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Review article

Handedness and sex effects on lateral biases in human cradling: Three meta-analyses

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ABSTRACT

The earliest form of social contact for a newborn is being cradled by its mother. This important behavior has been found to be lateralized to the left side by many, but not all empirical studies. Factors that have been suggested to modulate cradling asymmetry are handedness and sex. However, these factors have not been demonstrated consistently, possibly due to low sample sizes and inconsistent experimental paradigms. To address this issue, we used a meta-analytical approach to (1) quantify the widely reported leftward bias in human cradling and (2) identify moderating factors of the cradling bias such as handedness and sex. Across forty studies, we observed a leftward cradling bias showing that this effect is robust and replicable. Furthermore, we found that left-handers demonstrate a significantly less pronounced leftward bias compared to right-handers and that males are less lateralized compared to females. In conclusion, we could verify that parental handedness and sex contribute to a cradling population bias. Future studies examining genetic factors could illuminate the mechanism supporting a cradling bias.

1. Introduction

For both humans and non-human primates, social interactions are an integral part of everyday life (Adolphs, 1999; Dunbar, 2010). While social intent is often communicated verbally, a substantial amount of human interaction comprises non-verbal actions such as tactile actions (Forsell and Åström, 2012; Hinde, 2010). Humans regularly engage in social touch to convey affective states using for example embraces or kisses (Ocklenburg et al., 2018). The earliest form of physical interaction in life is being cradled by one's mother. Interestingly, there has been a widely reported lateral bias in the cradling of babies on the population level, namely that mothers prefer to cradle them on the left side of their body using their left arm (*e.g.*, Almerigi et al., 2002; Dagenbach et al., 1988; Fleva and Khan, 2015; Salk, 1960, 1973). This tendency in humans seems to be linked uniquely to infant holding as objects are preferably held on the right side of the body (between 64% and 81% depending on the object, Almerigi et al., 2002). A left-sided cradling bias has also been found in great apes, such as gorillas or chimpanzees with roughly 67% of cradles being left-sided (Manning and Chamberlain, 1990; Manning et al., 1994). This data has to be treated with caution however as sample sizes were low since no species was tested beyond 20 individuals. For Old and New World monkeys, the data has been even less conclusive as monkeys such as macaques did not show a population bias in infant holding or cradling (Tanaka, 1989; Tomaszycki et al., 1998) and sample sizes for baboons were exceedingly small (Damerose and Hopkins, 2002; Hopkins, 2004).

The first reported scientific study about a left-side cradling bias was conducted by Salk (1960). During his casual visits to the New York Zoo, he noted that a particular rhesus monkey mother preferentially held its infant on the left side close to the chest. This observation inspired him to test if human mothers display a similar bias after giving birth and what the underlying mechanism of that bias is. He found a general left-side bias across 287 tested mothers (82.5% of all mothers cradled on the left body side) that was irrespective of handedness (83.1% for the 255 right-handed mothers and 78.1% for the 32 left-handed mothers). He concluded that the cradling bias might be associated with the children being able to listen to the mother's heartbeat more easily due to the anatomical location of the heart in the left chest. However, positive effects of heartbeat stimulation in newborns could not be found in follow-up studies (Brackbill et al., 1966; Palmqvist, 1975). Furthermore, a case study performed in a mother with dextrocardia, a congenital condition resulting in the apex of the heart pointing to the right

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instead of the left chest side, revealed no different bias as compared to the general population (Todd and Butterworth, 1998). Nonetheless, no sufficiently powered studies in situs inversus samples were ever conducted leaving open if the heartbeat hypothesis provides a feasible account for the leftward cradling bias.

