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ARTICLE

Event-related brain potential correlates of the other-race effect: A review

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Abstract

People are better at remembering own-race relative to other-race faces. Here, we review event-related brain potential (ERP) correlates of this so-called other-'race' effect (ORE) by discussing three critical aspects that characterize the neural signature of this phenomenon. First, difficulties with other-race faces initially emerge during perceptual processing, which is indexed by an increased N170. Second, as evidenced by 'difference due to subsequent memory' effects, more effortful processing of other-race faces is needed for successful encoding into long-term memory. Third, ERP old/new effects reveal that a stronger engagement of processing resources is also required for successful retrieval of other-race faces from memory. The ERP evidence available to date thus suggests widespread ethnicity-related modulations during both perceptual and mnemonic processing stages. We further discuss how findings from the ORE compared with potentially related memory biases (e.g. other-gender or other-age effects) and how ERP findings inform the ongoing debate regarding the mechanisms underlying the ORE. Finally, we outline open questions and potential future directions with an emphasis on using multiple, ecologically more valid 'ambient' images for each face to assess the ORE in paradigms that capture identity rather than image recognition.

KEYWORDS
Dm effects, event-related brain potentials, face recognition, N170, old/new effect, other-race effect, own-race bias

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BACKGROUND

People more accurately remember faces from their own ethnic background than faces belonging to another ethnic group. This finding is referred to as the other-race[1] effect (ORE, or own-race bias; Malpass & Kravitz, 1969) and comprises one of the most widely researched and well-replicated phenomena in the face memory literature. Understanding the ORE is of substantial interest, as failing to correctly recognize an other-race person can have profound negative consequences, not only in security or legal contexts, but also in everyday social interactions (McKone et al., 2022). While substantial research effort has been put into gaining a better understanding of the ORE, the mechanisms underlying this bias are not yet fully understood.

Two broad theoretical accounts have been suggested to explain the ORE. On the one hand, according to perceptual expertise accounts, most people have only limited contact to individuals from other ethnic backgrounds, and this reduced expertise makes it difficult to adequately process and memorize other-race faces. Empirical work in support of this theoretical perspective has found that other-race faces are processed less efficiently at a perceptual level (Hancock & Rhodes, 2008; Hayward et al., 2013; Michel et al., 2006; Mondloch et al., 2010; Rhodes et al., 1989; Tanaka et al., 2004). In addition, it has been shown that other-race faces are less effectively encoded into memory (Hills & Lewis, 2006, 2011a), because the dimensions of our representational space for faces (the so-called multidimensional face space, or MDFS; Valentine & Endo, 1992; Valentine et al., 2016) have developed to optimally capture the differences between those faces we have previously encountered and are thus not optimal to code other-race faces we encounter only infrequently.

On the other hand, socio-cognitive (or motivational) accounts propose that the ORE is not primarily modulated by experience but instead results from differential amounts of processing resources dedicated to own- and other-race faces. Specifically, it is assumed that upon seeing a face, we categorize it as belonging to our in- or to an out-group based on features typical for a particular group (Levin, 1996, 2000). This in- versus out-group categorization can for instance be based on ethnicity, which might be quickly inferred from, for example skin tone, but it can also be based on other characteristics, such as gender or affiliation with a particular university or sports team. Crucially, faces categorized as belonging to the in-group are processed in an elaborate manner beneficial for subsequent recognition while out-group faces are only processed superficially and without emphasis on individuating characteristics, which in turn impairs subsequent recognition (Hugenberg et al., 2010; Rodin, 1987; Sporer, 2001; Young & Hugenberg, 2012). Thus, these theoretical frameworks offer two different, albeit not necessarily mutually exclusive, ways of understanding the ORE, stressing either the lack of long-term experience with other-race faces, or superficial processing of those faces after having been categorized as belonging to a social out-group. Importantly, perceptual expertise accounts suggest that the ORE reflects long-term expertise with own-race and a lack of experience with other-race faces, which cannot be easily overcome. By contrast, socio-cognitive accounts imply that the effect can be mitigated by short-term interventions, such as increasing motivation to individuate those faces.

Previous behavioural experiments have reported evidence for both of these theoretical positions (see e.g. Bernstein et al., 2007; Chiroro & Valentine, 1995; Hancock & Rhodes, 2008; Hugenberg et al., 2007; Sangrigoli et al., 2005; Wan et al., 2015; Young et al., 2010). Here, we focus on the contribution event-related brain potential (ERP) correlates of the ORE can make to understand its theoretical basis. ERPs can yield insights into both perceptual and mnemonic processing, and allow for high temporal resolution (i.e. in the millisecond time range) measurements of the individual processing steps that are initiated during both the learning and test phases of an experiment. As face recognition is typically considered to consist of a sequence of subsequent processing steps, which can in turn be linked to specific ERP components (Schweinberger & Neumann, 2016), the technique appears promising to inform about the mechanisms underlying the ORE.

[1]Please note that we use the term 'race' exclusively to refer to visually distinct ethnic groups.

We will focus primarily on three measures to capture both perceptual and mnemonic processes, and thus gain a broad perspective on the ORE[2]: First, we will discuss findings from the N170, which is the earliest component consistently modulated by ethnicity, indexing early perceptual processing of faces. Examining N170 may thus be particularly informative for theoretical accounts stressing difficulties during the perceptual processing of other-race faces. Second, we turn to learning phase potentials that contrast activity of successful versus unsuccessful memory encoding. As we will see, these so-called difference due to subsequent memory (Dm) effects are sensitive to the cognitive resources recruited during study and may provide particularly important information for theories of the ORE, which generally emphasize the importance of encoding processes. Finally, we discuss old/new effects, which reflect successful memory retrieval. Given their sensitivity to the amount of detail that is recollected and to the resources recruited during retrieval, old/new effect measures again appear particularly informative for own- and other-race face recognition. As will become clear, a comprehensive perspective that takes perceptual as well as mnemonic processes into account provides valuable information regarding the mechanisms underlying the ORE.[3]

In addition to the ORE, potentially similar memory effects have also been reported for gender (for a review, see Herlitz & Lovén, 2013), age (for a review, see Rhodes & Anastasi, 2012; Wiese, Komes, & Schweinberger, 2013) and 'purely' social dimensions, such as university affiliation or personality (see e.g. Bernstein et al., 2007). It is often assumed that these biases originate from a single, identical mechanism (see Wiese & Schweinberger, 2018, for a related discussion). However, the ERP research available to date suggests that memory biases in terms of ethnicity, gender and age rely on (at least partly) different mechanisms. As will be discussed in more detail below, the ORE seems to be primarily driven by differences in perceptual expertise for own- and other-race faces (as reflected in the N170). In contrast, gender biases seem to be more strongly modulated by socio-cognitive or motivational factors (as reflected in subsequent ERP components), while the contributions of experience and motivation to biases observed for age are less clear at present.

