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RESEARCH

Beyond the Surface: How Depth Alters Face Perception

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Abstract

Research in face perception has predominantly utilized two-dimensional images, which does not fully capture the complexities of human perception as it operates in real-world settings. Previous studies have demonstrated that 3D objects elicit different neural and behavioral responses compared to their 2D counterparts, suggesting a more profound engagement with and processing of real-world objects and environments. Grounded in the understanding that human visual perception has evolved in three-dimensional environments, this research addressed a notable gap in the literature on facial perception. This study investigates the impact of presentation modality (2D vs. 3D) on the perception of facial attractiveness, dominance, and masculinity using virtual reality (VR) technology. Results showed that 3D faces were perceived as slightly more attractive and masculine than 2D faces. Dominance ratings, however, appeared unaffected by dimensionality. Given the small effect sizes, our results should be interpreted viewed cautiously, and further research is needed to clarify the influence of dimensionality on social trait perception.

Keywords Face perception · Virtual reality · Three-dimensional perception · Visual cognition

Humans' visual perception in general, as well as our ability to process facial features of our conspecifics, has evolved in natural three-dimensional (3D) environments. Evolution is economical, allocating energy where it is of most value to an animal in a given environment. In other words, human eyes with their 3D perception have evolved because of their survival value, to make and maintain adaptive contact with the environment (Wade & Swanston, 2013). Nonetheless, the majority of perceptual and experimental studies of facial attractiveness perception have been conducted using conventional two-dimensional (2D) images as stimuli, which may have limitations in reflecting behaviours and brain processes responsive to tangible objects and environments (Snow et al., 2011; Snow & Culham, 2021). Snow and Culham (2021) point out that humans have evolved and visually adapted to the real-world environment and argue that real objects elicit different behavioural and neural responses than 2D images. This argument is supported by previous neuropsychological and behavioural research.

At the neural level, studies using EEG have shown that 2D projections and images produce different brain activity to 3D projections and real objects (Bohbot et al., 2017; Kober et al., 2012; Marini et al., 2019; Slobounov et al., 2015). Similarly, 3D movies displayed via stereopsis produced different and stronger brain connectivity and responses in a magnetic resonance imaging scanner (MRI) compared to presentations from a 2D screen (Forlim et al., 2019; Gaebler et al., 2014). In a functional magnetic resonance imaging (fMRI) study, Snow et al. (2011) compared real-world 3D objects to 2D pictures, revealing that 2D pictures elicit different brain responses than 3D objects. Collectively, this and related work suggests that neural mechanism involved in processing 3D objects differ from those processing a 2D representation of those same objects.

At the behavioural level, research has shown that individuals are more willing to pay for real food and rate them more satiating than 2D representations of those foods (Müller, 2013; Romero et al., 2018). Object-directed reaches are also modified in the near space of others, while image-directed

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reaches are not (Dosso & Kingstone, 2018). Moreover, object recognition is facilitated using real objects compared to their 2D pictures in patients with visual agnosia as well as healthy individuals (Holler et al., 2019; HumphRey et al., 1994). Real objects are more memorable compared to 2D pictures, as real objects are better recalled and recognized (Snow et al., 2014) and capture more attention (Gomez et al., 2018). Specifically, compared to 2D stimuli, real graspable objects elicited more powerful influence on attention in a flanker task (Gomez et al., 2018). Infants also display longer visual attention to real objects compared to pictures of those objects (Gerhard et al., 2016).

Despite the research on the advantages of real 3D objects over their matched 2D pictures, few studies have attempted to test the effect of 3D vs. 2D presentation of socially relevant stimuli, such as the human face, which is one of the most salient domains of human social cognition. Research on face perception has historically and conventionally used 2D images of faces, either as photographs of individuals or 2D renderings of 3D faces (for a recent review see Burt & CRewther, 2020). One particularly relevant aspect of social cognition is the perception of facial attractiveness. Facial attractiveness plays a vital role in how we interact with each other and influences our judgements and valuations of others. For instance, in line with 'what is beautiful is good' stereotype, individuals tend to associate positive characteristics, such as higher social and intellectual competence, to more attractive individuals (Dion et al., 1972; Little et al., 2011).