Since the heartbeat hypothesis did not provide a conclusive explanation for the leftward cradling bias, two major hypotheses were generated to understand the mechanism underlying this pronounced asymmetry. The first hypothesis proclaims that the cradling bias is due to hemispheric asymmetry in emotional processing (Ocklenburg et al., 2018). There has been substantial evidence using behavioral studies both in healthy and lesioned patients as well as neurophysiological and neuroimaging studies indicating that the right cerebral hemisphere is dominant in emotional processing (Adolphs et al., 1996; Borod et al., 1998; Godfrey and Grimshaw, 2016; Ley and Bryden, 1979; Narumoto et al., 2001). Manning and Chamberlain (1990) theorized that a leftward cradling bias results from the parents' preference to keep the child in their left visual field which is projected to the right hemisphere. Bourne and Todd (2004) tested this specific hypothesis by identifying both the cradling bias and the emotionally dominant hemisphere in facial processing in 32 healthy students. While they found no evidence of hemispheric dominance and the individual cradling bias in male participants, female participants with a leftward cradling bias demonstrated on average a right-hemispheric dominance for emotional processing whereas female participants with a right-side cradling bias displayed on average a left-hemispheric dominance. In a larger sample of 210 participants, Vauclair and Donnot (2005) found a corresponding result as participants with a leftward cradling bias preferred the left visual field for processing of emotional faces claiming that their result is indicating a right-hemispheric dominance. For both studies, it has to be noted however that they did not quantify a neurophysiological measure but rather inferred this result from a purely behavioral approach leaving open if this effect was truly due to a stronger right-hemispheric activation. Manning (1991) additionally found that the individual cradling bias is much stronger in females compared to males in 1696 individuals (577 males, 1119 females) by investigating photographs. Such a sex bias could be attributed to an emotional bias as mothers form a progressively developing emotional bond to the child during pregnancy and childbirth (Ammaniti, 1991; Fleming et al., 1997; Klaus and Kennell, 1976). While these results indicate that a leftward cradling bias could be due to an emotional bias based on hemispheric asymmetries in affective processing, there are several arguments that indicate against the feasibility of this hypothesis. First, humans have binocular vision and as long as the child is being foveated, the emotional bias theory does not provide a plausible explanation of the leftward cradling bias. Since parents are likely to look at their children during cradling, especially during very early childhood, the emotional bias hypothesis could not account for a leftward preference in cradling. Second, 12 out of 12 participants in an experiment with blind subjects demonstrated a left-sided cradling bias (Matheson and Turnbull, 1998) also indicating against this hypothesis. And third, Forrester and colleagues (2018) suggested that the cradling bias could simply result from a left visual field advantage in face processing irrespective of an emotional component.

The other major hypothesis states that a bias in motor preferences is the driving force underlying a cradling bias. Since the initial study by Salk (1960) demonstrated an almost equal cradling bias between left- and right-handers, the motor bias theory was initially discarded. Over 50 years of research, indications of a systematic influence of handedness were generally not found or at best a small effect was detected. Dagenbach et al. (1988) were the first to report a substantial difference between left- and right-handers in a sample of 74 parents as only 45% of left-handed mothers held their child on the left side compared to 74% of right-handed mothers. A well-powered study conducted by van der Meer and Husby (2006) demonstrated a significant effect of handedness influencing the cradling bias in a doll-holding task. They tested 765 participants of whom 71.5% were right-handed and 11% left-handed (with the remainder of the participants being ambidextrous). Of all right-handed participants, 79.1% showed a left-side cradling bias whereas only 39.3% of the left-handed participants cradled on the left side. They concluded that handedness plays a significant role in cradling lateralization supporting the motor bias hypothesis and suggested that the preference of using the non-dominant arm might result from the availability of the dominant arm to perform more fine-tuned motor tasks requiring precise movements.

In summary, a leftward cradling bias can be found in many studies investigating a cradling preference. This finding however is not universal in the literature as some studies have failed to find a leftward cradling bias (*e.g.* Reissland, 2000; Harris, Cárdenas, Spradlin Jr., & Almerigi, 2010; Turnbull and Lucas, 1991). Furthermore, influential underlying factors supporting this leftward cradling bias remain elusive even after 60 years of research as the results across individual studies have been inconclusive mostly due to low sample sizes resulting in underpowered studies incapable of finding effects. Inconsistent experimental designs (*e.g.* cradling of children vs. cradling of human dolls or real cradling vs. imagined cradling) only nurtured the lack of clear findings in the literature. Most importantly, the roles of handedness and sex influencing the cradling bias have often been implicated in various studies (*e.g.*, van der Meer and Husby (2006) and Dagenbach et al. (1988) for handedness with right-handers being more lateralized to the left compared to left-handers; Manning (1991) and Bröser (1981) for sex with females being more lateralized to the left compared to males), but could only rarely be replicated (*e.g.* Harris, Almerigi et al., 2001; Harris, Spradlin Jr., & Almerigi, 2010; Vauclair and Scola, 2008; Weatherill et al., 2016) and remain inconclusive. We therefore conducted a meta-analysis to investigate the presence of the cradling bias based on the contemporary literature as meta-analyses provide higher statistical power and are more resistant to sampling error due to inadequate sample sizes (Borenstein et al., 2011). In our study, we conducted three meta-analyses: the first meta-analysis aimed to quantify the widely reported left-side bias in the literature. Furthermore, since only very few studies found no leftward bias, reported research on the cradling lateralization could potentially be skewed due to a publication bias with null or even opposite results not being published. Therefore, we aimed to identify systematic publication biases in the concurrent literature. The second and third meta-analysis aimed to clarify whether handedness and/or sex play a significant role driving this asymmetry. For the general bias in the population, we hypothesize a left-sided cradling bias. For handedness and sex, we predict a stronger cradling bias to the left in right-handers compared to left-handers in accordance with the motor bias hypothesis and a stronger bias to the left in females compared to males in accordance with the emotive bias theory.

