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Functional lateralization in social-emotional processing: The influence of sexual orientation and gender identity on cradling preferences

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ABSTRACT

The left-cradling bias (i.e., the motor asymmetry for cradling infants on the left side) has often been associated to the right-hemispheric social-emotional specialization, and it has often been reported to be stronger in females than in males. In this study we explored the effects of sexual orientation and gender identity on this lateral bias by means of a web-based investigation in a sample of adults (485 biological females and 196 biological males) recruited through LGBTQIA+ networks and general university forums. We exploited a cradling imagery task to assess participants' cradling-side preference, and standardized questionnaires to assess participants' homosexuality (Klein Sexual Orientation Grid) and gender nonconformity (Gender Identity/Gender Dysphoria Questionnaire for Adults and Adolescents). Results confirmed the expected left-cradling bias across all sexual orientation groups except for heterosexual males. Importantly, higher homosexuality scores were associated with higher proportions of left cradling in males. These results suggest that sexual orientation can influence cradling preference in males, indicating a complex interaction between biological and psychological factors in the laterality of social-emotional processing. Finally, the left-cradling bias seems to confirm its role as a behavioral proxy of social-emotional functional lateralization in humans.

1. Introduction

The way in which humans and other species interact with their offspring provides critical insights into the biological, psychological, and social underpinnings of behavior (e.g., [1]). For instance, the lateral bias for cradling infants on the left side [2,3] represents a population-level motor asymmetry, with the observed prevalence in humans ranging from 66 % to 72 % across studies [4]. Left cradling emerges as a behavior that surpasses cultural and ethnical barriers [5], and it is rather independent of the cradler's manual preferences [6] (see [4] for a meta-analysis and [7] for conflicting results), suggesting a deep-rooted origin in evolution [8,9]. In fact, this phenomenon (i.e., positioning the offspring on the mother's left side) is widely documented across various species besides humans (e.g., [10,11]) and reflects a potential evolutionary advantage, consisting in facilitating the emotional and communicational bonding between the caregiver and the infant [12,13].

The typically maternal nature of this asymmetry has led many scientists over the last 65 years to usually study the left-cradling bias in adult female individuals, and mostly in mothers. In fact, several studies have reported the presence of left cradling in mothers (e.g., [2,3,14,15]), non-parent females (e.g., [5,16,17]), and even young girls (e.g., [18–20]), at a higher rate compared with fathers, non-parent males and young boys. However, given the substantial differences among these studies in terms of sample size and type of participants (e.g., parents or non-parent university students), assessing methods (using real infants, dolls, imagery tasks, examination of photo collections, etc.), and other potentially confounding factors (e.g., participants' handedness), a meta-analysis was conducted by Packheiser and colleagues on 19 studies from which data on sex differences in cradling lateralization were pooled and effects extracted [4]. This meta-analysis demonstrated that females are more likely to cradle on the left side compared with males. In detail, the incidence of left cradling in males was found to be about 64 %, and in females about 73 %. Therefore, contrary to prior assumptions that left-cradling bias should be manifested exclusively by mothers (or, more generally, by females) [21,22], males also exhibit a left-sided bias, though to a significantly lesser extent. Although it remains unclear

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whether this is due to genetic or cultural and environmental factors [8,9], the existence—consistently demonstrated—of such a sex difference elevates left cradling to a sexually dimorphic trait of behavior and, possibly, of cerebral lateralization of social and emotional functions [12].

Even though the most intuitive explanation for the left-cradling bias might be that individuals prefer to cradle on their non-dominant hand/arm [7], studies have shown that handedness is not the primary determinant of this behavior. In fact, both right- and left-handers tend to cradle on the left side [6], with left-handers showing a slightly lower degree of leftward preference compared with right-handers, while still maintaining an overall left-side bias [4]. This nuance suggests that, although handedness influences the prevalence of the left-cradling bias, it is not the main factor. It is also important to differentiate between hand preference and hand performance (see [23] for a recent extensive discussion), as the latter is a more accurate measure of handedness. Nevertheless, hand preference is the most frequently used measure in cradling studies [4] (but see [24]). Additionally, factors other than mere lateral preference for cradling might affect actual cradling side, with the choice of the dominant arm/hand for cradling increasing when the weight of the children rises with age [22] and decreasing when the cradler is asked to perform a precise motor task [25]. Conversely, the major account that has been advanced to explain left cradling aligns with functional lateralization theories proposing a right-hemispheric specialization for processing social-emotional cues in a percentage of the general population ranging from to 78 % to 86 % [26]. This bias would lead to a preference for processing emotionally salient stimuli (e.g., emotional face expressions) in the left (contralateral) sensory and perceptual hemispace [18,27–38] (but see [39–42] for inconsistent results). In fact, the main evidence for this explanation of the left-cradling bias has been collected using the chimeric face paradigm (see [43–45]). These studies have demonstrated a relationship between a left visual field advantage in processing emotional expressions and a preference for left cradling in tasks involving imagery (e.g., [29]) or dolls (e.g., [30–34]). In this regard, it is important to point out that the left-cradling bias is not exclusive to real infants but can also be elicited by objects resembling infants, such as dolls [5,16,34], or even by imagined babies [3,46,47]. However, this side bias appears to be highly selective, applying specifically to infant-like objects (i.e., conveying social-emotional content) and not to other objects of similar size and weight (i.e., not conveying social-emotional content) [32,40].