EARLY PERCEPTUAL PROCESSING: THE N170

The N170 is a negative-going ERP component that peaks approximately 170 ms after stimulus onset at occipito-temporal electrode sites. The N170 is widely acknowledged to be face-sensitive, as it is larger for faces than for other classes of objects (see e.g. Bentin et al., 1996). Since N170 amplitude has been reported to be similar for familiar and unfamiliar faces (see e.g. Bentin & Deouell, 2000; Eimer, 2000; Schweinberger et al., 1995), it is typically thought to reflect perceptual processes prior to the recognition of facial identity (for a review, see Eimer, 2011; but see Caharel & Rossion, 2021), such as structural encoding or the detection of a face-like configuration (see Eimer, 2011; Schweinberger & Neumann, 2016).

A number of studies have observed larger (i.e. more negative) N170 amplitudes for other-relative to own-race faces. However, this effect shows a degree of task-dependency (Wiese, 2013; see also Senholzi & Ito, 2013). Specifically, N170 ethnicity effects are usually absent in tasks in which faces or facial details are not task-relevant (e.g. responding to, or counting, target objects, such as butterflies; or deciding whether a face is presented in upright or inverted format; see e.g. Caldara et al., 2003; Chen et al., 2013;

[2] In addition to our own previous knowledge of the literature, we have looked for relevant articles via search engines (Google Scholar, Web of Science). For the literature search, we used keywords commonly selected to identify publications on ERP correlates of the ORE, such as variants of keywords referring to the ORE (e.g. 'own-race bias', 'other-race effect'; or corresponding terms for the related biases also discussed in this review) in combination with keywords referring to event-related potentials or the specific ERP components featured in this review. We did not conduct systematic backward/forward searches based on the articles identified via the literature search, nor did we apply any preset selection criteria. Only published manuscripts were included.

[3] We have refrained from reporting details regarding ethnicity of participants, ethnicity of stimuli used as 'other-race', and other stimulus specifications of the experiments on ERP correlates of the ORE discussed in the main text of this review. This information is instead provided in Table 1.

TABLE 1 Overview of design, ethnicity of participants and facial stimuli as well as stimulus characteristics of ERP experiments on the ORE discussed in this review

Study	Design	Participants	Ethnicity of stimuli	Origin of images	Images			
					Colour	Cropping	Adjustments	Other
Herzmann et al. (2011)	Cross-over	Caucasian East Asian	Caucasian Chinese	Database images	Grey-scale	Vertical ellipse (extends up to hairline)	Equated for luminance and spatial frequency	Neutral or weakly smiling expressions, no extraneous features (beards, glasses, etc.)
Herzmann et al. (2017)	Cross-over[a]	Caucasian East Asian	Caucasian Chinese	Database images	Grey-scale	Vertical ellipse (extends up to hairline)		Neutral or smiling expressions
Herzmann et al. (2018) **Expt. 1**	Single group	Caucasian	Caucasian Chinese	Database images	Grey-scale	Vertical ellipse (extends up to hairline)	Equated for luminance and spatial frequency	Neutral or weakly smiling expressions, no extraneous features (e.g. beards, glasses)
Herzmann et al. (2018) **Expt. 2**	Single group	Caucasian	Caucasian African American	Database images	Colour	Face shown with hair but without neck and clothing	Not equated for luminance and spatial frequency	
Lucas et al. (2011) ERP Expt.	Single group	White females	White, Black, East Asian, South Asian, Hispanic[b]	Multiple Sources	Colour	Faces displayed with neck and hair, but without background and clothing		Male faces only
Stahl et al. (2008)	Two groups: low versus extensive other-race contact	Caucasian	Caucasian Asian	Database images	Black and white			Frontal views without strong expression
Stahl et al. (2010)	Two groups: attractiveness rating versus ethnicity categorization	Caucasian	Caucasian Asian	Mostly database images	Grey-scale	Background removed		Frontal views, neutral expression

TABLE 1 (Continued)

Study	Design	Participants	Ethnicity of stimuli	Origin of images	Images			
					Colour	Cropping	Adjustments	Other
Tüttenberg and Wiese (2021)	Two groups: Individuation versus standard instruction	Caucasian	Caucasian East Asian	Database images	Grey-scale	Faces displayed with ears and hair covering forehead, but without neck		Frontal views, neutral expression
Wiese (2012) ERP Expt.	Single group	Caucasian	Caucasian East Asian (50% young, 50% elderly)	Various internet sources		Background removed	Not adjusted for low-level properties	Frontal views, neutral or moderately happy expression
Wiese (2013)	Single group	Caucasian	Caucasian Asian	Various internet sources	Colour	Background, clothing etc. removed	Adjusted for luminance and contrast	Frontal views, neutral or moderately happy expression
Wiese et al. (2014)	Cross-over	Caucasian Asian	Caucasian Asian[c]	Mostly database images	Grey-scale	Faces displayed with ears and hair covering forehead, but without neck		Frontal views, neutral expression
Wiese and Schweinberger (2018)	Two groups: Females, Males	Caucasian	Caucasian Asian	Database images and other internet sources	Colour	Faces displayed with ears and hair covering forehead, but without neck	Adjusted for luminance	Frontal views, neutral expression

[a]Due to differences in sample size, the authors mainly report Caucasian participants' data, but supplementary analyses including the between-subjects factor are available.
[b]This experiment includes three stimulus conditions: White faces, Black faces and a condition including White, Black, East Asian, South Asian and Hispanic faces.
[c]Stimuli categorized as Caucasian/Asian with near-ceiling accuracy and rated to be highly typical for the respective ethnicity.

Gajewski et al., 2008; Tüttenberg & Wiese, 2019b; Wiese et al., 2009). However, N170 ethnicity effects are typically present when either categorical information (such as categorizing faces according to race; e.g. Caharel et al., 2011; Montalan et al., 2013; but see Caldara et al., 2004) or identity information (Herrmann et al., 2007; Stahl et al., 2010; Wiese, 2012; Wiese & Schweinberger, 2018; but see Herzmann et al., 2011) is relevant for the task at hand.

The enhanced N170 for other- when compared to own-race faces has been suggested to reflect difficulties associated with the perceptual processing of other-race faces (Balas & Nelson, 2010; Caharel et al., 2011; Cassidy et al., 2014; Gajewski et al., 2008; Herrmann et al., 2007; Herzmann et al., 2018; Stahl et al., 2010; Wiese et al., 2014; Wiese & Schweinberger, 2018). This interpretation is based on similar effects being observed for contrast-negated or inverted faces (e.g. Itier & Taylor, 2002). Both of these manipulations are known to substantially reduce face recognition (Galper, 1970; Yin, 1969), presumably because they hamper the extraction of identity-relevant cues from the stimulus, and an enhanced N170 for these stimuli has been interpreted as reflecting additional processing due to these difficulties (Rossion & Gauthier, 2002). An enhanced N170 for other-race faces therefore likely represents increased effort during the structural encoding for this face category.