To date, research on facial perception, whether on facial recognition and emotion judgements (for a review see Krumhuber et al., 2013), or facial attractiveness (see below) has been limited in scope to using 2D images. Attempts to increase the ecological validity of the stimuli has led some researchers to use 2D dynamic stimuli (i.e., 2D video-recorded stimuli) yielding mixed results. Researchers who compared attractiveness ratings of static vs. dynamic faces found conflicting results in terms of sex differences of the stimuli (e.g., Lander, 2008; Roberts et al., 2009; Rubenstein, 2005). For example, Re et al. (2012) provided a surface map of 3D faces and presented them to participants on 2D screens. Comparing 2D versus rotating 3D images presented on a 2D screen, Tigue et al. (2012), using rotating 3D images of women's faces, found that men rated women's faces as more attractive in 3D images than in 2D images. A similar approach has been used, where scanned 3D faces were presented rotating as videos on 2D screens (Holzleitner & PerRett, 2016; Holzleitner et al., 2014, 2021; Třebický et al., 2018).

The research attempts on facial attractiveness as a function of stimulus modality (2D vs. 3D) has not yet utilised actual 3D stimuli (Coetzee et al., 2010; Holzleitner et al., 2021; Re et al., 2013; Třebický et al., 2018). Collectively, prior research that attempted to provide higher ecological validity by using 2D dynamic images or 2D renders (e.g., the introduction of photorealistic effects) of 3D images compared to real-world faces or facial representations in virtual reality (VR) remains limited in its methodological scope. In particular, the research has not actually used 3D stimuli. Importantly, while non-social real or 3D objects compared to their 2D images are more captivating, attention grabbing, memorable and appealing, the current state of the findings on facial attractiveness perception appears to suffer from lack of rigorous investigation using methods with higher degrees of ecologically validity, such as VR. The present study seeks to address this void by employing VR technology to examine whether 3D representations of faces, as opposed to 2D renderings of the same faces, influence perceptions of attractiveness, dominance, and masculinity within an ecologically valid setting for both male and female faces.

Method

Participants

A total of 53 participants were recruited from the University of British Columbia. 41 women between the ages of 18 and 39 ($M = 21.1$, $SD = 3.18$) and 12 men between the ages of 18 and 23 ($M = 20.58$, $SD = 3.29$) participated in the study. The marital status of participants indicated a total of 37 participants as being single (69.8%), 15 participants as being in a relationship (28.3%) and 1 participant preferred not to answer. In terms of their highest level of education achieved, 39 participants reported high school or GED (73.5%), 7 participants reported post-secondary diploma (1.32%), 6 participants reported undergraduate degree (1.13%) and 1 participant preferred not to answer.

Stimuli

Images of 20 male and 20 female faces, aged between 19 and 31 years and with a neutral expression, were obtained from the FACES database (Ebner et al., 2010). The faces from each 2D photograph were transferred to a corresponding male or female baseline avatar in Daz3D software using the Face Transfer feature. The Daz3D software employs facial detection algorithms to identify key landmarks of the 2D face image, such as the eyes, nose, mouth, and cheekbones (for more details see https://www.daz3d.com/face-transfer-unlimited). This process resulted in a 3D version of the face, including shape, bone structure, texture, and tone, resulting in 40 three-dimensional stimuli (see Fig. 1 for an example of the stimuli). 2D renders of the 3D stimuli showed flat faces with limited depth cues, a fixed viewpoint, and no interaction, while 3D VR models allowed dynamic viewing and depth perception for a more lifelike experience.

Fig. 1 From left to right: original image, 3D side view, and 2D side view of a male model, illustrating differences in dimensionality

Fig. 2 Examples of 2D and 3D stimuli of different male and female faces presented to the participants

The study consisted of a block of 2D face stimuli and a 3D face stimuli. In the 3D block, the avatars were positioned one meter away and at eye level with the participant. In the 2D block, faces were similarly presented at eye level in VR placed one meter away from the participant (see Fig. 2 for examples).