In humans, hemispheric functional segregation is observed, with language and praxis more commonly linked to the left hemisphere and with spatial attention, face recognition, and emotional prosody more commonly linked to the right hemisphere (see [26]). This pattern highlights the superiority of the right over the left hemisphere in social-emotional processing, such as in facial emotion perception [48,49]. For this reason, at a population level, at the same extent to which right handedness is employed as a proxy for prototypical (i.e., left) hemispheric specialization in praxis (e.g., [50]), left cradling has recently been advocated as a proxy for prototypical (i.e., right) hemispheric specialization in the processing of social-emotional information [51]. This approach has recently demonstrated that atypical phenotypes in hemispheric functional organization might serve as potential markers of neurodevelopmental and cognitive dysfunctions [19,52].

Neuroscientific research has extensively explored biological sex differences at a cerebral and a behavioral level (e.g., [53]). Behavioral findings seem to converge on the consensus that males typically outperform females in tasks involving motor speed and spatial processing, whereas females typically outperform males in tasks involving memory, social cognition, and emotional processing [54]. Thus, females appear to be significantly more proficient in recognizing and processing emotionally salient stimuli that induce empathic and social responses [55–58], possibly involving a stronger right-hemispheric activity [59]. However, consensus is less clear as regards sex differences in the lateralization of these functions and results are often inconsistent (e.g., [60–63]). Indeed, while it is well-established that females are more proficient than males in the processing of emotional expressions, the former show less right-hemispheric lateralization than the latter [64,65]. Paradoxically, it has been observed that males showing larger right-hemispheric lateralization in emotional processing not only exhibited higher proficiency in this domain but also exhibited higher emotional intelligence compared with males showing less right-hemispheric superiority [48,59,66]. This suggests that the relationship between functional lateralization and social-emotional processing may be more complex than previously hypothesized, involving nuanced interactions between brain asymmetry and functional outcomes.

To date, sexual orientation (e.g., homosexual) and gender identity (which may deviate from biological sex assigned at birth; e.g., psychological gender nonconforming), have been overlooked for a long time in studies on sex differences. Although studies exploring functional differences at the brain and behavioral levels in this context are scarce and show conflicting results (e.g., [67]), there is a growing consensus suggesting that differences related to sexual orientation and gender identity somewhat mirror those generally attributed to the opposite biological sex. This similarity applies in terms of both brain structure [68,69] and behavioral and cognitive performance (e.g., [70,71]). As regards the lateralization of social-emotional functions, research conducted so far remains in a nascent stage, with differences among the constructs investigated and the paradigms employed being quite disparate, most studies focusing on small samples of only homosexual males. Nevertheless, it has been observed that homosexual males exhibited better performance in a face recognition memory task compared with both male and female heterosexuals [72]. Potential difference for social-emotional functions could also be biologically mediated, an electroencephalographic study showing distinct hemispheric patterns of alpha activity between homosexual and heterosexual males, but not between homosexual males and heterosexual females [73]. Therefore, emerging evidence supports the notion that homosexual males show functional lateralization patterns for social-emotional content (e.g., faces) more similar to that typically shown by biological females than that shown by biological males [74]. For instance, Rahman and Yusuf showed that heterosexual males were significantly more right-hemispheric lateralized in processing female faces than both homosexual males and heterosexual females (who did not differ from each other), whereas homosexual males and heterosexual females were more left-hemispheric lateralized than heterosexual males in processing female faces [74]. This might be attributed to higher levels of emotional intelligence and empathic abilities in homosexual males compared with heterosexual males [75], leading to lateralization patterns more similar to those of biological females than those of their own biological sex (i.e., less lateralized but more proficient [48,64–66]).

There is still little evidence on the relationship between lateralization and gender identity. However, the majority of the few studies conducted so far seems to converge on the idea that individuals' psychological gender identity is more relevant than biological sex in modulating patterns of lateralization in behavior [76,77]. In fact, it has been suggested that the degree of psychological masculinity or femininity self-perceived by participants is a more accurate indicator of dimorphism in the lateralization of specific emotional functions than biological sex per se.