Of particular interest, the increased N170 for other-race faces appears to reflect differential long-term experience with own- and other-race faces, as several years of extensive contact do not reduce the effect (Stahl et al., 2008). It also seems to be relatively robust against variations of learning task requirements (that require some form of face processing, see above; Stahl et al., 2010). During the encoding phase of this study, participants either had to categorize faces according to race or were asked to rate faces in terms of attractiveness. While the emphasis on ethnicity in the categorization task condition likely encouraged differential processing of own- and other-race faces, shifting participants' attention to an attribute orthogonal to ethnicity should have counteracted this categorization and instead induced more elaborate individual processing of both own- *and* other-race faces (see e.g. Levin, 2000). Critically, Stahl et al. (2010) observed N170 ethnicity effects irrespective of learning task, suggesting that the enhanced N170 for other-race faces is not affected by differential motivational or attentional demands. Instead, this finding might be interpreted to reflect difficulties associated with reduced perceptual expertise for other-race faces.

While these studies seem to demonstrate difficulties with other-race faces at the perceptual level, it remains unclear whether N170 effects are linked to the ORE in memory, particularly as the N170 itself does not seem to be sensitive to facial identity (see above). Importantly, however, early perceptual difficulties can carry over to subsequent processing stages (e.g. Bruce & Young, 1986; Schweinberger & Neumann, 2016). In other words, if perceptual processes work less efficiently for a particular category of faces because visual information can only be insufficiently extracted, it is likely that this category is encoded into memory with less detail and is therefore also less likely remembered. Evidence for this idea comes from a study by Wiese et al. (2014) showing a correlational link between N170 and the ORE in memory. In this study, larger ethnicity effects in the N170 during learning were associated with larger memory biases at test, suggesting that more pronounced difficulties during the perceptual processing of other- (relative to own-) race faces also resulted in relatively poorer memory performance.

In sum, previous work shows that N170 is sensitive to face ethnicity. Although ethnicity effects in the N170 are task-dependent to some extent, they are typically present in tasks in which facial category or identity information is relevant. Results further suggest that N170 ethnicity effects are linked to differences in memory for own- and other-race faces and reflect differential long-term experience with own- and other-race faces rather than differences in motivation to individuate.

In contrast to ethnicity, gender does not seem to modulate the N170. Albeit much less frequently studied, N170 is similar for male versus female as well as own- versus other-gender faces (Mouchetant-Rostaing et al., 2000; Mouchetant-Rostaing & Giard, 2003; Rakic et al., 2018; Wiese & Schweinberger, 2018). This finding is well in line with the explanation of N170 ethnicity effects as reflecting differential perceptual expertise rather than motivational factors, because most people have comparable experience with (own-race) male and female faces.

Regarding the other-age effect, however, a somewhat different pattern has been observed. Both young adult (i.e. student) and older participants (i.e. typically 60 years or older) show larger N170 amplitudes for older as compared to young faces (Wiese et al., 2008, 2012). Therefore, it has on the one hand been suggested that the overall larger N170 for older faces irrespective of participant age reflects stimulus effects, such as enhanced high spatial frequency information in older faces due to wrinkles, changes to the eye region with eyes appearing smaller in older faces or other age-related changes. On the other hand, N170 age effects were not observed when own- and other-age faces were presented together with own- and other-race faces, which may suggest that other factors reflecting experimental context or task demands modulate the effect (Wiese, 2012). Importantly, independent of the exact interpretation, the pattern of age effects in the N170 is different from the one observed for ethnicity that is typically characterized by relatively larger N170 responses to other-race faces.

To conclude, the pattern observed for N170 differs across biases: In line with perceptual expertise accounts, face ethnicity systematically modulates the N170 component depending on the observers' ethnic background. In contrast, N170 is unaffected by gender of faces, in line with the assumption that expertise does not play a substantial role in this bias. Finally, N170 varies with facial age, yet the pattern is different from the one obtained for ethnicity: Larger N170 for older age faces were observed irrespective of participant age (see Figure 1a), pointing to stimulus rather than own-group effects.

ENCODING INTO MEMORY: DIFFERENCES DUE TO SUBSEQUENT MEMORY (DM) EFFECTS

Difference due to subsequent memory (Dm) effects represent an ERP measure of successful encoding (for a review, see Friedman & Johnson, 2000) and yield direct insights into the associated neural processes. Items presented during learning are retrospectively sorted according to whether they are correctly identified as 'old' (subsequent hits) or incorrectly classified as 'new' (subsequent misses) at test. Subsequent hits typically elicit a long-lasting and widespread positivity relative to subsequent misses, the so-called Dm effect, starting approx. 200–300 ms after stimulus onset (see Figure 1b,i). Dm effects not only have originally been reported for word material (e.g. Paller et al., 1987), but have also been observed when faces are used as stimuli (e.g. Kacin & Herzmann, 2021; Sommer et al., 1991, 1995, 1997; Yovel & Paller, 2004).

Lucas et al. (2011) directly compared Dm effects for own- and other-race faces and observed larger effects for the ethnic in-group between 200 and 400 ms at centro-parietal electrode sites (for a schematic illustration, see Figure 1b,ii). Moreover, Dm effects for own-race faces were more extended in time relative to those for other-race faces, which was interpreted to suggest more elaborate encoding. Lucas et al. (2011) also observed two Dm effects specific to other-race faces: An early (i.e. 200–240 ms) N200 Dm effect with more negative amplitudes for subsequent hits than misses at fronto-central sites, as well as a polarity-reversed P2 Dm effect with more positive amplitudes for subsequently remembered relative to subsequently forgotten other-race faces maximal at occipito-temporal sites in the same time window. As these effects occurred polarity-reversed at different scalp sites, they might well reflect activity measures at opposite ends of the same underlying dipole. P2 is generally considered to be sensitive to the perceived typicality of a face (e.g. Schulz et al., 2012; Wuttke & Schweinberger, 2019) and has additionally been suggested to reflect the processing of configural information (e.g. Latinus & Taylor, 2006). Importantly, while own-race faces elicit more positive P2 amplitudes relative to other-race faces (Lucas et al., 2011, see also Wiese & Schweinberger, 2018), this effect can be modulated by task demands and was found to be absent in a situation in which individuation of other-race faces was emphasized (i.e. in the attractiveness rating group in Stahl et al., 2010). Based on these findings, it was concluded that more elaborate information necessary for individuation is per default encoded for own- but not for other-race faces. At the same time, N200 and P2 Dm effects for *other*-race faces might reflect the detection of unique information in those faces, which aids subsequent recognition (Lucas et al., 2011). These effects also

