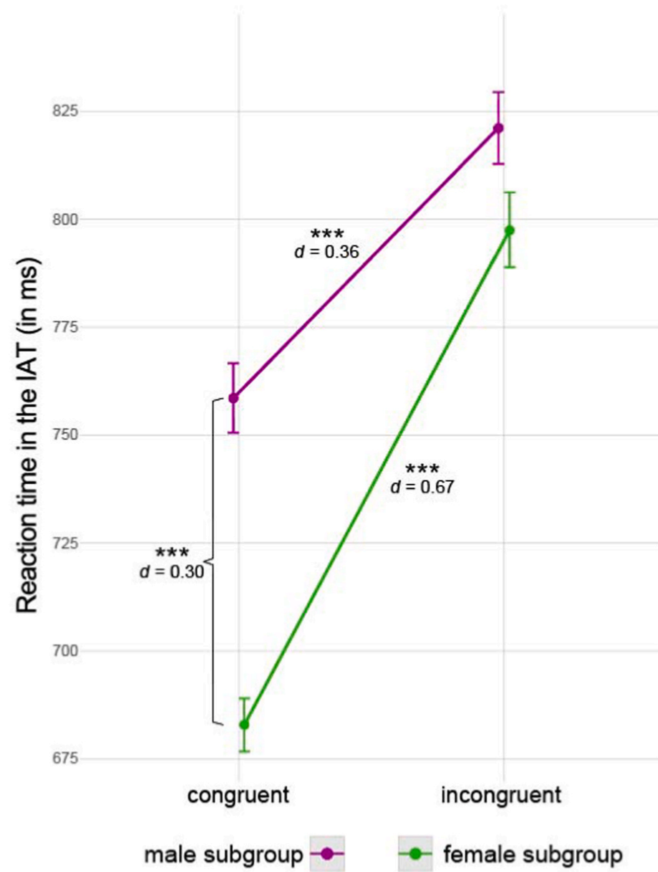

Fig. 4. Results of the interaction of congruency and sex in the IAT. Error bars represent standard errors.

effects and we estimated the related relevant random intercepts and slopes for participants and stimuli (see section 2.3 in the SM). Results of the LME models mirrored those of the ANOVA approach, confirming null results in the case of the DPT and AAT, and significant results for the IAT and SRCT that are of the same type (i.e., main effects or interactions) and direction as in the ANOVAs. Please see section 2.3 of the SM for more information regarding the LME results.

4. Discussion

Contour shapes are thought to play an influential role in how physical environments are perceived and evaluated, with a noted positive effect of curved vs. angular stimuli. The main explanations focused on either automatic appraisals or sensorimotor system responses (Corradi & Munar, 2019), with some attributing the effect to an avoidance of angularity (the threat hypothesis) (Bar & Neta, 2007), while others emphasize the attractiveness of curves (the curvature effect) (Bertamini et al., 2016; Vartanian et al., 2013). Another view highlighted the role of design trends in moderating this preference, at least within human-made domains (Carbon, 2010). Since previous research mainly relied on self-reports, we tested behavioural response tendencies towards contours in interior environments using a battery of four RT tasks that could detect potential automatic biases.

4.1. DPT

The "threat hypothesis" proposes that humans have evolved to prefer curvature due to their need to quickly detect and avoid edginess (Bar & Neta, 2007). We used the DPT as a marker of potentially biased attention and speculated that if angles would be perceived as "threatening", participants' attention would be drawn to angular conditions, leading to a faster detection of probes behind those. However, we observed no effects of contours on the DPT RTs, as participants' responses were independent of whether the probe appeared behind angular or curved stimuli.

There are several possible explanations for the null finding. Despite the demonstrated salience of angles/corners (Bertamini, Helmy, & Bates, 2013; Cole, Skarratt, & Gellatly, 2007), research suggests that scene gist is processed faster than individual objects, and understanding scene context might be more fundamental to threat judgement than object perception per se (Hochstein & Ahissar, 2002; Oliva & Torralba, 2006). It is possible that learning and exposure might have led to angular cues losing their threatening nature in living environments (Vartanian et al., 2013). Additionally, the contour differences in our stimuli may have been too subtle for participants to detect. The images represented overall room views in a relatively small size when compared to real-life scenarios, and also relative to the image size in the other tasks. Future research could compare environments with sharper angles or systematically vary the extent of angularity to explore whether the degree of edginess will affect participants' responses, as proposed in recent studies with abstract shapes (Clemente, Penacchio, Vila-Vidal, Pepperell, & Ruta, 2023).