Despite the extensive documentation of sex difference in cradling-side preference [4], the gradations of its expression across sexual orientations and gender identities have received limited, if any, attention compared with biological sex: all studies conducted to date focused on the binary categorization of sex, thus neglecting the spectrum of sexual orientations and gender identities that could instead provide clarifying hints to human neurodiversity and social-emotional functioning. In the present study, we aimed to fill this gap by using lateral cradling preference as a proxy for prototypical (i.e., right) hemispheric specialization at the population level in the processing of social-emotional information through the lens of both traditional biological sex categorization and the

more nuanced perspectives of sexual orientation and gender diversity.

In particular, the present study was administered to a large sample of individuals using a cradling imagery task with the aim to test the following hypotheses:

a) both biological males and biological females show a population-level left-cradling bias, but biological females are significantly more left-lateralized than biological males;
b) compared with heterosexual males, homosexual males show a population-level left-cradling bias more similar to that shown by heterosexual females;
c) left-cradling biological males show a higher degree of homosexuality compared with right-cradling biological males;
d) compared with heterosexual females, homosexual females show a population-level left-cradling bias more similar to that shown by heterosexual males;
e) left-cradling biological females show a lesser degree of homosexuality compared with right-cradling biological females;
f) gender-nonconforming males show a population-level left-cradling bias more similar to that shown by gender-conforming females rather than by gender-conforming males;
g) left-cradling biological males show a higher degree of gender nonconformity compared with right-cradling biological males;
h) gender-nonconforming females show a population-level left-cradling bias more similar to that shown by gender-conforming males rather than by gender-conforming females;
i) left-cradling biological females show a lower degree of gender nonconformity compared with right-cradling biological females.

While hypothesis a) is based on a large body of research, and hypotheses b) and c) are guided by a modest but existing literature on male homosexuality and social-emotional lateralization, the other hypotheses regarding female homosexuality and male/female gender nonconformity should be considered rather as exploratory. This is due to the extremely limited evidence collected on functional lateralization in such phenotypes. However, by analogy with the previous ones, these exploratory hypotheses were formulated assuming that both non-heterosexual orientation and gender nonconformity might reveal differences in brain and behavioral organization with respect to one's biological sex, and possible similarities with the opposite sex.

The present study aims to promote a broader understanding of the biological and psychological factors influencing the functional lateralization in social-emotional processing. We believe that this investigation is rather timely, considering the increasing recognition and acceptance of various and changing sexual and gender identities within society (e.g., [78,79]). By integrating these dimensions among the determinants of the cradling-side bias, the present study aims to shed a new light on aspects of human behavior that transcend traditional dichotomies of sex and gender, offering a more inclusive and comprehensive understanding of functional lateralization in social-emotional processing and may represent a key to interpreting the contradictory results in the field of sex differences in laterality research.

2. Method

2.1. Participants

A total of 682 individuals participated in this study: 485 were females assigned at birth (biological females), 196 were males assigned at birth (biological males), and one was intersexual. Participants' age ranged from 18 to 71 (M = 25.27, SD = 8.2) years. Based on the Edinburgh Handedness Inventory score [80,81], 61 participants were non-right-handed and 37 participants could not be classified in terms of handedness as they did not fully complete the questionnaire (the remaining 584 were right-handers). Participants were recruited on a voluntary basis, half of them through Italian general student social network groups and forums on the web, and the other half through Italian LGBTQIA+ (i.e., lesbian, gay, bisexual, transgender, queer or questioning, intersex, asexual, aromantic or agender individuals, plus identities not covered by the previous categorizations [79]) social network groups and forums on the web. The online advertisements included a brief description of the study and the distribution of a link to a questionnaire to be completed on the Qualtrics platform (Qualtrics, Provo, UT).

2.2. Instruments and procedure

After providing informed consent to participate in the study and agreeing on the anonymous use of their responses provided through an online form, participants completed the following sections of the Qualtrics questionnaire:

a) **Cradling Imagery Task** [46,82]. Via text-based instructions that appeared on the screen, participants were required to imagine cradling an infant approximately three months old, measuring around 60 cm in length, and to try visualizing the baby's face, eyes, mouth, arms, and body while they were cradling them in their arms. Once participants had a clear image of themselves holding the infant, they were required to position their arms as if they were actually holding the baby, to turn their head to face the baby, as if they were looking directly at their face, to maintain this pose and to focus on the imagined scenario for approximately 10 s, focusing on the details of the baby's appearance and interaction. After completing this imagination task, participants were asked to select between two stylized images representing an individual seen from behind and holding a baby on the left side and on the right side, by choosing the image that best matched their self-image while imagining performing the cradling action (Fig. 1).

