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Malleability of the sense of bodily self in early childhood: 5- and 6-year-old children show the enfacement illusion

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ABSTRACT

The mechanisms underlying the developing sense of bodily self are debated. Whereas some scholars stress the role of sensory factors, others propose the importance of contextual factors. By manipulating multisensory stimulation and social familiarity with the other person, we explored two factors that are proposed to relate to young children's developing sense of bodily self. Including an adult sample allowed us to investigate age-related differences of the malleability of the bodily self. To this end, the study implemented an enfacement illusion with children (N = 64) and adults (N = 33). Participants were exposed to one trial with synchronous interpersonal multisensory stimulation and one trial with asynchronous interpersonal multisensory stimulation—either with a stranger or with the mother as the other person. A self-recognition task using morph videos of self and other and an enfacement questionnaire were implemented as dependent measures. Results revealed evidence for the presence of the enfacement effect in children in both measures. The identity of the other person had a significant effect on the self-recognition task. Contrary to our hypothesis, the effect was significantly smaller in the caregiver condition. No significant differences between children and adults emerged. Our results demonstrate the role of both multisensory stimulation and contextual—here social familiarity—factors for the construction and development of a bodily self. The study provides developmental

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science with a novel approach to the bodily self by showing the validity of the self-recognition task in a child sample. Overall, the study supports proposals that the sense of bodily self is malleable early in development.

Introduction

The bodily self refers to one's subjective experience and perception of one's own physical body (Blanke et al., 2015; Montirosso & McGlone, 2020). The feeling that a certain physical body is one's own body—also called *sense of body ownership* (Tsakiris, 2011)—and recognizing one's bodily appearance are considered to be hallmarks of what it means to have a *bodily self* (Apps & Tsakiris, 2014; Gallagher, 2000; Tsakiris, 2017). The face is arguably the most representative instance of self-appearance (Povinelli & Simon, 1998; Rochat, 2015; Tsakiris, 2017), and therefore recognizing one's own face in distinction with others' faces is argued to be a fundamental component of bodily self-awareness (Gallup, 1970). Therefore, sense of face ownership and self-face recognition are of central interest when one wants to tackle the core of selfhood. The current study aimed to examine the psychological processes that contribute to the sense of body ownership, in particular the sense of one's own face, in early childhood.

The debate around the ontogeny of self-recognition has a long tradition. Early work focused on important steps in the development of self-recognition and resulted in a well-established developmental timetable of indicators of selfhood (for a review, see Rochat, 2015). However, despite progress in identifying central steps of the emergence of the self, the developmental mechanisms underlying the bodily self and self-recognition are still debated (Kollakowski et al., 2023). Influential cognitive theories suggest that multisensory integration processes play a central role by constructing representations of one's own body and face that underlie the sense of body ownership and self-recognition (De Klerk et al., 2021; Tsakiris, 2011). More precisely, watching and proprioceptively feeling one's hand moving or watching one's face in the mirror while sensing being touched in the face leads to an integration of visual, tactile, and proprioceptive sensory information and the construction of a body representation.

Current theories propose that the representations that are constructed by multisensory integration are not static. Instead, they are proposed to be malleable and plastic. That is, body representations are updated when new sensory information is available. Numerous studies have investigated the mechanisms underlying the malleability of the sense of face ownership and self-recognition in adults (e.g., Bufalari et al., 2019; Panagiotopoulou et al., 2017; Tajadura-Jiménez, Grehl, et al., 2012; for a review, see Porciello et al., 2018), leading to an increased interest in the malleability and plasticity of the self. Despite the fruitfulness of this novel theoretical perspective, only little developmental research has explored the malleability of the minimal self in young children. The current study aimed to contribute to this line of research. In particular, the current study aimed to make a novel contribution to our understanding of the mechanisms underlying the developing bodily self and self-recognition by implementing an enfacement illusion procedure in a sample of adults and children.

The enfacement illusion offers an excellent way to experimentally manipulate multisensory integration processes and thus can be used to study the mechanisms behind the plasticity of self-face representations (Porciello et al., 2018; Sforza et al., 2010; Tsakiris, 2008). In the following, three research questions that guided the current study are introduced:

1. Can the enfacement effect be captured in a sample of adults and children?
2. Does the effect of multisensory integration processes on self-recognition and sense of face ownership differ between children and adults?

3. Does social familiarity have an effect on the malleability of self-representations, and thus is the enfacement effect stronger with a caregiver than with a stranger?

Enfacement Illusion as indicator of the malleability of the bodily self

Evidence for the malleability of the bodily self comes from research on the so-called enfacement illusion. During the enfacement illusion, the participant is stroked by a cotton bud on the cheek while watching another person being stroked by an identical cotton bud on the congruent spot (interpersonal multisensory stimulation [IMS]; Tsakiris, 2008). If the stroking is executed synchronously, multisensory integration processes lead to the experience of ownership over the other's face and to increased self–other overlap or self–other blurring. That is, the perceived similarity between both faces increases and the other's face is integrated into the visual representation of the own face (Tajadura-Jiménez et al., 2013; Tsakiris, 2008, 2017). The illusion is usually captured by an enfacement questionnaire about the explicit experience of self-identification with and sense of ownership over the other's face (e.g., "I felt like the other's face was my face"). Comparing the participants' ratings of the statements after synchronous and asynchronous stroking shows significant differences, with more agreement in the synchronous condition (e.g., Tajadura-Jiménez, Grehl, et al., 2012; Tajadura-Jiménez, Longo, et al., 2012). A different, more implicit approach to the enfacement effect and changes in self–other overlap is the self-(other-) recognition task (Porciello et al., 2018). In this task, participants are presented with a video showing a morphing process between their own face and the other person's face and are instructed to stop the video when they see more of themselves or the other person, depending on the direction of the morphing process. Previous studies have shown that after synchronous stroking but not asynchronous stroking, self-(other-)recognition is changed. More precisely, after synchronous IMS, the other person is integrated into the representation of the participants' own face (Porciello et al., 2018; Tajadura-Jiménez, Grehl, et al., 2012; Tsakiris, 2008). That is, by synchronous IMS, features of the other person are recognized to some degree as own features (Hommel, 2018).