Of note, defining the angular condition as "congruent" might be viewed critically, albeit aligning with the origins of the DPT as a task to detect threat-related attentional biases (Kappenman et al., 2014). Some studies proposed that curves, more common in natural environments in which the visual system has evolved, are processed more fluently and can be responded to faster than angles (Bertamini, Palumbo, & Redies, 2019; Chuquichambi et al., 2020). Unlike angles, which are defined by a set of vertices with abrupt orientation changes, curved shapes have a continuous changes along their contour, enhancing the efficiency of contour integration (Bex, Simmers, & Dakin, 2001; Field, Hayes, & Hess, 1993). Still, we also found no evidence for faster responses to curved conditions.

4.2. AAT

We assessed potential automatic behavioural/motoric biases towards curvature vs. angularity using an AAT with stimulus-irrelevant design. This means that participants responded to image orientation (instead of contours) by pulling a stimulus towards themselves (approach) or pushing it away (avoidance). As in the DPT, we expected contour to be a relevant feature, even when participants were not explicitly instructed to attend to it. Unlike hypothesized, we did not find evidence of any motoric biases or tendencies to approach or avoid either of the contours.

Overall, these results are in line with literature mostly reporting non-significant effects using the AAT when instructions are implicit, i.e., participants are not made aware of differential stimulus characteristics (Phaf et al., 2014). A study investigating contour and symmetry in abstract patterns similarly found that the responses to an affective stimulus-response compatibility (aSRC) task were only influenced when participants were instructed to think of one of the two features when responding (Chuquichambi, Corradi, et al., 2021). In fact, some argue that when stimulus features are task-relevant, compatibility effects can be better detected since the processing of irrelevant information is reduced (Fujita, Gollwitzer, & Oettingen, 2007; Gollwitzer, 2012). As mentioned above, it could be that the differences between our contour conditions were too subtle to be detected by participants without having to consciously take note of the contour. Future research may investigate whether making the contour more extreme or applying explicit instructions would reveal significant effects. However, it is worth noting that both the DPT and AAT could have been carried out without being consciously aware of not only the contour content, but also the images per se, whereby participants may have been rather solely focusing on the image orientation (AAT) or expected probe (DPT).

4.3. IAT

We conducted an IAT to capture semantic associations with the approach-avoidance concept. Participants categorized stimuli into hypothetical congruent (curved-approach and angular-avoid) and incongruent (angular-approach and curved-avoid) pairings. As predicted, we observed significantly faster responses in congruent trials, indicating that participants were faster sorting the images when curved and approach as well as angular and avoid categories were mapped together in pairs. The pattern suggests that participants associated these concepts in these specific mappings more intuitively, therefore, these links seem to be stronger in their mental representation, than the opposite, hypothetically incongruent pairings.

The findings confirm the previously reported positive effect of curved objects (Bar & Neta, 2006; Leder & Carbon, 2005) and interiors (Dazkir & Read, 2012; Madani Nejad, 2007; van Oel & van den Berkhof, 2013; Vartanian et al., 2013, 2019), in particular with respect to the same stimulus set (Tawil et al., 2022). The results are also in line with earlier evidence supporting a self-reported tendency to approach curved vs. angular furniture (Dazkir & Read, 2012) and spaces (Vartanian et al., 2019). In addition to the previously detected biases to associate contours with affective concepts (valence, safety) (Palumbo et al., 2015), we demonstrated semantic associations with a behavioural/motoric outcome, namely, approach-avoidance words.