2. Materials and methods

2.1. Location of studies and inclusion criteria

The procedure for inclusion of research studies in the present meta-analysis were the following: initially, the electronic databases PubMed (https://www.ncbi.nlm.nih.gov/pubmed/), Web of Science (http://apps.webofknowledge.com) and Google Scholar (https://scholar.google.com) were searched using the terms "cradling" or "infant holding" either alone or with the added tags such as "laterality", "asymmetry", or "bias". Additionally, all reference lists of articles eligible for inclusion were inspected for further research items as well as already existing literature reviews on the topic (Donnot and Vauclair, 2005; Harris, 2010; Ocklenburg et al., 2018; Scola, 2009). In case of potentially eligible articles being unavailable through an online search, e-Mail requests were sent to the corresponding authors (where email addresses could be retrieved).

For incorporation, the following criteria had to apply to the respective studies:

1 Species: Only human participants were included in the current meta-analysis. All other primate species, while also displaying a cradling bias, were excluded.
2 Study language: Articles in English, German, and French were included.
3 Age: Only studies using adult participants were included. Children might have potential biases due to size of the child or the doll that had to be held (*e.g.*, Forrester et al., 2018; Souza-Godeli, 1996). In studies using both children and adults, only the adult data was used (only applied to the study of van der Meer and Husby, 2006).
4 Health: Participants suffering from diagnosed psychiatric diseases were excluded (*e.g.*, autism spectrum disorders (Pileggi et al., 2013)). Furthermore, blind participants or participants blindfolded by the experimenter were excluded.
5 Cradling bias: a cradling bias for the whole sample had to be determined within each individual study and the sample had to be unbiased by the experimenters in terms of cradling preference, *i.e.* the experiment could not be designed for the sample to consist of equal number of left- and right-cradlers.

In total, 58 full-text articles were assessed for eligibility. Of these articles, 40 fulfilled the inclusion criteria and were thus incorporated into the present meta-analysis (see Fig. 1). Studies included can be seen in Table 1. Data extraction was performed by JP and GB. Disagreements were resolved by discussion.

In case of multiple studies performed within the scope of one research article, data was only taken from several experiments if the sample was independent from the previous sample to prevent multiple collections of the same data point. The extraction of multiple experiments from one research article applied to three of the 40 articles. In one article, three experiments were used for our analysis (Scola and Vauclair, 2010b), whereas two articles provided two experiments using independent samples (Turnbull and Lucas, 1996; Turnbull et al., 2001). This amounted to a total of 44 independent samples. Since not all studies provided data broken down by handedness and sex, the number of studies eligible for further analysis of these factors were reduced. Overall, 19 studies provided data on differences between left- and right-handers and 19 studies on differences between sexes (studies only partially overlapping). Data collection was concluded in January 2019. Study selection and meta-analyses followed the PRISMA guidelines (Moher et al., 2009). The aim of this statement is to help authors improve the transparency of the reporting of systematic reviews and meta-analyses by providing them with a 27-item checklist that decouples several items that were presented in previous checklists, such as the QUOROM checklist (Moher et al., 1999). Moreover, the PRISMA statement is more elaborate when it comes to the flow diagram presenting the search strategy to identify studies to be included in the meta-analysis.