The enfacement illusion has been extensively studied in adults (for a review, see Porciello et al., 2018). From a developmental perspective, multisensory integration processes are proposed to be present from very early on (Rochat & Morgan, 1995; Zmyj et al., 2011) and are claimed to be an important developmental mechanism of the bodily self (De Klerk et al., 2021). However, as De Klerk et al. (2021) pointed out, the vast research on the malleability of self-representations by multisensory integration processes in adults does not necessarily allow strong claims regarding the role of multisensory integration in the development of self representations. This can only be done by investigating the role of multisensory integration across development. Research with children focused on the embodiment of an impersonal rubber hand implementing the rubber hand illusion (Cowie et al., 2013; Nava et al., 2017). Only one study has investigated an adapted procedure of the enfacement illusion during which the participating children touched themselves congruently or incongruently in the face (Cook et al., 2023). Findings demonstrate that children as young as 6 years experience the enfacement illusion, as evidenced by their greater agreement with enfacement questionnaire statements following congruent stimulation compared with incongruent stimulation. Although providing valuable first insights, the study by Cook et al. (2023) was not conducted in the laboratory but rather at home, was self-administered by the children and not with the standard procedure, and did not include the self-recognition task as an implicit measure. Therefore, the aim of the current study was to investigate potential changes in self–other overlap during the enfacement illusion in 5- and 6-year-old children with a standard procedure and including the self-recognition task as the most common implicit measure of self–other overlap (Porciello et al., 2018).

Enfacement illusion from a developmental perspective

Theories on the self propose that humans have plastic and malleable self-representations that can be altered by synchronous multisensory input. From a developmental perspective, there are reasons to assume that the degree of plasticity could differ in the course of development. In particular, it has been proposed that children's self-representations are more flexible due to continuous changes in their body's shape, size, and functionality (Cowie et al., 2022; Weijs et al., 2021). Therefore, children are proposed to rely more strongly on multisensory information, especially visual information, than adults (De Klerk et al., 2021). On the contrary, adults might depend more strongly on memorized representations of body and face. This leads to the intriguing question of whether children show a stronger enfacement effect than adults, meaning that children show greater self–other blurring after IMS. Furthermore, children have been shown to be less sensitive to visuotactile delay (Chen et al., 2018; Cowie et al., 2018). Thus, children are proposed to show a weaker modulation of the effect by the stimulation condition. That is, children could experience increased self–other overlap after both synchronous and asynchronous stimulation. Previous studies have tested these claims in other body illusion, revealing mixed evidence. Whereas some studies found evidence for stronger ownership changes in children or differences in modulation of synchronicity (Cowie et al., 2016, 2018, 2022), others did not find such developmental differences (Cowie et al., 2013; Nava et al., 2018). Studying the proposed claims with the enfacement illusion could reveal a clearer picture. Not only is the face of central theoretical interest, but children also have more limited experience with the outer appearance of their own face. One might speculate that in childhood memorized representations of the face might not be as stable as those of the hand, making differences between children and adults especially likely. Therefore, the current study aimed to investigate the claim of a developmental difference in the enfacement effect and the modulation of the synchronicity effect with the enfacement illusion.

The role of preexisting representations of self and other

Some scholars have proposed that the multisensory integration processes are sufficient and exclusive for constructing and updating body representations, offering a pure bottom-up approach to self-recognition (e.g., Armel & Ramachandran, 2003; Ehrsson, 2012). However, others have argued from a predictive coding perspective that existing representations of the body interact with the sensory input (e.g., Apps & Tsakiris, 2014; Tsakiris, 2011). According to this view, self-representations are constructed by an interaction between current multisensory input and a preexisting model of the body, allowing for contextual top-down effects on self-recognition. Depending on the compatibility between the preexisting body model and the sensory input, a feeling of ownership over the body is constructed and the body model is updated. Indeed, previous research has shown that the visual form of the viewed object and the felt body part need to be congruent to lead to an updating of the representation of the self (e.g., Tsakiris & Haggard, 2005).

Interestingly, it has been proposed that the representation of the self is not isolated but rather connected with the representation of others (Hommel, 2018). Similarly, from a developmental perspective, the self has been proposed to be grounded in social interactions (Hammond et al., 2010). These representations can be differently overlapping, opening up a continuum from strong overlap to clear self–other distinction (Keysers et al., 2010; Maister et al., 2020). Indeed, previous adult research has shown that the resonance with another person's tactile experiences, actions, and pain is greater when that person belongs to the same social or racial group (Azevedo et al., 2012; Molnar-Szakacs et al., 2007; Serino et al., 2009). Applied to the representation of the face during the enfacement illusion, the identity of the other's face is proposed to influence the updating of the representation of the face during IMS. To date, no studies exist that systematically manipulated the identity and familiarity of the other person during the enfacement illusion. We aimed to fill this gap by comparing the enfacement illusion with a stranger and the caregiver as the other person.

The relationship with the caregiver constitutes one of the closest and most intimate ones (Ainsworth, 1969). Thus, self–other overlap with the caregiver is proposed to be especially high; for example, previous studies have shown substantial overlap of neural activation when reflecting on the self and the mother (van der Cruijsen et al., 2017; Vanderwal et al., 2008). Studies focusing on the neural mechanism of self- and mother-face processing in infants show some mixed findings. Whereas one study did not find a significant event-related potential (ERP) difference between self- and mother-face processing in 18-month-olds (Stapel et al., 2017), another study found an ERP difference at a previously not expected time point while finding no differences in the hypothesized areas in 6- to 8-month-old infants (Rigato et al., 2024). Therefore, touch in the other's face during the IMS phase of the enfacement illusion could be experienced as more self-relevant when the other person is the caregiver compared with a stranger (Maister et al., 2020). This would lead to an enhanced enfacement effect with the caregiver. First evidence comes from a study by Maister et al. (2020), where infants were found to look longer at a display showing synchronous (vs. asynchronous) IMS only when the person in the video was their mother. Yet, this finding relied on indirect looking-time measures in infants. We aimed to investigate the hypothesis of an enhanced enfacement effect with the caregiver in a child sample using well-established measures of the enfacement effect.

Hypotheses and current study

To summarize, the current study aimed to advance our understanding of children's minimal self by investigating the enfacement illusion in a child sample and comparing the enfacement effects between a stranger and a caregiver of the children. Its goal was to contribute to the advancement of developmental theories by (a) capturing the enfacement effect in a sample of adults and children, (b) investigating potential differences in the enfacement effect between children and adults, and (c) exploring the social basis of self-recognition by comparing the enfacement effect with the caregiver and a stranger. Specific hypotheses are derived in turn.