While the interior design style (modern vs. classic) did not affect RTs, we observed a significant effect of participants' reported sex. The curved-approach and angular-avoid associations were more pronounced in female participants, who were also generally faster with the task. This higher sensitivity to contours in female participants aligns with prior research on children (Munroe, Munroe, & Lansky, 1976) and abstract shapes (Palumbo, Rampone, & Bertamini, 2021). It also manifested in the explicit preference response to the same stimulus material (Tawil et al., 2022). To note, the literature reports general sex differences in semantic processing (Wirth et al., 2007). For instance, studies have found that women process natural categories faster and more fluently while it is easier and quicker for men to process human-made categories (Bermeitinger, Wentura, & Frings, 2008; Capitani, Laiacona, & Barbarotto, 1999; Laws, 1999). Moreover, it appears that the two subgroups categorize the same common objects in systematically different ways (Pasterski, Zwierzynska, & Estes, 2011). Although both angular and curved conditions constitute man-made artifacts, curvature is considered a closer representation of nature (Coburn et al., 2020; Salingaros, 2015). However, we cannot say if curvature was indeed perceived as more natural as we have not explicitly tested for this.

We interpret the IAT effects as evidence for semantic/conceptual processes related to where such concepts are stored. The fact that effects were amplified in female participants reiterates the observation with explicit measures. In view of recent evidence suggesting that women may benefit more from salutogenic effects of natural environments (Sudimac & Kühn, 2022), further research is required to uncover societal and/or biological origins of this sensitivity to curved (interior) designs. Although the identified patterns might hint at a potential biophilic aspect of curves, the task was not designed to explain whether the effects relate to a tendency to approach curvature or conversely, to avoid angularity.

4.4. SRCT

The last measure to assess approach-avoidance tendencies was the SRCT. Hereby, participants were explicitly instructed to move a manikin towards/away from a stimulus, based on the depicted contours. As hypothesized, we observed a significant interaction between direction and contour, indicating that whether interiors had curved or angular features influenced how participants associated them with approach or avoidance movements: images of curved interiors were responded to with faster approach and slower avoidance responses, while images of angular interiors were approached and avoided equally fast. Additionally, angularity was always avoided faster than curvature. It seems that the effect lied within curvature yielding differential responses by instruction, whereas participants responded to angularity indifferently, regardless of instruction.

The results of the SRCT expand our knowledge from previous reports of an influence of contour on approach avoidance behaviour, further identifying the source of the effect. When comparing the findings with earlier evidence from studies that used a similar task to test abstract shapes (Bertamini et al., 2016; Palumbo et al., 2015), we confirmed consistent patterns in response to different contours, but with interior design stimuli. In particular, previous research also found faster approach and slower avoidance of curved abstract stimuli, and insignificant differences within angular ones, even when polygons had the most pronounced vertices (Palumbo et al., 2015).

There was also a significant interaction with style, similar to the effects found with explicit ratings of the same images, which revealed a preference for curves only within images depicting modern (compared to classic) style (Tawil et al., 2022). Here, modern style further descriptively increased the indifference towards angularity, but this time elicited both faster approach *and* slower avoidance towards curved vs. angular conditions. The findings, therefore, may propose a role of Zeitgeist in moderating responses to contours (Carbon, 2010). However, we note that objects in the modern and classic rooms included some differences in their geometrical properties, for instance the contrasting frames in the classic style, which might have affected participants' evaluations. Therefore, the effects should be further explored with a wider variety of styles.

Unlike the IAT, which demonstrated an influence of participant sex on how fast they associated contours with movement words, the SRCT yielded insignificant effects. This indicates that although these concepts were more strongly semantically connected in female participants' mental representations, this did not manifest in faster associative movements.

Our main interpretation of the SRCT findings supports a positive/pleasant effect of curved interior features (Vartanian et al., 2013), and hence motoric-approach-associations, rather than a negative/threatening effect of angular features. Although participants approached both contours generally similarly, it seems that it required them more effort to respond to images depicting curved features with an avoidance behaviour (slowest RTs), which suggests a tendency to come closer to curvature and stay longer compared with angularity. This also implies a biophilic aspect of curves (Browning et al., 2014; Salingaros, 2015).