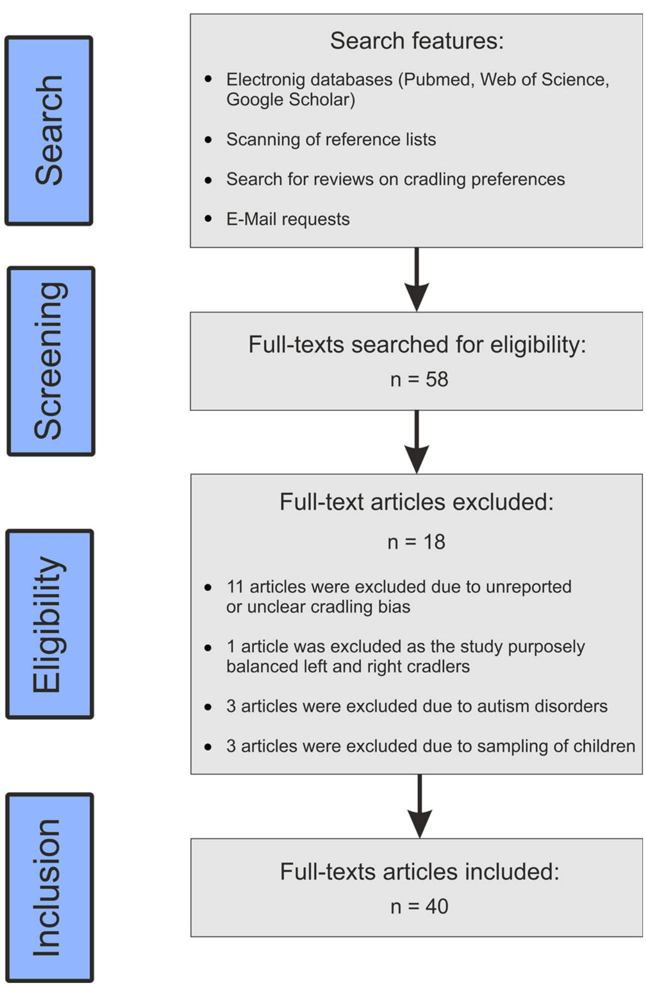


Fig. 1. Flowchart describing the process of article search and the application of criteria for eligibility.

2.2. Statistical analyses

For each study, we determined the number of participants cradling to the left within the whole sample. As most studies consisted of one trial experimental designs, we only sampled the data from the first session in the data set if multiple cradles were performed and this data was available. Furthermore, if sampled and made available for each study, we identified the number of people being left-handed and right-handed and their respective cradling bias. Participants that could be identified as ambidextrous were excluded from the handedness analysis as they did not provide enough power for a group analysis due to the low number of samples. For the same reason, midline cradles were excluded. In total, 19 studies provided data on the cradling bias for left- and right-handers. Additionally, we also determined the cradling bias broken down by sex.

The first step of the analysis used descriptive statistics and null hypothesis testing. A chi square goodness of fit analysis for equal distributions was employed to investigate whether the number of left-side cradlers in the population across all studies differed from a distribution predicted by chance (50% left; 50% right). For left- and right-handers as well as for male and female participants, the same analysis was repeated to identify whether these subgroups exhibited asymmetrical distributions in their cradling bias individually, *i.e.* if their cradling bias was significantly different from chance. Furthermore, we compared the cradling bias in left-handers vs. right-handers and in males vs. females to determine differences in the extent of the cradling bias between these subgroups. Here, the null hypothesis predicts no difference in the cradling bias between these subgroups. It is noteworthy that chi square analyses are using the aggregate data from all participants from the included studies (meaning that they are weighted by the sample size of each study) and are thus potentially heavily driven by individual studies with larger sample sizes. Meta-analytic procedures follow more nuanced weighting procedures and do not just rely on sample size. Rather, they use the inverse variance of each study. For random-effects models that acknowledge differences in study designs and data collection methods, they specifically use between-study variance in addition to within-study variance to assign weights to each study accounting for heterogeneity in the data. With regards to handedness, this is of particular importance as the measures for handedness were not uniform across studies. Most studies simply determined handedness as a measure of writing preference or reported overall hand preference whereas some used standardized handedness inventories, such as the Edinburgh Handedness Inventory (Oldfield, 1971). Using writing hand as the criterion for handedness gives a mismatch compared to hand preference

Table 1
Overview of all studies included in the meta-analyses. Presented is the overall left cradling bias (LC), cradling bias broken down by handedness (LH = left-handers, RH = right-handers) and by sex for each individual study. Furthermore, the incorporation of each individual study into the three different meta-analyses is shown.