Based on theoretical proposals of the role of multisensory integration for self-experience (De Klerk et al., 2021; Ehrsson, 2012), we hypothesized a positive effect of synchrony on the explicit measure of self–other overlap, which is ratings in an enfacement questionnaire (Hypothesis 1.1 [H1.1]). Likewise, we hypothesized a positive effect of synchrony on the implicit measure of self–other overlap, that is, more integration of the other in the self in the self-recognition task (H1.2).

Theoretical considerations propose that children rely less on preexisting representations and more strongly on current sensory input (Cowie et al., 2022; Weijs et al., 2021). Thus, children's representations of themselves might be more plastic, leading to an enhanced self–other overlap during the enfacement illusion compared with adults. We tested the developmental hypothesis that children show higher self–other blurring than adults independent of synchronicity of the stimulation in the enfacement questionnaire (H2.1) and the self-recognition task (H2.2). Furthermore, children have been shown to be less sensitive to visual–tactile delays (Chen et al., 2018). Consequently, we hypothesized an enhanced effect of synchrony in the adult sample compared with children, meaning a significant positive interaction effect of Age Group $\times$ Synchronicity on both the explicit measure (H2.3) and the implicit measure (H2.4). Thus, the effect of synchronicity was hypothesized to be stronger in adults than in children.

Theoretical accounts propose that the caregiver is represented as especially close to the self, and sensory input in the context of the caregiver has a self-specific quality (Maister et al., 2020). Following this position, children were hypothesized to show enhanced enfacement effects with the caregiver compared with a stranger. Therefore, we hypothesized an enhanced effect of synchrony in the caregiver condition, meaning a significant positive interaction effect of Caregiver $\times$ Synchronicity on both the explicit measure (H3.1) and the implicit measure (H3.2).

Taken together, by manipulating multisensory stimulation and social familiarity with the other person, we explored two factors that have been claimed to relate to children's developing sense of body ownership. To investigate the hypotheses, the study implemented an enfacement illusion protocol in a laboratory setting with both adults and children.

Method

Sample

In total, 64 typically developing children aged 5 and 6 years (n_{male} = 30, n_{female} = 34; M_{age} = 5.99 years, *SD* = 0.37) took part. Participating children were recruited by sending out invitation letters to families with children in the appropriate age range. The majority of the children had a full (*n* = 42) or partial (*n* = 8) White/Caucasian ethnic background (parental report). The adult sample consisted of 33 students (n_{male} = 2, n_{female} = 31; M_{age} = 22.18 years, *SD* = 2.95), with 32 participants having a full (*n* = 29) or partial (*n* = 3) White/Caucasian ethnic background.

The enfacement effect and potential interactions are quite substantial. Power analysis focused on the central interaction effect of Hypothesis 3. Maister et al. (2020) found an interaction effect between caregiver and synchronicity equivalent to r = .53. Following Murayama et al.'s (2022) simulation-based approach and assuming that effect size, a power of 80%, an alpha of 5%, 26 children per group would be needed. To have a more robust estimation of the effect and to allow for full counterbalancing and some missing values, we decided to test 64 children. Given that adults were tested only in the stranger condition, the size of the adult sample was set to 32 to be equivalent with half the child sample because only half the child sample was tested in the stranger sample. A sample size of around 30 participants per group is common in the field of body illusions (e.g., Cowie et al., 2013; Nava et al., 2017, 2018).

Given that predefined exclusion criteria were applied (see preregistration: https://aspredicted.org/CMS_SDF), 9 children needed to be excluded from the analysis of the questionnaire data because they scored too high on the control questions. The data of 6 tested children were excluded for the analysis of the self-recognition task because the children did not understand the task (n = 4) or did not look at the screen when deciding to push the pause button (n = 2). Informed consent was obtained for all participants prior to participation. Participating parents were reimbursed for traveling costs, and the children got a small gift. Participating adults received course credit or financial reimbursement. The study was approved by the local ethics committee.

Design

The study was carried out following a between/within-participant mixed design. Half the participating children were randomly assigned to the caregiver condition, and the other half were assigned to the stranger condition. Adults were tested only in the stranger condition. All children and adults received one trial of synchronous IMS and one trial of asynchronous IMS, the order of which was counterbalanced across all participants. Two dependent measures were obtained: (a) self-(face-) recognition task, which is an implicit measure of the enfacement illusion, delivered before and after the stimulation, and (b) an enfacement questionnaire, which is an explicit measure of the enfacement illusion, delivered only after the stimulation.

Materials

Stimulation video

In the stranger condition, a prerecorded induction video with a length of 120 s was used, showing a young woman being stroked by a cotton bud at a frequency of 0.33 Hz from the zygomatic bone downward. The strokes covered about 2 cm. The model confirmed consent to use the video during the testing. In the caregiver condition, an equivalent video of the mother was recorded at the beginning of the session. The video was presented in full-screen mode on a 24-inch screen positioned approximately 50 cm away from the participants.

The frequency of the strokes was chosen due to considerations regarding the synchronicity detection in young children. Previous research has shown that the effects of the rubber hand illusion occurred during both the synchronous and asynchronous conditions in 4- to 9-year-old children (Cowie et al., 2013, 2016). This might be a result of the children not detecting asynchronies when the distance between stimuli is small (Greenfield et al., 2017). Indeed, Chen et al. (2018) showed that even at a stimulus onset asynchrony of 800 ms between a visual stimulus and a tactile stimulus, 7-year-olds consider the stimuli as simultaneous in 18.3% of the trials. The lower frequency—compared with other studies using the enfacement paradigm—should be sufficient to ensure that children perceive asynchronous trials indeed as asynchronous.