b) **Demographic Information**. Participants were asked to provide their age in years, province of residence, and marital status.
c) **Biological Sex**, **Sexual Orientation**, **and Gender Identity**. Participants were asked to state their biological sex assigned at birth (female, male, or intersex), their sexual orientation (lesbian, gay, heterosexual, bisexual, or other—in this latter case, they were required to specify which sexual orientation), and their perceived gender identity (woman, man, transgender woman male-to-female, transgender man female-to-male, genderqueer, crossdresser, or other—in this latter case, they were required to specify which gender identity).
d) **Edinburgh Handedness Inventory** (**EHI** [80,81]). Participants were required to self-assess their lateral preference for actions performed with hand, foot, eye, and ear, filling out a 21-item questionnaire. EHI score ranges from −1 (completely left preference) to +1 (completely right preference), with 0 indicating ambi-laterality.
e) **Klein Sexual Orientation Grid** (**KSOG** [83]). Participants were required to fill out a 21-item questionnaire on a 7-point Likert scale from 1 (e.g., "Exclusively attracted to people of the opposite sex/heterosexual") to 7 (e.g., "Exclusively attracted to people of the same sex/homosexual") regarding their past (from early adolescence to 1 year ago), present (last 12 months), and ideal preferences ("what you would choose if you could choose freely") to assess their sexual orientation across 7 dimensions: sexual attraction, sexual behavior, sexual fantasies, emotional preferences, social preferences, lifestyle preferences, and self-identification. KSOG score ranges from 21 (completely heterosexual) to 147 (completely homosexual), lower scores thus indicating higher heterosexual preferences and higher scores indicating higher homosexual preferences.
f) **Gender Identity/Gender Dysphoria Questionnaire for Adults and Adolescents** (**GIDYQ-AA** [84]). Finally, participants were required to fill out a 27-item questionnaire on a 5-point Likert scale from 1 ("Never") to 5 ("Always") to assess their subjective

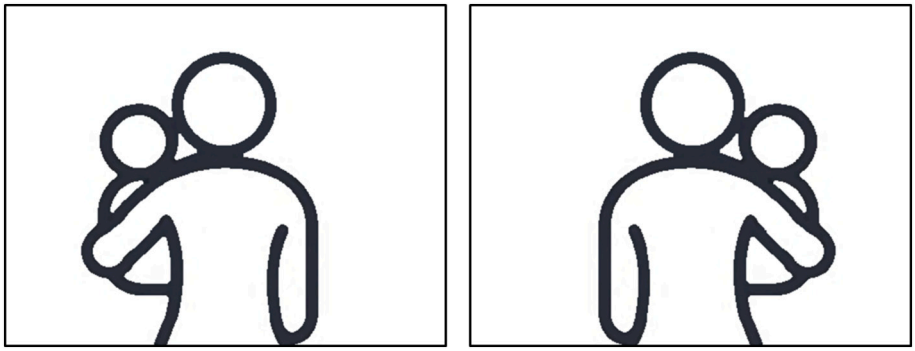

Fig. 1. Cradling imagery task. On the left, a stylized image depicting an individual performing a left-sided cradling action; on the right, a stylized image depicting an individual performing a right-sided cradling action. With this item, participants were required to select which of the two images best represented how they imagined cradling the infant.

experiences of gender identity and gender dysphoria across several aspects: subjective indicators of gender dysphoria (which include feelings related to one's body and gender roles), social indicators (which relate to interactions with others and societal roles), somatic indicators (which concern physical aspects of gender dysphoria), and socio-legal indicators (which may involve legal and social recognition of one's gender identity). GIDYQ-AA scaled score ranges from 1 (indicating stronger incongruence between one's experienced gender and the sex assigned at birth) to 5 (indicating stronger alignment between one's experienced gender and the sex assigned at birth), lower scores thus indicating higher gender nonconformity and higher scores indicating higher gender conformity. Individuals with gender dysphoria typically score below 3 [84].

3. Results

3.1. Sample distribution according to sexual orientation and gender identity categories

Table 1 shows the distribution of female and male (biological sex assigned at birth) participants with respect to self-reported sexual orientation.

Table 2 shows the distribution of female and male (biological sex assigned at birth) participants with respect to self-reported gender identity.

Table 1
Distribution of participants across sexual orientation categories based on biological sex.

Biological sex	Sexual orientation	N	%
Female	Lesbian	63	13
	Gay	2	0.4
	Heterosexual	232	47.8
	Bisexual	153	31.5
	Other	35	7.2
	Total	485	100
Male	Gay	77	39.3
	Heterosexual	102	52
	Bisexual	10	5.1
	Other	7	3.6
	Total	196	100
Intersexual	Heterosexual	1	100

As regards the 'Other' category, females who detailed their orientation self-identified as: aromantic ($N = 1$), asexual ($N = 5$), graysexual ($N = 1$), heterocurious (N = 1), heteroflexible (N = 1), homoflexible (N = 1), pansexual ($N = 9$), and queer ($N = 2$); males who detailed their orientation self-identified as: non-heterosexual (N = 1), pansexual ($N = 3$).

Table 2
Distribution of participants across gender identity categories based on biological sex.