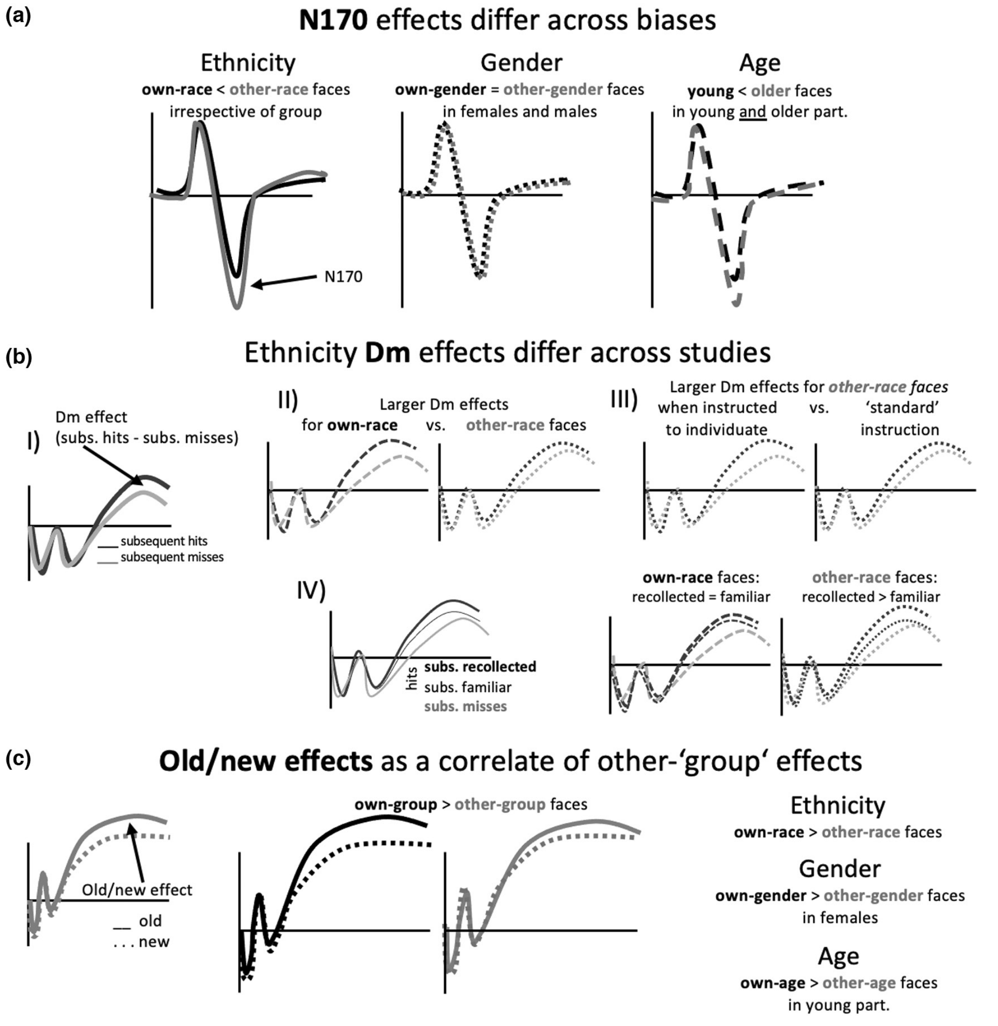

FIGURE 1 Schematic illustration of ERP effects for the other-race and related memory biases. (a) Differential pattern of N170 effects across biases. (b) Schematic illustration of how Dm effects are measured (I), and exemplary findings (II–IV): (III) larger Dm effects for own- versus other-race faces (Lucas et al., 2011), (IV) larger Dm effects for other-race faces when participants are informed of the ORE and are told to focus on individuating information in other-race faces versus when no such instructions are provided (Tüttenberg & Wiese, 2021), and (V) when familiarity- and recollection-based processes are taken into account, comparable recollection- and familiarity-related activity is observed for own-race faces, while for other-race faces, these differ significantly (Herzmann et al., 2011). (c) Old/new effects reflect a correlate of own-group biases more generally.

suggest that additional neuronal resources might be required for successful recognition of other-race faces.

Herzmann et al. (2011) analysed Dm effects for own- and other-race faces in a manner that allows for an additional assessment of familiarity- and recollection-based processes (see Yonelinas, 2002).[4] In addition to a behavioural ORE, Caucasian participants showed comparable recollection- and

[4]Familiarity and recollection refer to two qualitatively different processes that contribute to recognition memory (Yonelinas, 2002). In short, familiarity refers to a general feeling of oldness or recency, for example a sense of having encountered something before. Recollection is characterized by the retrieval of explicit details from the study episode. Note that Herzmann and colleagues further distinguish between familiarity and recollection, thus adopting a different analysis approach compared with the subsequent hits versus subsequent misses contrast. These differences make a direct comparison of studies somewhat difficult (see also Herzmann et al., 2011).

familiarity-based Dm activity for own-race faces, while for other-race faces, ERP amplitudes were more positive for subsequently recollected relative to subsequently familiar faces (for an illustration, see Figure 1b,iv; see also Herzmann et al., 2018). This finding was interpreted as suggesting that own- but not other-race faces are automatically encoded in a deeper and more elaborate manner. In addition, recollection-related activity was more pronounced for other- when compared to own-race faces, which – together with the behavioural recognition memory bias – might indicate less efficient encoding of other-race faces.

Using an associative-memory task in which faces had to be remembered along with their corresponding background colour, Herzmann et al. (2017) observed comparable recollection- (i.e. faces remembered correctly with correct background colour) and familiarity-related (i.e. faces remembered correctly with incorrect background colour) Dm activation for both own- and other-race faces. This finding differs from the experiment discussed in the previous paragraph, in which comparable recollection- and familiarity-related Dm effects were only found for own-race faces (see above). Herzmann et al. (2017) suggested that this discrepancy might result from differential task demands. Specifically, when faces have to be memorized along with associative information, this more complex task may encourage deeper encoding of own- as well as other-race faces. In addition, more positive amplitudes were obtained for subsequently remembered other- relative to subsequently remembered own-race faces, irrespective of whether the correct background colour was retrieved. Although this result again slightly differs from Herzmann et al. (2011), it nonetheless suggests that more resources are required for successful other-race face recognition.