Morph videos

At the beginning of the session, a digital photograph of the participant was taken, converted to grayscale, and mirror transposed. To remove nonfacial features such as background, hair, and ears, the photograph was imported into a black template using GNU Image Manipulation Program (GIMP). The same procedure was done with a pre-taken picture of the stranger or of the mother—depending on

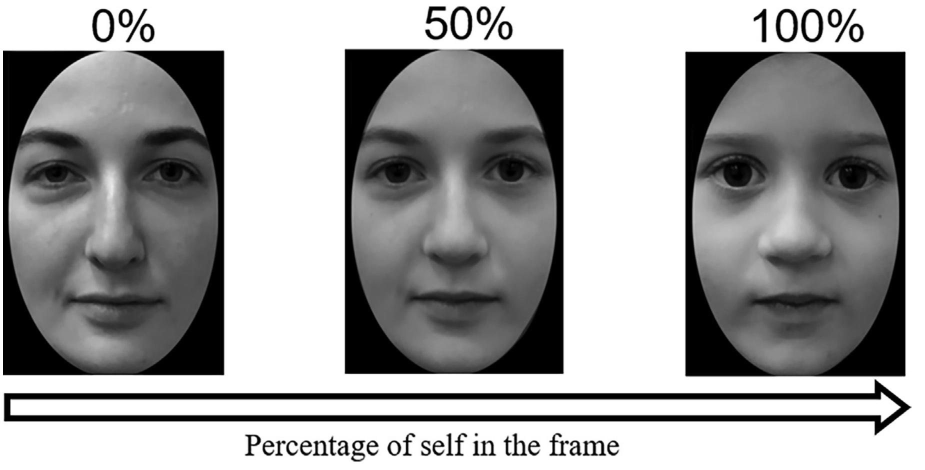

Fig. 1. Morph video from 0% self to 100% self.

the condition. Both pictures were used to create morph videos using Abrosoft FantaMorph (see Fig. 1). Following standard procedures, the videos lasted 33 s, showing three frames per second with 100 frames in total (e.g., Panagiotopoulou et al., 2022). Those frames represented 1% steps in the respective morphing direction. Two videos were produced for each participant: one starting at the picture of the participant's face and ending at the stranger's/mother's face and another starting in the opposite direction.

Measures

Self-recognition task

The morph videos were shown in full-screen mode, and the participants were instructed to push the spacebar when they saw more of themselves or the other person than of the other person or themselves—depending on the direction of the morph videos (e.g. "Please press this button [spacebar] as soon as possible if you think it's your mum rather than yourself"). Both directions were shown sequentially, with the order being counterbalanced between participants. The number of seconds with two decimal places at which the participants stopped the video by using the spacebar was recorded by the experimenter.

Enfacement questionnaire

Questions regarding the experience and sensations during the IMS were preselected from previous studies (e.g., Tajadura-Jiménez, Grehl, et al., 2012) according to which seemed suitable to use with children. During piloting with 13 5- to 7-year-old children, four questions appeared to be appropriate (see Table 1). The questions covered different aspects of the phenomenal experience, namely (1) sense

Table 1
Items of the enfacement questionnaire.

Item number	Question
1	Did you have the feeling that you could feel the touch in the face of the other person?
2	Did you have the feeling that you saw yourself in a mirror?
3	Did you have the feeling that if you had winked that the other person would have winked as well?
4	Did you have the feeling that the face of the other person looked similar to your own face?
5	Did you have the feeling that you had more than one face?
6	Did you have the feeling that your hair turned blue?

of referred sensation, (2) sense of facial ownership, (3) sense of agency over the other face, and (4) sense of similarity with the other face. Questions 5 and 6 were used as control questions to ensure that participants did not just agree to any statement after the stimulation. Participants used a 5-point scale displaying different-sized circles to answer. The scale reached from *no, not at all* to *yes, a lot.* Children could point to the circle that corresponded to their answer.

Procedure

The experimental session took about 1.5 h to finish. During the whole procedure, participants were alone in the room with the experimenter while the parent waited in a different room filling out questionnaires. After children were trained to use the 5-point scale using easy-to-answer questions (e.g., "Do you like chocolate?") and to use the spacebar to stop a morphing video showing the morphed transition from Donald Duck to Daisy Duck, they completed the baseline self-(other-)recognition task for the first enfacement trial. Half the child sample saw the morph videos of the own picture with the picture of the own mother, and the other half did so with the picture of a stranger. Adults did not receive such training because the standard procedure for adults does not include one. After the baseline, participants were instructed to watch the stimulation video, sit as still as possible, and observe how it feels for them. During the video, they were stroked with the same cotton bud as was used in the video at the specular congruent location (left side of the participants). The stimulation was delivered either synchronously or asynchronously (1.5 s onset asynchrony). After the IMS phase, participants completed the same self-recognition task as at baseline and the enfacement questionnaire.

After this first enfacement trial, measures of cognitive development from other studies were conducted for about 45 min. At the end of the testing session, a second enfacement trial was carried out with the same procedure as in the first trial (baseline–IMS–posttest–questionnaire), but with the other stimulation condition (synchronous/asynchronous). The order of the synchronous/asynchronous trials was counterbalanced between participants.

Data analysis and preregistration

Exclusion criteria and the statistical models for the analysis of the child data were preregistered (https://aspredicted.org/CMS_SDF). Two deviations from the preregistered analysis strategy were made. First, because we decided to add an adult sample after we started testing, we included the factor age group in the models. Second, a hierarchical approach was adopted by gradually adding factors to the models to allow for the interpretation of main effects without confoundation of interaction effects. Given that repeated measures (Level 1) were nested within participants (Level 2), a multilevel model was calculated including random intercepts. All the statistical analyses were carried out in R (R Core Team, 2021), implementing the package "lme4" (Bates et al., 2015). Anonymized raw data as well as the analysis script can be retrieved from the Open Science Framework (Steinmassl & Paulus, 2024; https://osf.io/52fyt/?view_only=fad7c30e3ef84cf386c5084e5403e71c).

To test hypotheses regarding the explicit measure (H1.1, H2.1, H2.3, and H3.1) an overall enfacement score (EQ-sum) was calculated by averaging the child's rating on the first four questions of the enfacement questionnaire. For the analysis of the self-recognition task, the number of seconds at which the child stopped the video was converted to the percentage of frames that were still judged as "self". Both directions of morphing were aggregated given that both directions did not reveal any different results in previous studies (Heinisch et al., 2011; Payne & Tsakiris, 2017). Because baseline scores in the self-recognition task can be quite variable, the mean-centered pretest score of self-recognition was always included as a control variable.