Biological sex	Gender identity	N	%
Female	Woman	462	95.3
	Man	1	0.2
	Transgender FtM	7	1.4
	GenderQueer	13	2.7
	Other	2	0.4
	Total	485	100
Male	Man	194	99
	Transgender MtF	1	0.5
	Other	1	0.5
	Total	196	100
Intersexual	CrossDresser	1	100

As regards the 'Other' category, females who detailed their gender identity identified as: gender fluid (N = 1), and non-binary ($N = 1$); males who detailed their gender identity identified as: gender fluid ($N = 1$).

3.2. Criteria for categorization and exclusion

Given that only one participant assessed her/himself as intersexual, we excluded such a participant from further analyses. No other exclusion criteria were considered. However, since the vast majority of participants, both biological female (95.3 %) and male (99 %), were gender-conforming to their biological sex, we decided not to consider gender identity in the categorization of participants. Finally, given the relatively small numbers of participants falling into several categories of sexual orientation, all categories different from "heterosexual" with respect to the sexual orientation for both biological sexes were collapsed in data analyses. Therefore, for each measure, we compared biological female and male "heterosexual" participants with biological female and male "non-heterosexual" participants. Table 3 shows the sample distribution for the collapsed sexual orientation categories and participants' mean scores for age, EHI, KSOG, and GIDYQ-AA. Il should be noted that not all participants provided responses that could be used to obtain valid scores for EHI, KSOG, and GIDYQ-AA. However, all participants included in the analyses provided information regarding age and their self-categorization on cradling-side preference, sexual orientation, and gender identity. Data were analyzed using Statistical Package for Social Sciences (SPSS) software Version 20 (IBM Corp., Armonk, NY).

3.3. Cradling-side preferences

Overall, 442 out of 681 participants (64.9 %) significantly showed a left-cradling bias ($\chi^2_{(1)} = 60.512$, $p < 0.001$). According to biological sex, 320 out of 485 female participants (65.98 %) significantly showed a left-cradling bias ($\chi^2_{(1)} = 49.536$, $p < 0.001$), and 122 out of 196 male participants (62.24 %) significantly showed a left-cradling bias ($\chi^2_{(1)} =$

Table 3
Participant demographics and scores.

Biological sex	Sexual orientation		Age (years)	EHI	KSOG	GIDYQ-AA
Female	Heterosexual	N	232	221	208	192
		Mean (SD)	26.06 (8.97)	0.65 (0.41)	45.43 (11.11)	4.74 (0.29)
	Non-Heterosexual	N	253	237	213	202
		Mean (SD)	23.25 (6.56)	0.6 (0.46)	90.16 (23.94)	4.49 (0.58)
Male	Heterosexual	N	102	99	93	89
		Mean (SD)	28.59 (9.63)	0.61 (0.49)	36.51 (8.66)	4.62 (0.29)
	Non-Heterosexual	N	94	88	79	77
		Mean (SD)	24.81 (6.37)	0.58 (0.51)	107.63 (17.53)	4.51 (0.48)

Number (N) of heterosexual and non-heterosexual participants of both biological sexes and their mean scores with standard deviations (SD) for the following variables: age, Klein Sexual Orientation Grid (KSOG), and Gender Identity/Gender Dysphoria Questionnaire for Adults and Adolescents (GIDYQ-AA).

11.755, $p < 0.001$). The difference in left-cradling proportions between biological females and males was not statistically significant ($\chi^2_{(1)} = 0.403$; $p = 0.376$).

3.4. Cradling-side preferences according to sexual orientation categories

In biological females, 154 out of 232 heterosexuals (66.38 %) showed a left-cradling preference ($\chi^2_{(1)} = 24.897$, $p < 0.001$), and 166 out of 253 non-heterosexuals (65.61 %) showed a left-cradling preference ($\chi^2_{(1)} = 24.668$, $p < 0.001$). The difference in left- and right-cradling proportions between heterosexual and non-heterosexual females was not statistically significant ($\chi^2_{(1)} = 0.007$; $p = 0.935$).

In biological males, 56 out of 102 heterosexuals (54.90 %) did not show a left-cradling preference ($\chi^2_{(1)} = 0.98$, $p = 0.322$), whereas 66 out of 94 non-heterosexuals (70.21 %) showed a left-cradling preference ($\chi^2_{(1)} = 15.362$, $p < 0.001$). The difference in left- and right-cradling proportions between heterosexual and non-heterosexual males reached statistical significance ($\chi^2_{(1)} = 4.249$, $p = 0.039$). Furthermore, the proportion of left and right cradling shown by non-heterosexual males did not significantly differ from those shown by either heterosexual ($\chi^2_{(1)} = 0.291$, $p = 0.59$) or non-heterosexual ($\chi^2_{(1)} = 0.463$, $p = 0.496$) females. Fig. 2 shows all these comparisons between left and right cradling, as percentage for each category of biological sex and sexual orientation.