Study Name	Sample Size	LC Bias	LC Bias LH	LC Bias RH	LC Bias Male	LC Bias Female	Analysis Use
Alzahrani (2012)	369	76.40%	Not assessed	Not assessed	68.63%	79.40%	1,3
Bogren (1984)	162	81.48%	76.47%	82.06%	82.72%	80.25%	1,2,3
Bourne and Todd (2004)	32	59.38%	No Left Handers	59.38%	66.67%	55.00%	1,3
Brüser (1981)	286	59.79%	Not assessed	Not assessed	36.84%	65.50%	1,3
Dagenbach et al. (1988)	297	72.73%	44.83%	75.00%	78.48%	70.18%	1,2,3
Donnot and Vauclair (2007)	186	69.35%	Not assessed	Not assessed	No males	69.35%	1
Donnot and Vauclair (2011)	131	64.89%	Not assessed	Not assessed	No males	64.89%	1
Donnot (2007)	60	65.00%	65.00%	No RH	No males	65.00%	1
Donnot et al. (2008)	100	68.00%	Not assessed	Not assessed	No males	68.00%	1
Ginsburg et al. (1979)	78	64%	Not assessed	Not assessed	No males	64%	1
Harris and Fitzgerald (1985)	171	63.20%	Not assessed	Not assessed	62.50%	63.41%	1,3
Harris et al. (2000)	554	70.04%	56.60%	71.48%	66.06%	71.72%	1,2,3
Harris et al. (2001)	250	66.80%	62.00%	68.00%	68.33%	66.32%	1,2,3
Harris et al. (2007)	354	63.84%	Not assessed	Not assessed	67.14%	63.03%	1,3
Harris et al. (2010)	60	53.33%	Not assessed	Not assessed	No males	53.33%	1
Huggenberger et al. (2009)	46	56.52%	Not assessed	Not assessed	No males	56.52%	1
Lucas et al. (1993)	86	72.09%	Not assessed	Not assessed	No males	72.09%	1
Manning and Denman (1994)	3297	56.08%	Not assessed	Not assessed	45.94%	60.10%	1,3
Manning (1991)	1696	56.19%	Not assessed	Not assessed	46.97%	61.04%	1,3
Matheson and Turnbull (1998)	48	64.58%	Not assessed	Not assessed	45.83%	83%	1,3
Nakamichi and Takeda (1995)	3510	69.57%	64.89%	69.84%	64.72%	72.26%	1,2,3
Reissland (2000)	45	53.33%	Not assessed	Not assessed	No males	53.33%	1
Reissland et al. (2009)	79	74.68%	Not assessed	Not assessed	No males	74.68%	1
Saling and Cooke (1984)	139	88.49%	Not assessed	Not assessed	No males	88.49%	1
Saling and Tyson (1981)	120	89.17%	Not assessed	Not assessed	No males	89.17%	1
Salk (1960)	287	82.58%	78.13%	83.14%	No males	82.58%	1,2
Salk (1973)	466	80.04%	Not assessed	Not assessed	No males	80.04%	1
Scola and Vauclair (2010a)	94	64.89%	53.33%	67.09%	64.89%	No females	1,2
Scola and Vauclair (2010b) 1	260	71.15%	51.72%	73.59%	No males	71.15%	1,2
Scola and Vauclair (2010b) 2	123	69.11%	Not assessed	Not assessed	No males	69.11%	1
Scola and Vauclair (2010b) 3	40	62.50%	Not assessed	Not assessed	No males	62.50%	1
Sieratzki and Woll (2004)	30	73.33%	40.00%	80.00%	No males	73.33%	1,2
Suter et al. (2007)	32	65.63%	Not assessed	Not assessed	No males	65.63%	1
Turnbull and Bryson (2001)	48	75.00%	50.00%	80.00%	No males	75.00%	1,2
Turnbull and Lucas (1991)	67	46.27%	Not assessed	Not assessed	46.27%	No females	1
Turnbull and Lucas (1996) 1	90	77.78%	75.00%	78.21%	82.93%	73.47%	1,2,3
Turnbull and Lucas (1996) 2	50	62.00%	55.56%	63.41%	47.83%	74.07%	1,2,3
Turnbull et al. (2001) 1	70	82.86%	85.00%	82.00%%	88.46%	79.55%	1,2,3
Turnbull et al. (2001) 2	70	75.71%	66.67%	78.46%	61.54%	84.09%	1,2,3
van der Meer and Husby (2006) (Adults)	456	72.15%	34.85%	78.50%	31.71%	75.30%	1,2,3
Vauclair and Donnot (2005)	206	67.48%	60.00%	68.75%	70.45%	64.41%	1,2,3
Vauclair and Scola (2008)	142	70.42%	69.23%	70.54%	No males	70.42%	1,2
Scola (2009)	76	71.05%	42.80%	73.90%	No males	71.05%	1,2
Weatherill et al. (2016)	146	63.01%	73.50%	56.52%	No males	63.01%	1,2