4.5. Limitations and directions for future research

This study has limitations to consider. First, due to technical errors, the sample for the AAT was reduced by 75 participants from the original sample. Moreover, given the high rate of errors (67% of the original pool eventually qualified for evaluation), it remains uncertain whether all participants used a mouse (as instructed), especially since we did not assess compliance with this requirement. Second, the subtleness of our contour manipulation might have prevented us from detecting some expected effects in stimulus-irrelevant paradigms. However, as indicated by our previously reported manipulation check and participants' explicit ratings (Tawil et al., 2022), as well as the as-expected responses to the IAT and SRCT, the contour contrast was likely sufficiently pronounced. The absence of significant effects in both the DPT and AAT could hence be due to numerous other reasons. For instance, the SRCT may be better suited than the AAT to detect approach-avoidance reactions and biases, as it has previously shown better criterion validity in that it has been demonstrated to be significantly associated with self-reports for fear of spiders (Krieglmeyer & Deutsch, 2010). This difference may be attributed to inherent properties of the tasks, such as the intuitive nature of moving the manikin body towards or away from a stimulus in the SRCT, compared to directly moving the stimulus in the AAT, with the zoom feature potentially being perceived as an abstract effect. This taps into a more general, urgently needed critical discussion about implicit measures per se. The terms 'implicit' or 'automatic' should be used cautiously, as they formally require to be produced with explicit goals, awareness, substantial cognitive resources, and time (see De Houwer, Teige-Mocigemba, Spruyt, & Moors, 2009). In this paper, we used the term 'automatic' which is often used interchangeably with 'implicit'. However, we cannot rule out explicit goals and awareness. Concerning cognitive and time resources, we would argue that these were inherently limited by the task setup – albeit we cannot formally prove this claim. Especially in the two tasks where participants were made aware of attending and responding to the contour dimensions (IAT, SRCT), significant effects were found, which may call into question the 'implicitness' or 'automaticity' of responses and, arguably, providing a less clear distinction from explicit approaches such as self-reports.

A few last critical methodological remarks shall be made. Since the study was conducted on a platform dedicated for research, a sample bias might limit the generalizability of the results (i.e., highly educated sample, experienced with experiments). Similarly, the presented stimuli are limited in terms of representativeness. For one, we used static stimuli to generate conclusions about a dynamic experience. For another, we investigated the living room space, which, although multi-functional, is not representative of every other space. Future research may want to include more styles and target different functional spaces as well as different presentation modes to determine whether the effects can be exhibited similarly or ultimately differently.

5. Conclusion

In sum, this study confirmed effects of curved vs. angular interior designs using RT paradigms. Results identified associative biases with approach-avoidance words (IAT) and movements (SRCT), but neither attentional (DPT) nor motor biases (AAT), whereby findings were consistently shown with both reaction times and error rates as outcome parameters. The IAT demonstrated semantic associations indicating that curvature and approach, and angularity and avoidance were closely connected concepts in participants' mental representations. This is held especially true for women, who are perhaps more prone to the positive effects of (biophilic) curves. The SRCT particularly indicated weaker curvature-avoidance (as compared to relatively stronger curvature-approach) representations, similar to previous findings from abstract shapes. This effect was pronounced in modern style, now additionally yielding a significant difference concerning faster approach towards curved relative to angular interior designs.

Overall, this study provides evidence in favour of an attractive and pleasant intrinsic effect of curved interior designs rather than a threat afforded by angular ones, using behavioural measures hypothetically less influenced by conscious evaluations and expectancies in comparison to self-reports. More research is needed to study the criterion validity of the detected effects, such as for example in how far they relate to in-situ physiological and psychological responses in interior settings. In addition, a systematic approach to implicit task selection is needed to pinpoint hypothetical underlying psychological processes.

CRediT author statement

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Data availability statement

The datasets presented in this study along with the statistical codes can be found on: https://osf.io/vmw4f/.

Ethics statement

The studies involving human participants were reviewed and approved by Local Psychological Ethics Committee of the psychosocial center at Medical Center Hamburg-Eppendorf (LPEK-0215). The participants provided their written informed consent to participate in this study.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2023.102197.

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