In a recent study, Tüttenberg and Wiese (2021) investigated whether the ORE results from reduced motivation to individuate other-race faces during learning (see e.g. Hugenberg et al., 2010). As previous behavioural work has shown that explicit instructions to individuate other-race faces eliminated the ORE (Hugenberg et al., 2007; Rhodes et al., 2009; but see Wan et al., 2015), Tüttenberg and Wiese (2021) examined Dm effects to directly tap into the neural processes engaged during own- and other-race face encoding with varying task instructions, thus providing a more direct test of the hypotheses put forth by socio-cognitive accounts. In this study, individuation instructions attenuated the ORE, indicating that increased effort and attention can reduce the behavioural effect to some extent. At the same time, individuation instructions increased Dm effects selectively for other-race faces (see Figure 2; see also Figure 1b,iii), again suggesting that substantially more resources are needed for successful other-race face recognition.

While relatively few studies on the ORE analysed Dm effects, hardly any work has studied this measure in other memory biases. Wolff et al. (2014) yielded comparable late (450–1000 ms) Dm effects for own- and other-gender faces in female and male participants, although both groups displayed an own-gender bias in recognition memory. As in Lucas et al. (2011), Wolff et al. (2014) also observed Dm effects in the P2 (and polarity-reversed in the N200) component, although these effects were limited to male faces. Specifically, more pronounced amplitudes were obtained for subsequently remembered versus forgotten male faces in male participants, whereas the opposite pattern (i.e. larger amplitudes for subsequently forgotten versus remembered male faces) was seen in female participants. It thus appears plausible that these effects may be stimulus-dependent to some extent since they only emerged for male faces. Moreover, P2 amplitude was negatively correlated with ratings of perceived distinctiveness of the faces. Most importantly, the overall pattern differed from the one observed for ethnicity, as an overall modulation of Dm effects by own- versus other-gender was absent, whereas corresponding effects were clearly evident for ethnicity.

In sum, experiments investigating neural activity associated with successful encoding show that own-race faces are encoded more effectively when compared to other-race faces, for which additional or more pronounced activation is often observed. However, given the lack of comparable results for age and gender, more research is clearly needed to more closely examine possible differences in Dm effects between the different biases.

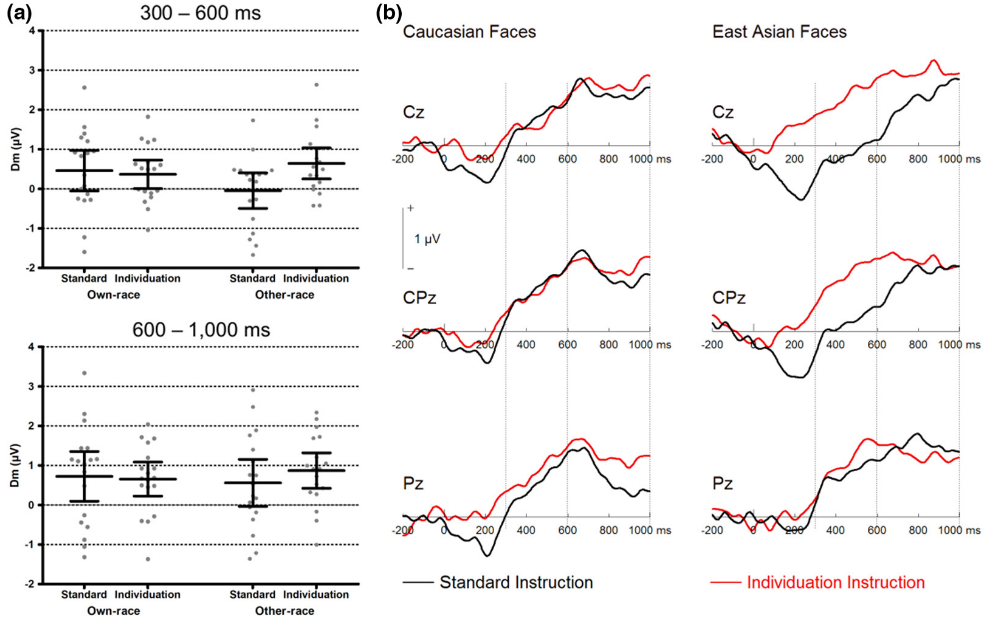

FIGURE 2 (a) Dm effects (subsequent hits minus subsequent misses) averaged across midline electrode sites (Fz, FCz, Cz, CPz and Pz) for own- and other-race faces of participants receiving individuation instructions (i.e. participants receive information on the ORE, are told to avoid the bias and to attend to individuating information in other-race faces during encoding) and those not receiving corresponding instructions (standard instruction). (b) Difference waveforms (subsequent hits minus subsequent misses) for standard and individuation instruction conditions at three exemplary midline electrodes for own-race (left) and other-race faces (right). Between 300 and 600 ms, Dm effects are significantly larger for other-race faces in the individuation versus standard instruction condition. Reprinted from Tüttenberg and Wiese (2021). Reprinted with permission from Elsevier.

SUCCESSFUL MEMORY RETRIEVAL: ERP OLD/NEW EFFECTS

In test phases of ERP recognition memory experiments, items correctly identified as having previously been presented during study (i.e. 'old' items) elicit more positive amplitudes relative to items correctly identified as newly presented (i.e. 'new' items).[5] This so-called old/new effect starts approximately 200–300 ms after stimulus onset and is typically subdivided into an early (approx. 300–500 ms) and late (approx. 500–800 ms) part (for a review; see Friedman & Johnson, 2000). These effects have originally been reported for word material and have been linked to familiarity and recollection, respectively (e.g. Curran, 2000, 2004; Rugg & Curran, 2007). Note that while for word material, these effects commonly have a fronto-central maximum for familiarity and left parietal maximum for recollection, old/new effects for faces are often more widely distributed across the scalp (MacKenzie & Donaldson, 2007; Yick & Wilding, 2008). Studies investigating old/new effects for own- and other-race face recognition mostly focus on the late old/new effect, which is sensitive to the amount of information or detail that is retrieved from the study episode (see e.g. Vilberg et al., 2006).

It appears that the majority of studies on the other-race effect report larger old/new effects for own- relative to other-race faces, suggesting the retrieval of more detailed study phase information for the former category of faces (Herzmann et al., 2011; Stahl et al., 2010; Wiese, 2012). Similarly, in the

[5]Note that while Dm effects compare *learning* task activity for items correctly recognized as old (subsequent hits) and items incorrectly judged as new (subsequent misses) at test, representing a measure of successful encoding, old/new effects are measured during the *test phase* of a recognition memory experiment, contrasting activity for items with (old) and without (new) study history that are correctly classified as old or new, respectively.

associative-memory paradigm mentioned above, recollection-related old/new effects (contrasting recollected and familiar items) were only detected for own-race faces, suggesting that recollection, and thus detailed memory retrieval, may primarily occur for own-race faces (Herzmann et al., 2017, see Figure 3).