questionnaires of only 0.4% for right-handers, but 13.5% for left-handers (Papadatou-Pastou et al., 2013). This means that a left-hander is more likely to be classified as a right-hander if handedness is assessed by asking for the writing hand since 13.5% of left-handers write with their right hand. Due to these differences in data collection potentially resulting in an over- or underestimation of the actual prevalence of left- or right-handedness in the population, a simple aggregation of all points cannot provide an accurate summary of the literature as it does not consider possible heterogeneity between studies and is less nuanced in its weighting procedure.

The second step of the analysis was to conduct meta-analyses that provide more nuanced weighted estimates to account for the above mentioned flaws in classical null hypothesis testing. Furthermore, using meta-analyses, heterogeneity can be calculated across study results and potentially, should heterogeneity exist, moderating effects can be investigated. The meta-analyses were conducted using Comprehensive Meta-Analysis Version 2.2.064 (https://www.meta-analysis.com/) software.

The first meta-analysis aimed to assess the population bias in cradling asymmetry across all sampled studies (meta-analysis 1). For each study, we compared the absolute numbers of left-lateralized cradles to the overall sample. The second and third meta-analyses were conducted to identify differences in subgroups within the population, namely between left- and right-handers (meta-analysis 2) and between males and females (meta-analysis 3) using the subset of studies that reported the respective data. The number of "events" in comparison to the overall sample size of each individual study then determined the event rate in analysis 1 (predicted event rate by chance is 0.50). For meta-analyses 2 and 3, we compared the number of left- and right-side cradlers both for left- and right-handers as well as male and female participants resulting in an odds ratio for each study. An odds ratio of 1 indicates no difference between the groups.

Since studies strongly differed in their experimental design, we used random-effects models for all meta-analyses that provide a better estimate in case studies do not come from a single population (a result we verified for all meta-analyses by determining heterogeneity using the Q statistic, the I^2 index, and the Tau^2 statistic). I^2 index levels can be classified into low (25%), moderate (50%), and high (75%) (Higgins et al., 2003). These three statistics provide complimentary information, as the Q statistic is used to ascertain whether the primary level effect sizes estimate a common population effect size and the I^2 index can be interpreted as the percentage of total variation across studies that is due to heterogeneity rather than chance. The Tau^2 statistic is an estimate of the between-studies variance. Thus, the Q statistic tests the null hypothesis that there is no dispersion across effect sizes, but the I^2 and the Tau^2 statistics quantify this dispersion. To determine statistical significance of the overall effects, the random-effects model uses the Z value. For data visualization, we used Forest plots. For each analysis, we also computed the publication bias (also known as ascertainment bias), which occurs when the results of studies are skewed due to factors such as poor data collection methods or insufficient sample sizes. Publication bias was calculated using Egger's t Test, the funnel plot graphical test, and Duval and Tweedie's (2000) trim and fill method of correcting bias. The funnel plot should resemble a symmetrical funnel with the diameter of the funnel decreasing (*i.e.*, effect-size estimates becoming more accurate) as the sample size increases in the case of an absence of publication bias. Thus, publication bias is reflected in the asymmetry of the plot. Egger's t provides a qualitative estimate of the asymmetry of the funnel plot, with positive values ($a > 0$) indicating a trend towards higher levels of test accuracy in studies with smaller sample sizes. Duval and Tweedie's (2000) trim-and-fill method aims at making the funnel plot symmetrical by omitting and/or adding hypothetical data sets to the plot where necessary. Then, it provides an adjusted estimate of the effect size, including the added studies.