Equipment and Procedure

After consenting to participate in the study, participants answered sociodemographic questions. The stimuli were viewed using an HTC Vive headset (HMD). Participants were asked to sit comfortably in a stationary chair and to respond to the questions displayed in the headset using a Vive controller. The virtual environments were created using the Unity game engine software (Version 2020.3.25f1), and all experimental functionality and events were coded in the C# programming language. All virtual avatars used in this study were made in Daz3D, with a total 20 male and 20 female avatars with different faces. This was a within-subjects experimental design and participants randomly observed either the block with 2D faces or the block with 3D faces first. Each participant completed 80 trials (2 dimensions × 2 stimulus sexes × 20 stimuli per sex).[1]

For each stimulus, participants were presented with three questions, each displayed below the stimulus face: "How attractive do you find this person?", "How dominant do you find this person?", and "How masculine do you find this person?". Participants judgements were measured on a 7-point scale from 1 (not at all) to 7 (very), with their responses executed by aiming a laser beam projected from the tip of the controller. Once the first condition block was completed, participants proceeded to the second block.

[1] The order of trials and blocks were not recorded and, therefore, cannot be included as a factor in the analysis.

Table 1 Estimates for the effects of stimuli sex, and medium (2D vs 3D) on the ratings of attractiveness in faces

			95% CI				
Effect	β	*SE*	Lower	Upper	*df*	*t*	*p*
(Intercept)	3.05	0.14	2.78	3.33	57.45	22.1	< 0.001***
Stimuli Sex (male)	0.41	0.05	0.31	0.51	4743.97	7.89	< 0.001***
Medium (3D)	0.10	0.05	0.00	0.19	4743.97	1.97	0.049*
Stimuli Sex × Medium	−0.08	0.07	−0.23	0.06	4743.97	−1.11	0.266

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

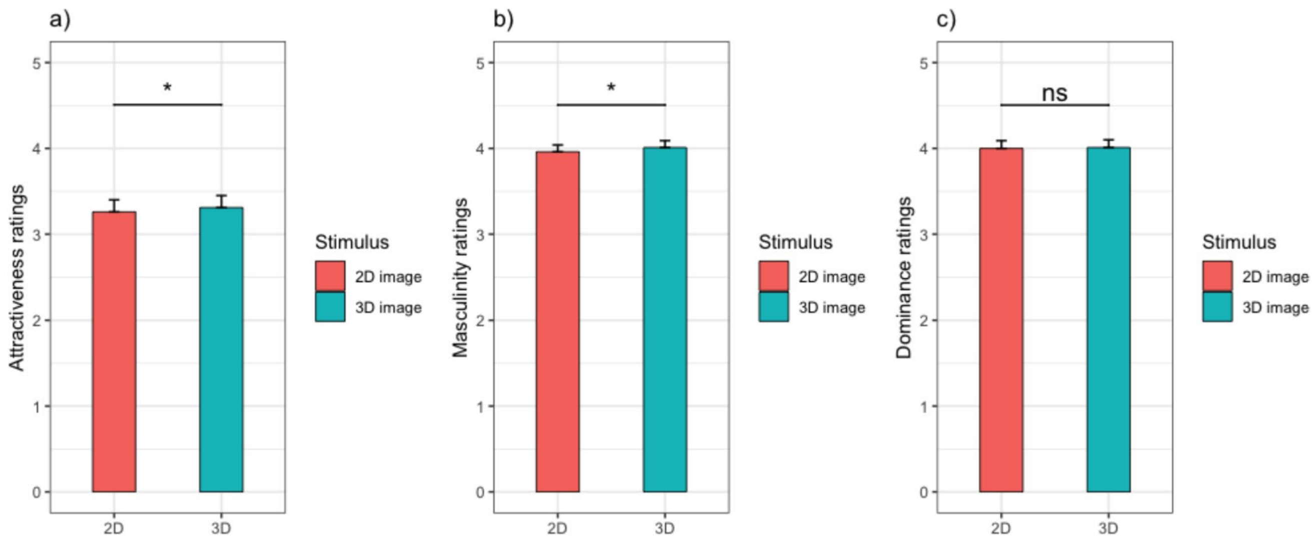

Fig. 3 **a** Attractiveness, **b** masculinity, and **c** dominance ratings as a function of dimension