Interestingly, old/new effects seem to be task-dependent to some extent. Stahl et al. (2010) found more pronounced old/new effects for own- as compared to other-race faces when faces were rated for attractiveness during study while a corresponding difference in old/new effects between own- and other-race faces was not observed when faces had to be categorized according to ethnicity. Irrespective of this modulation, both learning tasks resulted in a similar behavioural ORE at test. Similarly, Wiese and Schweinberger (2018) observed comparable old/new effects for own- and other-race faces in a combined own-race/own-gender bias experiment that employed a gender categorization task during study. However, an earlier experiment observed larger old/new effects for own- versus other-race faces when facial age was emphasized during encoding (Wiese, 2012). Thus, the pattern is somewhat inconsistent across studies, and potential task-related modulations of old/new effects for the ORE (and related memory effects) may be systematically investigated in future research.

Successful retrieval of other-race faces may also require additional resources. For instance, more pronounced activity was observed for familiar old and correctly rejected new *other*- than own-race faces, reflecting the recruitment of additional neural resources to successfully distinguish between old and new other-race faces (Herzmann et al., 2017). Moreover, late (recollection-related) old/new effects for other-race faces have been demonstrated to extend more strongly to frontal regions relative to the corresponding effect for own-race faces (Herzmann et al., 2011). Interestingly, this pattern was

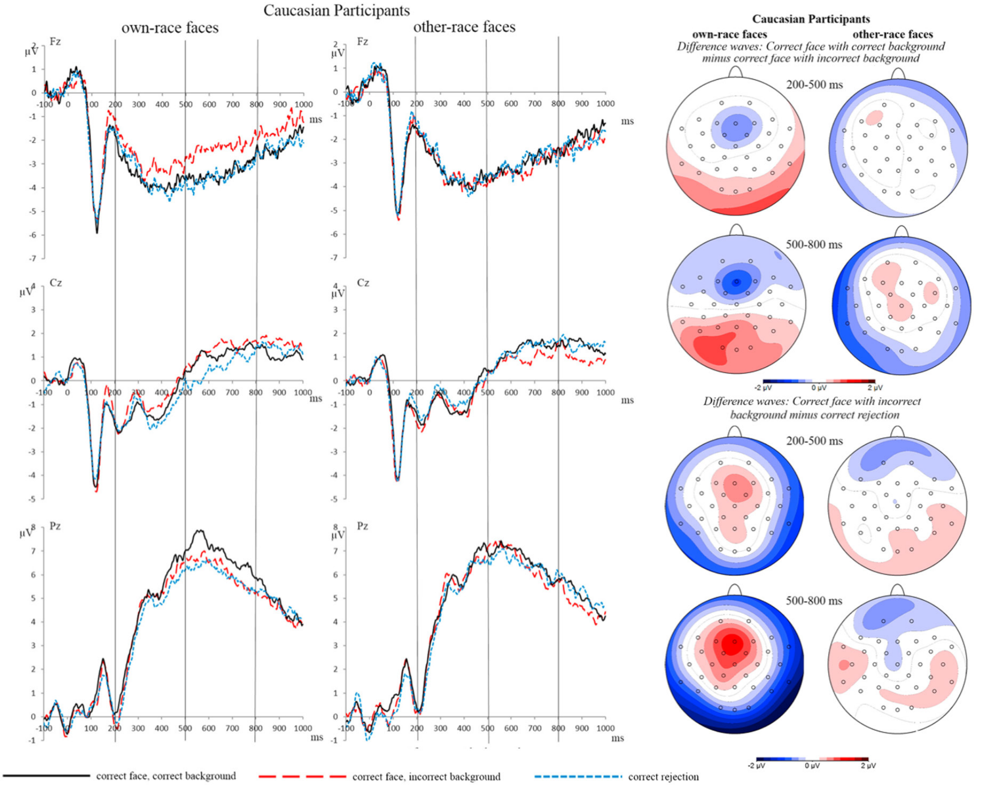

FIGURE 3 Left panel: ERP waveforms at Fz, Cz and Pz of the test phase of Herzmann et al. (2017). Right panel: Voltage maps of ERP difference waveforms. Upper two rows show contrast that indexes recollection, lower two rows shows contrast indexing familiarity in two separate time windows for own- and other-race faces. Caucasian participants show significant recollection old/new effects between 500 and 800 ms for own-race faces only. Adapted from Herzmann et al. (2017). Reprinted with permission from Elsevier.

observed in Caucasian participants who also displayed a recollection-related ORE in recognition memory. Conversely, Asian participants, who did not show a comparable recognition memory bias, also did not yield topographically dissociable late old/new effects, pointing to a link between behavioural and neural measures of the ORE. Herzmann et al. (2011) also observed an additional late (i.e. 900–1200 ms) frontal old/new effect that was limited to other-race faces (see also Herzmann et al., 2018), which might indicate that retrieval of other-race faces takes more time. Alternatively, given that late frontal old/new effects are associated with post-retrieval processes or retrieval effort (see e.g. Herron et al., 2016; Ranganath & Paller, 2000; Wilding & Rugg, 1996), successful retrieval of other-race faces may require a larger degree of post-retrieval monitoring (Herzmann et al., 2011). Together, these findings point to more effortful retrieval for other- when compared to own-race faces.

Mirroring the finding observed for ethnicity, larger late old/new effects were also obtained for own- versus other-gender faces (Wiese & Schweinberger, 2018; Wolff et al., 2014). However, while this finding was limited to female participants in both studies who also displayed a behavioural other-race effect in memory, Wolff et al. (2014) also obtained a behavioural memory advantage for own-gender faces in male participants in the absence of a corresponding old/new effect in this participant group.

A corresponding pattern has also been detected for the own-age bias: Young participants showed enhanced memory performance as well as larger late old/new effects for own- as compared to other-age faces (Wiese et al., 2012; but see Wiese, Wolff, et al., 2013), while comparable effects for own- and other-age faces were observed for older participants (Wiese et al., 2008). At the same time, and similar to the N170 effects discussed above, a modulation of old/new effects by stimulus age may depend on the saliency of this attribute. Using face stimuli that varied more continuously with regard to age abolished the modulation of old/new effects by face age discussed above (Wolff et al., 2012). Moreover, larger late old/new effects for own- versus other-age faces in young participants were not detected when these faces also varied in terms of ethnicity (Wiese, 2012).

In conclusion, results from old/new effects, in particular those that reflect recollection, suggest that the retrieval of own-race faces is more detailed when compared to other-race faces. In line with the results revealing that other-race face encoding (as indexed by Dm effects) is accompanied by increased or more widespread neural activation, additional resources and monitoring may also be required for successful retrieval of other-race faces. Evidence from other own-group biases suggests that larger old/new effects are often observed for those face categories that are also more accurately remembered by the respective group of participants. In contrast to the effects discussed in previous sections, the increased late old/new effect therefore may reflect a neural marker of all own-group biases discussed here (see Figure 1c).