3.5. KSOG and GIDYQ-AA scores according to biological sex and cradling-side preferences

A multivariate analysis of variance (MANOVA) was performed considering KSOG and GIDYQ-AA scores as dependent variables, and biological sex and cradling-side preferences as independent variables. When a significant effect was found, a Bonferroni correction for multiple comparisons was applied to post-hoc comparisons. Multivariate tests on KSOG and GIDYQ-AA scores revealed non-significant effects of biological sex ($F_{(2, 555)} = 1.155$, $p = 0.316$) and cradling-side preferences ($F_{(2, 555)} = 2.797$, $p = 0.062$), and a significant interaction between biological sex and cradling-side preferences ($F_{(2, 555)} = 4.181$, $p = 0.016$) pertaining only to the KSOG scores ($F_{(1, 556)} = 7.684$, $p = 0.006$). Post-hoc comparisons showed that male left-cradling participants scored higher on the KSOG (M = 75.17, SD = 38.54) compared with male right-cradling participants (M = 58.26, SD = 34.73; $t_{(170)} = 2.849$, $p = 0.01$; Fig. 3). No significant differences were observed for females and on GIDYQ-AA scores.

4. Discussion

This study explored cradling-side preferences in a large sample of individuals, considering potential influencing factors such as sexual orientation and gender identity—besides biological sex—to unveil their potential associations with functional lateralization of social-emotional processing. In our opinion, these results provide intriguing insights into the interaction between biological and psychological aspects of human behavior.

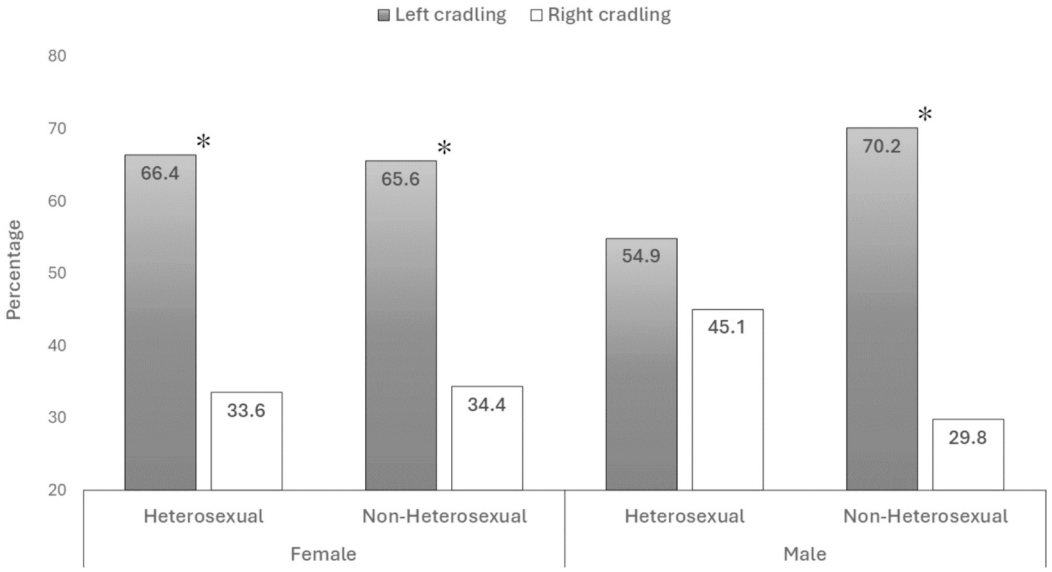

Fig. 2. Mean percentages of left (grey) and right (white) cradling in biological female and male participants according to sexual orientation categories. Asterisks indicate statistically significant comparisons ($p < 0.001$).