First, only synchronicity (dummy coded; 0 = asynchronous, 1 = synchronous) was added to the model, with the overall enfacement score and posttest self-recognition as dependent variables. Second, age group (dummy coded; 0 = children, 1 = adults) was added to the model. Third, caregiver (dummy coded; 0 = stranger, 1 = mother) was added to the model. Fourth, a model with only age group and not synchronicity as a factor was calculated.

H1.1 and H1.2 would be supported by significant, positive main effects of synchronicity in Models 1, 2, and 3. H2.1 and H2.2 would be supported by a significant negative effect of age group in Model 4.

H2.3 and H2.4 would be supported by significant positive interaction effects, Synchronicity × Age Group, in Models 2 and 3. H3.1 and H3.2 would be supported by a significant positive interaction effect of Synchronicity × Caregiver in Model 3.

To inform future studies on appropriate items for child samples, exploratory *t* tests were conducted to compare the difference between the items in the synchronous and asynchronous conditions of the child sample—not differentiating between the caregiver and stranger conditions. Also for the child sample—following Nava et al. (2017)—the four enfacement items were compared with Control Question 5 within each synchronicity condition using *t* tests to explore differences in the rating of the enfacement questions and the control question in relation to the synchronicity condition.

Results

Descriptive statistics and correlations

Means and standard deviations of the self-recognition task and the enfacement questionnaire sum score under different conditions are depicted in Table 2. Initial correlations were calculated with a difference score between the posttest and pretest self-recognition task because we were interested in changes of self–other overlap and not a static self–other overlap. Table 3 depicts correlations between implicit and explicit measures of the enfacement illusion and the factor age group. A significant correlation was found between EQ-sum and the self-recognition differences score in the synchronous condition. EQ-sum in the synchronous condition also correlated significantly with age group and EQ-sum in the asynchronous condition. This indicates that agreement with the enfacement questionnaire in the synchronous condition was associated with less changes in self–other overlap in the self-recognition task and more agreement in the asynchronous condition.

Model 1: Only synchronicity as factor

A linear mixed model did not reveal a significant effect of synchronicity (b = 0.021, SE = 0.011, p = .067, 95% confidence interval (*95% CI*) [−0.001, 0.044]) on the self-recognition posttest score when controlling for pretest self-recognition score (b = 0.168, SE = 0.063, p = .009, *95% CI* [0.033, 0.305]), indicating that changes in the self-recognition task were not significantly bigger in the synchronous condition.

A linear mixed model with EQ-sum as dependent variable revealed a significant effect of synchronicity (b = 0.273, SE = 0.087, p = .002, *95% CI* [0.102, 0.443]), indicating higher agreement with the enfacement questionnaire statements in the synchronous condition.

Model 2: Adding age group as factor

The results of the model including the factor age group are depicted in Table 4 for the self-recognition task and in Table 5 for the enfacement questionnaire. The analysis revealed no significant

Table 2
Descriptive statistics of the enfacement questionnaire and the self-recognition task.

	Child–Caregiver		Child–Stranger		Adults	
	EQ-sum	Control	EQ-sum	Control	EQ-sum	Control
Mean (*SD*)—Synchronous	1.79 (0.87)	0.80 (1.27)	1.46 (0.99)	1.29 (1.38)	1.52 (0.80)	0.35 (0.44)
Mean (*SD*)—Asynchronous	1.55 (0.96)	1.05 (1.20)	1.22 (0.96)	0.95 (1.22)	1.15 (0.68)	0.33 (0.41)
	Pre	Post	Pre	Post	Pre	Post
Mean (*SD*)—Synchronous	0.48 (0.09)	0.47 (0.10)	0.46 (0.12)	0.48 (0.11)	0.44 (0.10)	0.47 (0.07)
Mean (*SD*)—Asynchronous	0.46 (0.08)	0.48 (0.11)	0.46 (0.12)	0.42 (0.10)	0.42 (0.11)	0.45 (0.07)

Note. Descriptive statistics of enfacement questionnaire are presented in first two rows. EQ-sum, enfacement questionnaire sum score. Only the first four items were averaged for the sum score. Control, sum score of control questions. Last two rows present statistics from the self-recognition task. The values here represent decimals of the proportion of the other person in frames that are judged as self.

Table 3
Correlation table of dependent measures.

	Posttest–Pretest self-recognition		EQ-sum		Age group
	1 Asynchronous	2 Synchronous	3 Asynchronous	4 Synchronous	
1	–	−.094	−.001	.075	.120
2		–	−.180	−.211*	.094
3			–	.673***	−.139
4				–	−.208*

Note. Posttest-Pretest self-recognition, posttest score of self-recognition task minus pretest score. EQ-sum, enfacement questionnaire sum score. Only the first four items were averaged for the sum score.
* p < .05.
*** p < .001.

Table 4
Model 2 for self-recognition task: Age group and synchronicity as factor.

Effect	*b*	*SE*	*p*	*95% CI*	
				Lower bound	Upper bound
Intercept	0.452	0.012	<.001***	0.429	0.475
Sync	0.023	0.014	.109	−0.005	0.052
Age group	−0.005	0.020	.802	−0.043	0.033
Pretest	0.168	0.064	.009**	0.033	0.305
Age Group * Sync	−0.006	0.024	.810	−0.053	0.041

Note. CI, confidence interval. Sync, synchronicity.
** p < .01.
*** p < .001.

Table 5
Model 2 for enfacement questionnaire sum score: Age group and synchronicity as factor.

Effect	*b*	*SE*	*p*	*95% CI*	
				Lower bound	Upper bound
Intercept	1.411	0.119	<.001***	1.179	1.642
Sync	0.218	0.110	.050	0.003	0.433
Age group	−0.259	0.194	.184	−0.638	0.119
Age Group * Sync	0.146	0.179	.417	−0.205	0.496

Note. CI, confidence interval. Sync, synchronicity.
*** p < .001.

effect of synchronicity on the self-recognition task in the child sample and no significant interaction effect of synchronicity with age group. The 95% confidence interval of the effect of synchronicity on EQ-sum indicates a significant effect, whereas the p value is not significant. Descriptive values for each age group are depicted in Table 2. Overall, this shows that both dependent measures as well as the modulation by synchronicity were not significantly affected by age group.