DISCUSSION

In this review, we have discussed three ERP correlates of the other-race effect in face recognition memory, with the aim to characterize its neural signature and compare it to other memory biases. We believe that this approach can offer valuable insights into the mechanisms underlying the ORE and potentially own-group biases more generally. We will first discuss these mechanisms for the ORE and then compare results across biases, before outlining open questions and future directions.

Mechanisms underlying the ORE

As noted before, participants generally display reduced memory for other- relative to own-race faces at the behavioural level (see e.g. Herzmann et al., 2011; Lucas et al., 2011; Wiese & Schweinberger, 2018), which has been interpreted to reflect differential expertise for own- versus other-race faces. In line with this interpretation, the ORE in recognition memory has been repeatedly observed to be reduced in participants who had more pronounced contact with other-race people, for example due to living in countries where the predominant ethnic group is different from their own (e.g. Herzmann et al., 2011; Wiese et al., 2014; see also Chiroro & Valentine, 1995; Hancock & Rhodes, 2008; Sangrigoli et al., 2005). In addition, and counter to the idea that motivation drives the effect, experimental tasks that encouraged deeper encoding of other-race faces had no or only small effects on the behavioural ORE (e.g. Stahl et al., 2010; Tüttenberg & Wiese, 2021). Together, these findings support an account of the ORE that emphasizes perceptual expertise (e.g. Michel et al., 2006; Valentine et al., 2016). At the same time, however, others have also reported behavioural findings in favour of socio-cognitive accounts (see e.g. Hugenberg et al., 2007, 2010). It has previously been suggested that these conflicting findings may be reconciled when the setting in which the ORE is investigated is taken into account (Wan et al., 2015). More specifically, it has been argued that differential contact or expertise is driving the effect when contact with other-race people is low (i.e. in most of the populations examined in the ERP studies discussed above where Caucasians have limited contact with Asian people). In contrast, in settings where people have regular contact with other-race people (such as African and European American people in parts of the United States), the ORE may be predominantly, or perhaps even exclusively, modulated by motivational factors.

The ERP research outlined above seems to be more in line with a perceptual expertise account. First, the N170, a component thought to index perceptual processing of faces, is typically larger for other- when compared to own-race faces. This effect may reflect difficulties associated with other-race face processing at the perceptual level. Moreover, neither limited (i.e. approximately 3 years of) contact with other-race faces (Stahl et al., 2008) nor experimental approaches that encourage deeper encoding (Stahl et al., 2010) reduce the N170 ethnicity effect, and its size is correlated with the ORE in recognition memory (Wiese et al., 2014). At the same time, OREs in recognition memory have also been reported in the absence of corresponding effects in the N170 (e.g. Herzmann et al., 2011), which cannot be fully explained in terms of differential task demands. However, the absence of an N170 ethnicity effect in this study could in principle result from comparable contact towards own- and other-race people. Overall, it seems adequate to conclude that perceptual difficulties captured by the N170 likely contribute to the ORE, but cannot solely explain the effect.

Ethnicity has also led to modulations of encoding-related activity, as captured by Dm effects. Although there is some discrepancy across studies, both regarding the operationalization of effects (for a discussion, see Herzmann et al., 2011) and results (see Tüttenberg & Wiese, 2021), successful other-race face encoding seems to require more resources. In particular, other-race faces (i) per default seem to be encoded less efficiently (Herzmann et al., 2011), (ii) seem to require more processing resources when tasks are more demanding (Herzmann et al., 2017) or when special emphasis is laid on them (Tüttenberg & Wiese, 2021) and (iii) appear to recruit additional neuronal resources relative to own-race faces (Lucas et al., 2011).

Similarly, as evidenced by old/new effects measured at test, other-race face recognition is characterized by (i) less detailed memory retrieval (Herzmann et al., 2011; Stahl et al., 2010), (ii) a stronger reliance on familiarity as opposed to recollection (Herzmann et al., 2017) and (iii) the recruitment of more resources, and perhaps even additional monitoring processes (Herzmann et al., 2011, 2018). Coupled with the behavioural ORE that is typically observed, this is particularly noteworthy given that overall fewer other- (as opposed to own-) race faces are recognized. As such, the recruitment of additional resources does not seem to compensate for the difficulties associated with other-race face recognition.

In conclusion, the research reviewed here suggests that the ORE largely results from reduced expertise with this face category, as it is at least partly based on differences in perceptual processing that do not seem to be modifiable by changing the motivation to individuate other-race faces. Moreover, difficulties with other-race faces are typically observed during mnemonic processes which manifest as enhanced effort to encode and retrieve study phase detail, presumably in an attempt to compensate for early perceptual deficits. This latter point of enhanced processing effort for other-race faces (without explicit instruction) again seems to argue against motivational accounts,[6] as these additional neural resources do not seem to be effective at the behavioural level, where clear OREs in memory are typically observed.

Comparing the ORE to other memory biases

In addition to ethnicity, own-group biases in recognition memory have also been observed for gender (Herlitz & Lovén, 2013) and age (Rhodes & Anastasi, 2012; Wiese et al., 2013). The other-gender effect is typically observed in female but not necessarily in male participants, who display a more variable pattern across studies (Lewin & Herlitz, 2002; Loven et al., 2011; Steffens et al., 2013; Tüttenberg & Wiese, 2020; Wiese & Schweinberger, 2018; Wolff et al., 2014; Wright & Sladden, 2003). The mere existence of such own-group biases has been used as an argument against expertise accounts for the ORE (Bernstein et al., 2007). For instance, an explanation of the other-gender effect in terms of expertise is not straightforward, since most people have equal amounts of contact to, and therefore experience with, female and male faces (for an alternative developmental framework, see Herlitz & Lovén, 2013). If the ORE and the other-gender effect were based on the same underlying mechanisms, as assumed in this line of argument, this common basis cannot consist of differential perceptual expertise. However, as outlined in detail above, ERP studies suggest substantial differences in the neural signature of different own-group biases, which suggests that the basic assumption of a common underlying mechanism may not hold.

Accordingly, and in line with the interpretation of N170 ethnicity effects reflecting long-term differential contact for own- versus other-race faces, N170 is not modulated by gender (see e.g. Mouchetant-Rostaing et al., 2000; Mouchetant-Rostaing & Giard, 2003; Wiese & Schweinberger, 2018). In addition, the only study that investigated neural correlates of successful encoding observed comparable Dm effects for own- and other-gender faces (Wolff et al., 2014), which, as discussed above, again differs from the findings of more pronounced or additional neuronal activation obtained for other- relative to own-race faces. Differences between own- and other-gender faces typically manifest in the old/new effect time range, where larger old/new effects for own- relative to other-gender faces have been reported in female participants who also showed a corresponding memory bias at test (Wiese & Schweinberger, 2018; Wolff et al., 2014). Thus, although socio-cognitive accounts rather than differences in experience appear to offer a more parsimonious explanation of the other-gender effect, it seems to rely on partly different neural processes than the ORE.