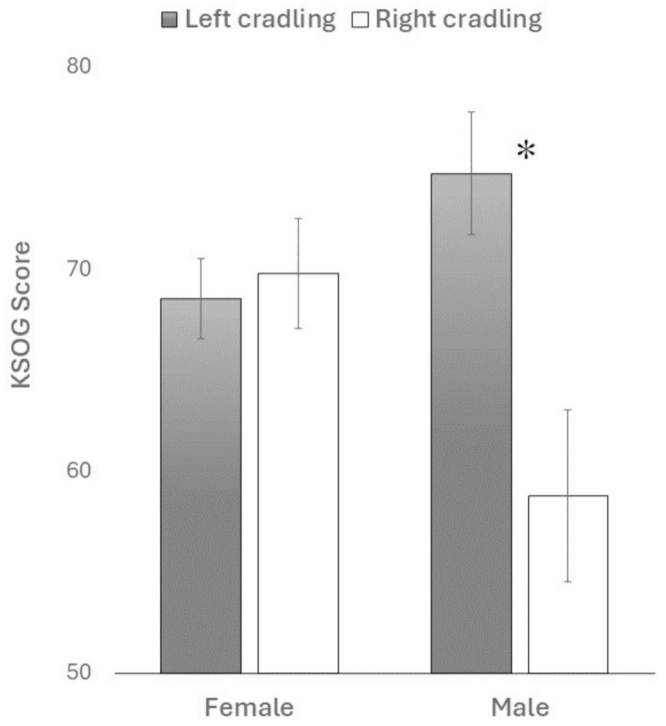

Fig. 3. KSOG mean score of left- (grey) and right- (white) cradling participants by biological sex. An asterisk indicates a statistically significant comparison ($p = 0.01$). Bars represent standard error.

The hypothesis that both biological females and males show a population-level left-cradling bias was confirmed, with only a slight and non-significant prevalence in females. This aligns with the extensive documentation in literature which suggests a left-cradling bias in both biological sexes but with a higher prevalence in females, likely reflecting the population-level right-hemispheric dominance for processing social-emotional cues. In fact, although the prevalence of left cradling we found (females 66 %, males 62 %) somehow differed from that found by Packheiser and colleagues in their metanalysis (females 73 %, males 64 %) [4], the directional pattern remains rather consistent. However, this difference in prevalence between sexes may be attributed to the method used to assess lateral bias. Specifically, imagined cradling might reveal more "basic" hemispheric lateralization differences, which seem to be rather independent of the affiliative and attachment components often involved in mother-infant behavior [6,13,39,85], thus reflecting the more strongly lateralized patterns usually found in males compared with females in other tasks [48,59,66].

In fact, studies that have used imagination as a research tool have reported percentages consistent with our findings (e.g., [29,82]). In addition, the absence of left cradling reported in heterosexual males might be explained by findings related to another type of interactive social touch, i.e. lateralized embracing behavior [28]. It has been observed that the typical right-side bias observed in embracing decreases below the population-level prevalence when the embracing pair consists of two males [86]. This phenomenon has been observed in the laboratory more than in naturalistic settings and it was explained as due to the fact that male participants experienced unpleasantness when asked to embrace another individual (or even a mannequin) of their same sex [87]. These findings are further supported by the fact that heterosexual males report unpleasantness simply receiving interpersonal touch from an individual they believe to be of their same sex, and these negative feelings are not alleviated even by the administration of hormones that typically mediate affiliative responses, such as oxytocin [88]. Therefore, the disruption of the typical left-cradling bias in heterosexual males in our sample might represent a consequence of their discomfort in physical contact with any individual not clearly identified as an adult female. Furthermore, the lack of reporting a sex difference in cradling-side preferences may be attributed to the very nature of the study, specifically to the intentional biasing of the sample toward homosexual individuals who, as we showed in biological males, can exhibit different lateral patterns that could have altered the overall prevalence.

As regards sexual orientation, the hypothesis that homosexual males would show a cradling-side pattern similar to that shown by heterosexual females was confirmed (i.e., 70 % and 66 %, respectively). This might suggest that homosexual males share—at least in part—a certain degree of right-hemispheric social-emotional specialization with biological females rather than with heterosexual males. Possibly, this pattern reflects higher emotional intelligence or empathic abilities (elicited by infant cradling behavior) in both homosexual males and biological females [59,75]. Interestingly, heterosexual males did not exhibit a significant left-cradling bias (i.e., 55 %), thus highlighting a potential variation in brain functional laterality associated to male sexual orientation. In light of these results, it might be speculated that some of the inconsistent results found in social-emotional lateralization studies focusing on sex differences (e.g., [60,61]) could also be due to overlooking this factor in favor of a binary categorization of participants' biological sex. With the present study we showed that merely dividing biological males into heterosexual and non-heterosexual categories can dramatically alter the lateral patterns observed, in this case elevating left cradling to the female-like level in non-heterosexuals and reducing left cradling below statistical significance in heterosexuals. It cannot be ruled out that this same pattern may be observed in future studies investigating more thoroughly sex differences in social-emotional lateralization (e.g., facial emotion processing).

Furthermore, such a pattern of results for non-heterosexual males is strengthened by the KSOG score analysis, which measured participants' degree of homosexuality: we showed that biological male participants exhibiting a left-cradling bias had significantly higher scores (i.e., they were more oriented to homosexuality) than those exhibiting a right-cradling bias. This places the category-based finding on a *continuum*, suggesting that the higher the degree of male homosexuality, the closer it appears to align with female-like patterns of lateralized social-emotional behavior.