3. Results

3.1. Descriptive statistics and results from null hypothesis tests

A population bias in cradling was analyzed using a chi square goodness of fit test assuming equal distributions for both left- and right-sided cradling. In total, 9790 left-sided cradlings (65.66%) and 5119 right-sided cradlings (34.34%) were reported in the included studies. This distribution was found to be significantly asymmetrical demonstrating an overall left-sided bias ($\chi^2 = 1464.05$, $p < .001$). For handedness, we calculated a chi square test to identify an asymmetrical distribution in cradling between left- and right-handers. Overall, 592 left-handers and 6207 right-handers were examined. Of the 592 left-handers, 353 preferred to cradle on the left body side, which was significantly different from chance (59.63%, $\chi^2 = 21.95$, $p < .001$). Of the 6207 right-handers, 4452 preferred to cradle on the left body side (71.73%). This was also found to be significantly different from chance level ($\chi^2 = 1171.00$, $p < .001$). The distribution was also significantly asymmetrical with left-handers being less preferential of leftward cradling than right-handers ($\chi^2 = 38.16$, $p < .001$).

Finally, we calculated potential sex differences again using a chi square test. Across the 19 examined studies, 3940 male and 8028 female participants were tested. Of the 3940 males, 2241 preferred to cradle on the left side (56.88%) whereas 5358 out of the 8028 females (66.74%) preferred to cradle on the left side. Both preferences were statistically different from a prediction based on chance ($\chi^2 = 74.56$, $p < .001$ for males, $\chi^2 = 900.01$, $p < .001$ for females). For sex, we found an asymmetrical distribution as females conducted significantly more cradling on the left and were thus more lateralized than males ($\chi^2 = 110.92$, $p < .001$).

3.2. Meta-analyses

3.2.1. Analysis 1: general cradling bias

3.2.1.1. Overall estimate. To assess whether a general cradling bias exists within the population, we first conducted a meta-analysis across all the 40 studies that were deemed eligible based on our criteria. There was significant heterogeneity within the set of studies ($Q(44) = 461.04$, $p < 0.001$, $\mathrm{Tau}^2 = 0.15$, $I^2 = 90.67\%$). The random-effects model yielded a significant result (ER = 0.69, CI = [0.66, 0.72], $Z = 12.61$, $p < .001$) indicating that there is a left side cradling bias across all populations studied (see Fig. 2). The confidence interval indicates that the range of the cradling bias within the distribution of populations studied ranges from 66% to 72%. A publication bias analysis reached significance ($t(42) = 2.78$, $p = .008$). A visual inspection of the funnel plot demonstrated that the right side of the funnel (indicating a leftward cradling bias) is underrepresented in studies on the general cradling bias (Fig. 3). Using Duval and Tweedie's trim and fill method for bias correction for the random-effects model, seven data sets were "filled" to the right of the plot. When recalculating the event rate including these studies, this resulted in ER = 0.72 (CI = [0.68, 0.75]).

3.2.1.2. Moderator variables analysis. As heterogeneity reached significance, we identified the task design as a potential moderator as the studies were divided into an actual or imagined cradling of a child and the cradling of a doll. We therefore ran a categorical analysis divided by task design. Both task types demonstrated significant effects using a mixed-effects model (ER = 0.70, CI = [0.66,0.73], $Z = 10.60$, $p < .001$ for child cradling; ER = 0.70, CI = [0.62,0.74], $Z = 5.57$, $p < .001$ for doll cradling, Fig. 4). There was no significant heterogeneity between the sub-categories ($Q(1) = 0.09$, $p = .765$).

3.2.2. Analysis 2: Effects of handedness in cradling

3.2.2.1. Overall estimate. To identify the effects of handedness, we conducted a meta-analysis comparing left- and right-handers with regards to their cradling bias based on 19 studies. Of these studies, only four studies individually demonstrated significant differences between left- and right-handers. Heterogeneity was significant between studies ($Q(18) = 42.56$, $p = 0.001$, $\mathrm{Tau}^2 = 0.25$, $I^2 = 57.71\%$). The random-effects model demonstrated a significant odds ratio with left-handers being less preferential to cradle on the left than right-handers (OR = 0.54, CI = [0.39, 0.75], $Z = 3.74$, $p < .001$, see Fig. 5). The combined odds ratio can also be understood as a proportion using the formula LHLC = RHLC*OR/[1 + RHLC(OR-1)] where LHLC is the likelihood of a left-hander to cradle to the left and RHLC is the probability of a right-hander cradling to the left (Markou et al., 2017). If the proportion of right-handers cradling to the left were to be 74%, as observed in our sample, the corresponding proportion of left-handers cradling to the left would be 61%. There was no significant publication bias in studies comparing left-handers and right-handers with regards to their cradling bias ($t(17) = 0.35$, $p = .733$, Fig. 6). However, using Duval and Tweedie's trim and fill method for bias correction for the random-effects model, two data sets were "filled" to the left of the plot to make it symmetrical. When recalculating the odds ratio including these studies, this resulted in an OR = 0.49, CI = [0.35, 0.68].