Model 3: Adding caregiver as factor

The results of the model including the factor age group and caregiver are depicted in Table 6 for the self-recognition task and in Table 7 for the enfacement questionnaire. The analysis revealed a significant effect of synchronicity on the self-recognition task in the child–stranger sample and a significant interaction effect of synchronicity with caregiver. This pattern of a significant effect of synchronicity only for the stranger condition in children is also evident in Fig. 2. The model for EQ-sum revealed no significant main or interaction effects. This shows that in the self-recognition task, a significant effect

Table 6
Model 3 for self-recognition task: Caregiver added as factor.

Effect	b	SE	p	95% CI	
				Lower bound	Upper bound
Intercept	0.423	0.017	<.001***	0.391	0.456
Sync	0.056	0.020	.007**	0.017	0.095
Age group	0.023	0.023	.314	−0.021	0.068
Pretest	0.166	0.063	.009**	0.034	0.300
Caregiver	0.054	0.024	.022*	0.009	0.010
Age Group * Sync	−0.038	0.028	.168	−0.092	0.015
Caregiver * Sync	−0.063	0.028	.028*	−0.118	−0.008

Note. CI, confidence interval. Sync, synchronicity.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 7
Model 3 for enfacement questionnaire sum score: Caregiver added as factor.

Effect	b	SE	p	95% CI	
				Lower bound	Upper bound
Intercept	1.265	0.168	<.001***	0.939	1.591
Sync	0.199	0.157	.207	−0.105	0.507
Caregiver	0.289	0.236	.223	−0.170	0.746
Age group	−0.113	0.227	.619	−0.555	0.327
Age Group * Sync	0.164	0.212	.441	−0.250	0.576
Caregiver * Sync	0.039	0.220	.861	−0.392	0.467

Note. CI, confidence interval. Sync, synchronicity.
*** $p < .001$.

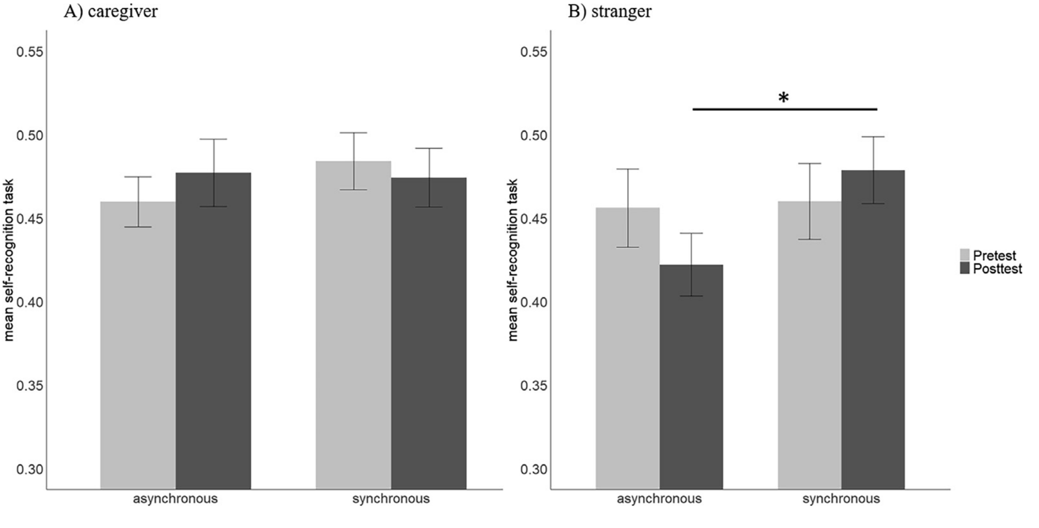

Fig. 2. Plot for the self-recognition task in the child sample: (A) caregiver condition; (B) stranger condition. The mean proportion of other in the self is depicted on the y-axis split up by the condition of the model, stimulation condition, and baseline and poststimulation test. Error bars depict standard errors. The asterisk indicates a significant difference between posttest of the asynchronous and synchronous conditions for the stranger condition only.

was found in the stranger condition, whereas this effect was significantly smaller in the caregiver condition.

Model 4: Only age group as factor

Model 4 with only age group as factor revealed no significant effect of age group (b = −0.008, SE = 0.016, p = .616, *95% CI* [−0.038, 0.023]) on the self-recognition posttest score when controlling for pretest self-recognition score (b = 0.183, SE = 0.064, p = .005, *95% CI* [0.051, 0.322]). A linear mixed model with EQ-sum as dependent variable also revealed no significant effect of age group (b = −0.187, SE = 0.172, p = .281, *95% CI* [−0.524, 0.150]), indicating no significant differences between the age groups in both dependent measures across conditions of synchronicity.

Exploratory analyses of the enfacement questionnaire

Comparisons of the synchronous and asynchronous conditions (see Table A1 in Appendix) revealed only a significant effect in Item 1 (sense of referred sensation; see Table 1). Comparing the single items with the Control Item 5 in each condition of synchronicity revealed significant differences for Items 1, 3, and 4, and for the overall enfacement score only in the synchronous condition (see Table A2 in Appendix), but not in the asynchronous condition, indicating that these items can capture the enfacement effect in young children.

Discussion

The current study investigated the psychological mechanisms subserving the sense of face ownership in young children. More specifically, we examined whether and to what extent 5- and 6-year-old children show the enfacement illusion, that is, whether they experience ownership over another person's face. By manipulating multisensory stimulation and social familiarity with the other person, we explored two factors that have been claimed to relate to children's developing sense of bodily self. We hypothesized that IMS affects self–other boundaries on an explicit level and an implicit level. The explicit level was captured by an enfacement questionnaire, whereas the implicit level was operationalized with a self-recognition task. Overall, we found evidence for the presence of the enfacement effect in young children in both measures. This supports theoretical views that the minimal self is based on multisensory integration processes (De Klerk et al., 2021) given that developing self-representations are malleable by synchronous multisensory stimulation. The effect in children was comparable to a group of adults, suggesting that the mechanisms underlying the construction of self representations do not differ between children and adults. Theoretical notions that these processes undergo changes during development and that children rely more strongly on sensory information in their self-representation were not supported (Cowie et al., 2022). Most interesting and contrary to our hypothesis, when the other person was the caregiver and not a stranger, the effect of synchronicity on the self-recognition task was significantly smaller. This was not the case for the enfacement questionnaire. The negative interaction effect of caregiver supports notions of top-down contextual effects on the malleability of self-representations (Apps & Tsakiris, 2014), but not of an increased self–other blurring with close others (Maister et al., 2020). Overall, the study provides evidence that multisensory stimulation and social familiarity with the other person relate to children's sense of bodily self. Central findings are discussed in more detail in turn.