On the contrary, the hypothesis that homosexual females would show a cradling-side preference similar to that shown by heterosexual males was not supported by the results. In fact, both heterosexual and homosexual females exhibited cradling-side preferences in a similar proportion (i.e., around 66 %), which might indicate that in females the influence of biological sex on cradling laterality is more effective than that of sexual orientation. In this regard, it has been suggested that while homosexual males exhibit sex-atypical performance in both male- and female-favoring cognitive tasks, homosexual women are sex-atypical only in male-favoring cognitive performance [71]. In this specific context (i.e., the typically female/maternal behavior of infant cradling), it is plausible that differences in lateralization among homosexual females might not emerge. However, further research focusing on the lateralized behavior of homosexual women is necessary, given the scarcity of studies involving them compared with the longer history of studies involving homosexual men. This gap has inevitably resulted in less information about homosexual females' behavioral patterns at both the brain and behavioral levels. The different results obtained in the male and the female homosexual groups, together with the fact that left-cradling bias is especially associated with being biologically female, also leaves the door open to interpretations of this phenotype as a secondary sex characteristic shaped by the interplay between the genetics of sex determination (e.g., through X-linked dominant inheritance) and epigenetic effects (e.g., through prenatal exposure to sex hormones). We put forward the intriguing speculation that the left-cradling bias might represent one very archaic form of phenotypic plasticity selected to grant stability via a maternal effect gene (as suggested by the findings of [89]) but allowing for some degree of variability via exposure to

androgens and estrogens (in line with the findings of [24]). Despite we neither checked whether our participants had used or were using some type of hormone therapy, nor we measured their 2D:4D ratio as a proxy of exposure to prenatal testosterone, we suggest that future research on the left-cradling bias should factor in hormone levels and the available hormone history of participants besides their sexual orientation. This would allow not only to better understand this lateral bias biologically as related to genetic and epigenetic effects, but also to help framing sexual orientation as deeply rooted in subtle aspects of biology that have been neglected so far. The different prevalence we found between gay and bisexual males (favoring the former) and between lesbian and bisexual females (favoring the latter) have been frequently observed in previous studies (e.g., [90]). This suggests that the various forms of non-heterosexuality in the female sexual orientation spectrum may arise through distinct evolutionary-developmental mechanisms compared with males (e.g., [91]). Therefore, further studies (hopefully with larger sample sizes) are warranted in order to detect possible differences between lesbian and bisexual females.

Unfortunately, the hypotheses regarding cradling-side preferences in gender-nonconforming individuals could not be verified in the present study due to the extreme underrepresentation among both biological female (4.7 %) and male (1 %) participants—albeit percentages were above the normative population data, which place gender incongruence in the general population at 0.7 % in males and 0.6 % in females (e.g., [92])—despite efforts made to share the questionnaire within LGBTQIA+ groups. More targeted studies focusing on this population appear necessary to disclose potential differences in functional social-emotional lateralization besides biological sex and which take psychological gender identity into account, also considering the significant cultural changes rapidly occurring in society. Nevertheless, the fact that GIDYQ-AA scores did not show significant differences (as occurred for the KSOG scores) between left- and right-cradling individuals leads us to speculate that cradling behavior may not significantly differ as a function of gender identity, or that the questionnaire we used might not fit this purpose (e.g., it might assess gender dysphoria, but might not detect more subtle aspects of psychological gender identity).

To summarize, the present study highlighted important hints regarding social-emotional functional lateralization and sexual orientation. These insights not only might advance our knowledge of human neurodiversity, but also challenge the classical views of sex and gender in scientific studies, thus promoting an inclusive understanding of human behavior. Nonetheless, we are aware that this study has a few limitations. For instance, the interpretation of cradling-side preferences as an indicator of hemispheric specialization is still debated, and the influence of cultural and individual differences (e.g., whether or not participants were experienced with infant care) were not fully controlled. Future studies exploring these and other aspects in different populations and including different experimental paradigms to observe how individual preferences—and their potential neurobiological correlates—evolve over time are still lacking and particularly urgent.

Ethical statement

The study protocol was reviewed and approved by the Institutional Review Board of Psychology (IRBP) of the Department of Psychological, Health and Territorial Sciences of the University "G. d'Annunzio" of Chieti-Pescara (protocol number 22003 of April 8, 2022).

CRediT authorship contribution statement

Gianluca Malatesta: Writing – original draft, Visualization, Validation, Software, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Daniele Marzoli:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Chiara Lucafò:** Writing – review & editing, Visualization, Software, Methodology, Investigation, Data curation. **Anita D'Anselmo:** Writing – review & editing, Visualization, Software, Methodology, Investigation, Data curation. **Teresiana Azzilonna:** Writing – review & editing, Visualization, Software, Methodology, Investigation, Data curation. **Giulia Prete:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Funding acquisition. **Luca Tommasi:** Writing – review & editing, Validation, Supervision, Resources, Funding acquisition, Project administration, Methodology, Conceptualization.

Declaration of competing interest

None.

Data availability

The analyzed data are available at the following link: https://osf.io/xaq2d/

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