With regard to age, better memory for own- relative to other-age faces is typically observed in young participants (Hills & Lewis, 2011b; Wiese, 2012; Wiese et al., 2008; Wiese, Wolff, et al., 2013), but the effect appears more variable in older age participants. Of note, however, a person's age gradually changes over the lifespan. As a result, our levels of contact and experience with people from different age groups likely change in the course of our life, too.

Previous behavioural findings generally support a modulation of the other-age bias in terms of contact. For example, older participants who had substantially more contact towards own- versus other-age people displayed better memory performance for own- versus other-age faces whereas older participants having equal amounts of contact to own- and other-age people showed no corresponding memory bias (Wiese et al., 2012). Similarly, other-age effects were absent in geriatric nurses (Wiese et al., 2013) and trainee teachers (tested with own-age and children's faces; Harrison & Hole, 2009), who spent a substantial amount of time with older age people and children, respectively (for related findings, see Anastasi & Rhodes, 2005; Bartlett & Leslie, 1986; Cassia et al., 2009; Kuefner et al., 2008).

[6]Note that experiments investigating ERP correlates of face memory biases based on purely social dimensions (such as 'personality'), which are not discussed in detail in this review, would be well-suited to investigate the role of motivation. However, ERP research on memory effects for purely social groups is sparse (for a notable exception, see Herzmann & Curran, 2013). This might potentially be related to the observation that such other-group effects are typically small (Herzmann & Curran, 2013) and cannot always be replicated (Fuller et al., 2021; Tüttenberg & Wiese, 2020).

Regarding the neural correlates of the other-age effect, N170 is often larger and the late old/new effect smaller for other- versus own-age faces in young participants (Neumann et al., 2015; Wiese et al., 2012; Wiese et al., 2008; but see Wiese, Wolff, et al., 2013), although these effects seem to be somewhat less robust relative to those observed for ethnicity (Wiese, 2012). Moreover, as older participants also show an increased N170 to old faces, this difference seems to reflect a stimulus rather than an own-group effect. It thus appears that the ERP effects discussed here do not provide a straightforward conclusion about the mechanisms underlying the other-age effect. A larger old/new effect for own-age faces in younger adults is comparable to findings for the other biases (i.e. larger old/new effects for own-race faces irrespective of group, and for own-gender faces in female participants) described above. Given that such effects apparently occur for all face memory biases examined here, they may well reflect a common mechanism based on motivational differences (see also Figure 1c). Critically, however, the neural basis of the other-age effect again seems to be partly different from the one described for the ORE.

In sum, while the ERP evidence discussed above supports the role of perceptual expertise in the ORE, memory effects in terms of gender and age seem to rely on at least partly different mechanisms. Specifically, while an explanation of the other-gender effect in terms of differential experience is not straightforward, further research is needed to inform the mechanisms underlying the other-age effect.

Open questions and future directions

As discussed in more detail above, inconsistencies in the ORE literature and, in particular, in the N170 may, at least in part, be reconciled when considering the context in which the ORE (with regard to the relative amount of contact towards other- versus own-ethnicity people) is investigated. ERP research on the ORE is predominantly based on White participants who typically have high levels of contact towards own-race people, but low levels of contact towards people from the respective other race. Testing groups with various ethnic backgrounds that vary more strongly in terms of other-race contact clearly represents an important endeavour for future research. A more systematic investigation of how ERP and behavioural OREs change depending on context (e.g. in cross-cultural studies) and levels of contact with the other race would offer valuable information towards a hypothesis that is currently based on indirect support only.

We have argued in this review that the various other-group effects in face memory are based on at least partially different mechanisms. At the same time, only very few ERP studies directly compared biases within a single experiment (for exceptions, see Wiese, 2012; Wiese & Schweinberger, 2018). This experimental approach offers a strong test of the question whether different biases rely on the same or different mechanisms and allow for a direct assessment of the relative size of the effects while controlling for methodological and/or participant characteristics which may differ across studies (for a more detailed discussion, see Wiese & Schweinberger, 2018). With these advantages in mind, future studies may examine combinations of specific memory biases more frequently. Particularly, as most studies on the ORE use both male and female face stimuli and test male and female participants, the combined investigation of ethnicity and gender-based biases is not only theoretically highly interesting, but also relatively easy to implement.[7]

Some inconsistencies across studies may also result from insufficient statistical power. Many of the ERP effects discussed in this review are relatively small, and therefore not likely to always replicate, given the typical sample sizes in ERP studies. Accordingly, we would not expect to obtain statistically significant effects in every single experiment. Future studies should aim at testing appropriately sized samples to increase the chance of true effects being detected. This requires a priori considerations of sample size for a given effect (of a given size) that is to be examined. It also seems crucial to report effect sizes with corresponding confidence intervals to take information about the uncertainty of a particular estimate into account (see e.g. Cumming, 2012).

[7]Note however, that a combined investigation of biases in a single experiment requires longer experiments with larger sets of stimuli.

Finally, some authors have convincingly advocated to study face perception in more ecologically valid conditions (Burton, 2013; Burton et al., 2016). Rather than using tightly controlled face images (i.e. front-facing views, neutral facial expression, uniform background, etc.), researchers increasingly opt for more naturally looking and less controlled images that show a particular face under naturally varying viewing conditions (so-called 'ambient' images; Jenkins et al., 2011 that vary on dimensions such as viewpoint, expression, lighting, hairstyle, etc.). Such stimuli allow to more accurately measure *face* (as opposed to *image*) recognition and thus more closely resemble the more complex demands in real life, where a given face rarely appears in the exact same conditions more than once. Recently, researchers have started to study the ORE using ecologically more valid stimulus material and paradigms (see e.g. Cavazos et al., 2019; Hayward et al., 2017; Laurence et al., 2016; Tüttenberg & Wiese, 2019a; Yan et al., 2016; Zhou et al., 2018). However, only very few studies have adopted this approach in ERP studies of the ORE (Tüttenberg & Wiese, 2019b). Studying the neural basis of the ORE and related memory effects using these experimental approaches will more closely capture the difficulties associated with other-race face recognition in real life.

AUTHOR CONTRIBUTIONS

Simone C. Tüttenberg: Conceptualization; visualization; writing – original draft; writing – review and editing. **Holger Wiese:** Conceptualization; writing – original draft; writing – review and editing.

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CONFLICT OF INTEREST

All authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

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