Changes in self-representation and face ownership by synchronous multisensory stimulation

The first aim of the study was to test theoretical notions that multisensory integration processes underlie the construction of the developing self-representations (De Klerk et al., 2021; Ehrsson, 2012). Therefore, synchronous multisensory stimulation is proposed to change self-representations and the sense of face ownership. Even though not all effects (in the different models) of synchronicity were significant, overall we found evidence supporting the theoretical claim of multisensory integration as the underlying mechanism of self-representations. This extends previous findings on other bodily illusions (Cowie et al., 2013; Nava et al., 2017) and studies that implemented indirect measures in infancy (for a review, see De Klerk et al., 2021) by showing that multisensory integration processes play a role in developing self-face representations. Thus, not only the congruency of the stimulation (Cook et al., 2023) but also the temporal synchronicity plays an important role for the developmental construction of sense of face ownership and self-recognition. Thus, the synchronous and contingent multisensory stimulation the child experiences when looking at a mirror is proposed to lead to the integration of different sensorimotor modalities, the construction of a body/face representation, and the recognition of oneself. This is particularly interesting because the face is supposed to be one of the most personal characteristics of a person.

For the two dependent measures, slightly different patterns emerged and the effect of synchronicity was not significant in all tested models. In the case of the explicit measure, even though adapted and piloted, the items of the enfacement questionnaire were quite abstract, especially when compared with items used for the rubber hand illusion. Our exploratory analysis of single items can help to identify items that can be used to reliably investigate the enfacement illusion in preschool children. Regarding the self-recognition task, the negative interaction effect of Caregiver × Synchronicity may account for the nonsignificant effects of synchronicity in the other models. The negative interaction effect is discussed in the next section.

Interestingly, initial correlational analyses show a significant negative correlation between the sum score of the enfacement questionnaire and the pretest–posttest difference score of the self-recognition task in the synchronous condition. Given that both measures are proposed to measure self–other blurring, this is a surprising finding. Although both measures are affected by the same manipulation, underlying mechanisms could be different. For example, one study showed that sensory susceptibility relates to the strength of the rubber hand illusion in the explicit measure but not in the implicit measure (Marotta et al., 2016). Another study showed that cognitive load differentially influences implicit and explicit measures of body ownership (Qu et al., 2021). Thus, our finding extends previous critical discussions of the relation between implicit and explicit measures of sense of body ownership by providing evidence for a partial dissociation of implicit and explicit measures also in the enfacement illusion (Ma et al., 2021). Future studies should examine this systematically to clarify what implicit and explicit measures of the enfacement illusion specifically measure and how they differ in underlying mechanisms.

Diminished self–other blurring with the caregiver

Another aim of the current study was to test whether the social familiarity of the other person constitutes a top-down contextual influence on the malleability of self–other boundaries. We proposed that children represent themselves as especially close to the caregiver and that sensory stimulation of the caregiver is experienced as self-relevant (Maister et al., 2020). Therefore, we expected to find enhanced effects of synchronicity in the caregiver condition in both dependent measures of the enfacement illusion. Results show some mixed findings with a top-down modulation by the identity of the other person in the implicit measure. Surprisingly, this modulation was in the opposite direction than expected. Overall, our findings do not support the claim that the closeness with the caregiver enhances the self-relatedness of the stimulation and thus self–other blurring by multisensory stimulation. Interestingly, different patterns emerged for the two dependent measures, which are discussed in turn.

In the enfacement questionnaire, the identity of the other person did not modulate the effect of synchronicity significantly. On an explicit level, children did not experience significantly greater self–other blurring with the caregiver than with a stranger during synchronous stimulation compared with asynchronous stimulation.

Contrary to our hypothesis, we found a significant negative interaction effect of Caregiver × Synchronicity on the poststimulation self-recognition task. First, this result provides support for the general notion of an influence of the identity of the other person on the malleability of self–other overlap. Thus, preexisting representations of the other person influence the plasticity of self–other boundaries. This supports claims that the bodily self is constructed by an interaction of top-down contextual and bottom-up processes (e.g., Apps & Tsakiris, 2014). However, more discussion is needed on the reported effect in the opposite direction than hypothesized.

One explanation could be that self-representations of 5- and 6-year-old children are already relatively stable and established, especially in their connections with close others. Assuming that self-representations indeed develop in social interactions with close others (Maister et al., 2020; Montirosso & McGlone, 2020), we can posit that 5-year-olds already have a long history of self-relevant stimulation by the caregiver, seeing the caregiver being touched and experiencing (a)synchronous stimulation on themselves and the caregiver. The bodily representations of the self and the mother therefore could strongly overlap prior to any stimulation. Two minutes of (a)synchronous stroking might not be enough to modulate self–other boundaries. In other words, because the face of the own mother is so familiar, self–other overlap is already established and the plasticity of self–other boundaries might be smaller. Given that the self-recognition task as used in the current study can only capture changes in self–other overlap but not a static diagnosis of self–other overlap, we cannot directly infer from our data that initial self–other overlap was higher with the mother than with a stranger. However, previous findings support that notion, for example, showing that neural activation overlaps when reflecting on the self and the mother (van der Cruijsen et al., 2017; Vanderwal et al., 2008). Previous studies have also found different neural responses to familiar faces compared with unfamiliar faces (e.g., Caharel et al., 2011). Most interesting, in young children processing of the caregiver compared with a stranger is characterized by a stronger N170 ERP signal compared with strangers (Kungl et al., 2017). These findings can be interpreted as indicating a very robust and stable representation of the caregiver. At the same time, one study did find an ERP difference between processing of self-face and mother-face in 6- to 8-month-old infants in an exploratory analysis, although not at the hypothesized time points (Rigato et al., 2024). Taken together, although the studies do not paint a coherent picture and therefore more research is needed, it is possible that an initial high and stable bodily self–other overlap with the mother limits the malleability and plasticity of self–other boundaries.