Results

Three linear mixed models were conducted to investigate the effects of stimuli sex and medium (2D or 3D) on each of the ratings of attractiveness, masculinity, and dominance, with participant as a random effect in each of models.[2] All post hoc comparisons throughout the results of this study were performed using Bonferroni correction and is reflected in the p values. As for the ratings on attractiveness, results showed a significant main effect for stimuli sex and medium. Participants rated male faces ($M = 3.47$, $SEM = 0.14$) as more attractive than female faces ($M = 3.10$, $SEM = 0.14$); and 3D faces ($M = 3.31$, $SEM = 0.14$) as more attractive than 2D faces ($M = 3.26$, $SEM = 0.14$, Table 1, Fig. 3a).

As for the ratings on masculinity, results showed significant main effects for stimuli sex and medium. Participants rated male faces ($M = 4.92$, $SEM = 0.08$) as more masculine than female faces ($M = 3.05$, $SEM = 0.08$, Table 2); and 3D faces ($M = 4.01$, SEM = 0.08) as more masculine than 2D faces ($M = 3.96$, $SEM = 0.08$; Fig. 3b).

Finally, for the ratings on dominance, results showed a significant main effect for stimuli sex and a significant two-way stimuli sex × medium interaction. Participants rated male faces ($M = 4.64$, $SEM = 0.09$) to be more dominant than female faces ($M = 3.37$, $SEM = 0.09$, Table 3). The interaction could be attributed to males being perceived as less dominant in 3D than 2D (a decline of 0.05), with this pattern reversing by 0.07 for female faces. However, pairwise comparisons indicate that these small changes were statistically nonsignificant ($ps > 0.581$). Moreover participants rated males faces consistently as more dominant than females faces both for 2D ($M = 4.69$, $SEM = 0.09$ vs. $M = 3.33$, $SEM = 0.09$, $p < 0.001$) and 3D ($M = 4.60$, $SEM = 0.09$, $p < 0.001$).

[2] Correlations were conducted between attractiveness, masculinity, and dominance ratings. While masculinity and dominance were highly correlated, no significant associations were found between attractiveness and masculinity (female 3D, male 2D, and male 3D faces) or between attractiveness and dominance (male 2D and 3D faces). In light of these findings, a MANOVA was not initially undertaken, and instead, mixed linear models were conducted for each dependent variable separately. Nonetheless, a MANOVA was included in the supplementary materials in response to a reviewer's request.

Table 2 Estimates for the effects of stimuli sex, and medium (2D vs 3D) on the ratings of masculinity in faces

Effect	β	*SE*	95% CI Lower	Upper	*df*	*t*	*p*
(Intercept)	3.00	0.08	2.84	3.15	68.08	37.15	< 0.001***
Stimuli Sex (male)	1.92	0.05	1.83	2.02	4743.89	39.64	< 0.001***
Medium (3D)	0.11	0.05	0.02	0.2	4743.89	2.47	0.014*
Stimuli Sex × Medium	−0.12	0.07	−0.25	0.02	4743.89	−1.69	0.091

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3 Estimates for the effects of stimuli sex and medium (2D vs 3D) on the ratings of dominance in faces

Effect	β	*SE*	95% CI Lower	Upper	*df*	*t*	*p*
(Intercept)	3.33	0.09	3.16	3.51	65.03	37.59	< 0.001***
Stimuli Sex (male)	1.35	0.05	1.26	1.45	4743.92	27.71	< 0.001***
Medium (3D)	0.07	0.05	−0.02	0.16	4743.92	1.52	0.128
Stimuli Sex × Medium	−0.16	0.07	−0.29	−0.02	4743.92	−2.25	0.024*