From a methodological perspective, the effect of IMS on self–other overlap as captured by the self-recognition task could be undermined by the fact that the mother and child share facial features and look alike to some degree. Self–other blurring in this task is commonly interpreted as an integration of facial features of the other person into the self (Hommel, 2018). We used the self-recognition task because it is the most common measure of the enfacement illusion and due to its ties with theoretical debates around the development of self-recognition. However, future studies should validate our findings by implementing measures that do not rely on the integration of external features of the other person. For example, differences in heart rate and skin conductance when an object is approaching are suitable for this purpose (Tajadura-Jiménez, Grehl, et al., 2012).

Developmental similarity in self–other blurring by multisensory integration

Theoretical notions that children rely more strongly on sensory information in their self-representation (Cowie et al., 2022) were not supported. First, children did not show enhanced self–other blurring than adults after IMS. That is, they did not rely more strongly on sensory information. By 5 or 6 years of age, the representation of one's face might already be well-developed and does not undergo developmental changes afterward. Second, the effect of synchronicity was not modulated by age group in either dependent measure. Taken together, we did not find evidence for developmental differences in the mechanisms underlying the construction of self-(face-)representations and the sense of face ownership.

Other characteristics than the proposed reliance on sensory stimulation differ between young children and adults; for example, young children show overly positive self-worth and face the challenge to develop autonomy (Graves & Larkin, 2006; Harter, 2015). These characteristics could influence self–other processing during the enfacement illusion besides the reliance on sensory stimuli. For example, the challenge of autonomy development is proposed to lead to a stronger focus on oneself (Broesch et al., 2011). By this focus on oneself and one's actions, the malleability of the sense of bodily self could be decreased in young children compared with adults. Furthermore, a higher self-worth in young children and a more optimistic view of oneself could be linked to a lower flexibility when accepting changes in body representations. Some adult studies have investigated the link between self–other recognition and self-esteem (Ma & Han, 2010; Richetin et al., 2012). However, no study to date has investigated the influence of self-worth on the malleability of the bodily self from a developmental perspective. Taking together, clarifying theoretically proposed developmental and individual differences in self–other information processing remains an open question and an interesting field for future research.

A methodological difference could account for our null finding compared with other studies that report developmental differences (e.g., Cowie et al., 2016): In the current study, the interval between two strokes was increased. Thus, the asynchronicity was more salient and might have prevented children from experiencing asynchronous strokes as synchronous. Future studies could vary the stroking frequency systematically to explore the effect of children's abilities to detect visuotactile asynchronies on the experience of the enfacement illusion. This can inform notions about developmental differences in the mechanistic role of (a)synchronous multisensory stimulation on the construction of the bodily self.

Methods to detect the enfacement illusion across development

On a methodological level, our study provides developmental science with a new method to investigate psychological mechanisms behind the developing bodily self. More precisely, the self-recognition task evidenced how children's sense of bodily self is affected by different processes. The use of a self-detection task provides promising avenues for future research because it relies less on the specific wording of questionnaire items and might be less susceptible to response bias. It would be interesting to examine whether this method allows for investigation of the bodily self also in younger children for whom it might be difficult to respond to explicit questionnaires.

Regarding the enfacement questionnaire, our exploratory analyses of single items revealed item-specific effects. These findings can be used as recommendations for future studies regarding the decision of which items to use.

Limitations and open questions

Although the current study adds to the field by demonstrating the impact of multisensory stimulation and social familiarity on children's sense of face ownership, and by establishing the use of morphed faces in the self-recognition task as a promising measure in young children, it also comes with some limitations. First, the study cannot distinguish between a general effect of familiarity and a specific effect of the caregiver. Future studies could test this by including a condition with a sibling, friend, or kindergarten teacher of the child. Second, due to the within-participant design, it was not possible to include a third condition in which either no stimulation or incongruent stimulation is applied. These additional control conditions could provide insight into specific roles of temporal and spatial congruencies of multisensory stimulation for the bodily self. Therefore, future studies should include such additional control conditions.

Furthermore, more developmental studies could shed light on other proposed influencing factors on the malleability of the bodily self. Future studies should compare more age groups and corroborate this by investigating the relation between individual differences of the malleability of the bodily self and potential influencing factors such as sense of agency as an autonomy-related construct, attachment security, and self-worth.

Conclusion

Overall, we found evidence for the presence of the enfacement illusion in 5- and 6-year-old children. This supports theoretical claims about the role of multisensory integration processes for the developing bodily self and self-face representations. Furthermore, it provides first evidence that the enfacement illusion in children can be captured by an implicit self-recognition task, providing the field with a valuable tool for further investigating the mechanisms underlying the developing bodily self.

CRediT authorship contribution statement

Konstantin Steinmassl: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Markus Paulus:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Data availability

Data was uploaded in a OSF repository. The link is in the manuscript.

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Appendix

Tables for exploratory analysis

Table A1
Comparison of single items between synchronous and asynchronous conditions in the child sample.

Item number	Means	*p*	*95% CI*	Cohen's *d*
1	M_{sync} = 2.00 M_{async} = 1.18	<.01**	[0.28, 1.32]	0.48
2	M_{sync} = 1.18 M_{async} = 1.38	.43	[−0.70, 0.30]	−0.12
3	M_{sync} = 1.60 M_{async} = 1.51	.70	[−0.38, 0.56]	0.05
4	M_{sync} = 1.62 M_{async} = 1.49	.53	[−0.27, 0.54]	0.08
5	M_{sync} = 0.93 M_{async} = 1.09	.51	[−0.59, 0.30]	−0.10
6	M_{sync} = 0.35 M_{async} = 0.29	.73	[−0.26, 0.37]	0.06

Note. *p* values, 95% confidence intervals (CIs), and Cohen's *d*s are derived from one-sample *t* tests.
** $p < .01$.

Table A2
Comparison of single items and EQ-sum with Control Question 5.

Item number	Synchronous			Asynchronous		
	Mean difference with Item 5	*p*	*d*	Mean difference with Item 5	*p*	*d*
1	1.06	<.01**	0.66	0.11	.69	0.07
2	0.25	.32	0.17	0.24	.39	0.15
3	0.67	.02*	0.43	0.35	.27	0.23
4	0.69	.01*	0.45	0.43	.10	0.07
EQ-sum	0.67	<.01**	0.54	0.29	.18	0.21

Note. *p* values and Cohen's *d*s are derived from one-sample *t* tests. EQ-sum, enfacement questionnaire sum score. Only the first four items were averaged for the sum score.
* $p < .05$.
** $p < .01$.

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