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Discussion

In the late 1920s, René Magritte painted a picture of a pipe and beneath it wrote the caption "*Ceci n'est pas une pipe*" (English: "This is not a pipe"). This painting called *The Treachery of Images* points to the problem of pictorial representations, that is, pictures of objects are not equal as the objects themselves. Indeed, during the last decade research has revealed that real objects elicit different behavioral and neural responses than 2D images (Bohbot et al., 2017; Forlim et al., 2019; Gaebler et al., 2014; Gerhard et al., 2016; Gomez et al., 2018; Kober et al., 2012; Marini et al., 2019; Slobounov et al., 2015; Snow et at., 2011, 2014). However, no rigorous research has yet investigated the perception of social cues, such as facial attractiveness, using methods with high degrees of ecological validity. By comparing ratings of attractiveness, masculinity and dominance of male and female faces in 2D vs. 3D in VR, the current study aimed to fill this gap.

Overall, our results revealed that 3D faces were rated as more attractive and masculine, but not more dominant, compared to 2D faces; however, the differences were small. While the effect sizes and mean differences on the 7-point scale were small, these results may suggest that 3D presentations, by offering a more ecologically valid depiction of depth and detail (Snow & Culham, 2021; Snow et al., 2011), provide enhanced realism and visual nuance that participants could process more similarly to real human faces. Nonetheless, given the limited magnitude of the effects, caution is warranted in interpreting the practical significance of these findings. Future research with larger and more diverse samples will be important to further clarify the influence of stimulus dimensionality on face perception.

One possible explanation for the lack of a significant medium effect on dominance ratings is that evolutionary pressures may have shaped the human visual system to recognize dominance cues in faces irrespective of dimensionality. However, we recognize that a lack of statistical significance does not provide evidence for the absence of an effect. Accordingly, we refrain from drawing strong conclusions based on this result. Future research, incorporating larger sample sizes and formal power analyses, is necessary to establish the reliability of this finding. Although dominance and masculinity are often linked in social perception, recent research indicates that they are not entirely overlapping constructs (Dong et al., 2023), which aligns with the pattern observed in the current study. Overall, this complexity highlights the need for further investigation into how social cues are perceived from faces.

Furthermore, our results showed that male faces were rated more attractive, masculine, and dominant compared to female faces, regardless of the presentation dimensionality (2D or 3D). Male faces are, on average, more masculine and dominant and, in fact, are considered as such; however, the finding that male faces were rated more attractive than female faces may be explained by the fact that the majority of the participants were female. This limitation in the imbalance of sample size, which contributed to the lack of consideration of participants' sex as a factor in the analysis, needs to be considered in future research. Another potential explanation could be the inherent attractiveness of the male and female stimuli used. Future research could address this by selecting faces with similar average levels of attractiveness. Furthermore, a potential limitation of the present study is that block order might have influenced ratings. Future research could include block order as a factor or by employing between-subjects designs to further isolate the effects of dimensionality on social perception.

In conclusion, our findings suggest that 3D facial presentations may influence perceptions of attractiveness and masculinity, but not necessarily dominance. This highlights the importance of dimensionality in face perception research while also underscoring the complexity of social trait evaluation. Future research should aim to replicate and extend these findings using larger, well-powered samples and explore whether dimensionality interacts with other factors, such as emotion, context, or individual differences, to shape social judgments from faces.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40806-025-00439-1.

Author Contribution FP contributed to the conceptualization of the study, performed data analysis, drafted the manuscript, and participated in revising the paper. JW conducted the study and contributed to manuscript revision. KA performed data analysis and manuscript revision. AK contributed to the conceptualization of the study and provided critical revisions to the manuscript.

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Data Availability No datasets were generated or analysed during the current study.

Declarations

Human Ethics and Consent to Participate Declarations This research was approved by the Behavioural Research Ethics Committee of the University of British Columbia and was conducted in accordance with the Declaration of Helsinki as it pertains to research with human participants.

Consent to Participate All participants consented to taking part in the study.

Competing Interests The authors declare no competing interests.

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