3.2.3. Moderator variables analysis

A potential moderator influencing the handedness bias could be the assessment of handedness as there is considerable mismatch between self-report of hand preference and hand preference as measured by hand preference questionnaires in left-handers (Papadatou-Pastou et al., 2013). A mixed-effects model revealed significant heterogeneity in the cradling bias between studies using a self-report measure and studies using handedness questionnaires ($Q(1) = 6.69$, $p = .010$). Studies using a standardized handedness questionnaire demonstrated a significant difference between left- and right-handers concerning their cradling bias (OR = 0.41, CI = [0.27, 0.64], $Z = 4.04$, $p < .001$, see Fig. 7). For self-report, the model did not reach significance (OR = 0.80, CI = [0.62, 1.04], $Z = 1.70$, $p = .089$). Task design was also tested as a potential moderator in analysis 2. A mixed-effects model did not demonstrate significant heterogeneity between child cradling and doll cradling ($Q(1) = 0.54$, $p = .461$, Fig. 8).

3.2.4. Analysis 3: Effects of sex in cradling

3.2.4.1. 3.2.3.1 Overall estimate. Finally, we compared males and females to identify sex differences in cradling biases. Here, a total of 19 studies were included in the meta-analysis. Eight individual studies provided significant differences between males and females. Heterogeneity was significant between studies ($Q(18) = 95.89$, $p < 0.001$, $\mathrm{Tau}^2 = 0.17$, $I^2 = 81.23\%$). The employment of a random-effects model resulted in a significant difference between males and females with females being more lateralized to the left compared to

Study name	Event rate	Lower limit	Upper limit	Z-Value	p-Value
Alzahrani (2012)	0.764	0.718	0.805	9.589	0.000
Bogren (1984)	0.815	0.747	0.867	7.325	0.000
Bourne & Todd (2004)	0.594	0.419	0.747	1.054	0.292
Bruser (1981)	0.598	0.540	0.653	3.290	0.001
Dagenbach et al. (1988)	0.727	0.674	0.775	7.528	0.000
Donnot & Vauclair (2007)	0.694	0.624	0.756	5.135	0.000
Donnot & Vauclair (2011)	0.649	0.563	0.726	3.355	0.001
Donnot (2007)	0.650	0.522	0.759	2.287	0.022
Donnot et al. (2008)	0.680	0.583	0.764	3.516	0.000
Ginsburg et al. (1979)	0.641	0.529	0.739	2.456	0.014
Harris & Fitzgerald (1985)	0.632	0.557	0.701	3.400	0.001
Harris et al. (2000)	0.700	0.661	0.737	9.154	0.000
Harris et al. (2001)	0.668	0.607	0.724	5.206	0.000
Harris et al. (2006)	0.638	0.587	0.687	5.139	0.000
Harris et al. (2010)	0.533	0.408	0.655	0.516	0.606
Huggenberger et al. (2009)	0.565	0.421	0.700	0.882	0.378
Lucas et al. (1993)	0.721	0.617	0.805	3.948	0.000
Manning & Denman (1994)	0.561	0.544	0.578	6.966	0.000
Manning (1991)	0.562	0.538	0.585	5.086	0.000
Matheson & Turnbull (1998)	0.646	0.502	0.767	1.991	0.047
Nakamichi & Takeda (1995)	0.696	0.680	0.711	22.544	0.000
Reissland (2000)	0.533	0.389	0.672	0.447	0.655
Reissland et al. (2009)	0.747	0.640	0.830	4.181	0.000
Saling & Cooke (1984)	0.885	0.820	0.928	7.674	0.000
Saling & Tyson (1981)	0.892	0.822	0.936	7.177	0.000
Salk (1960)	0.826	0.777	0.865	9.999	0.000
Salk (1973)	0.800	0.762	0.834	11.984	0.000
Scola & Vauclair (2010a)	0.649	0.548	0.738	2.843	0.004
Scola & Vauclair (2010b) 1	0.712	0.654	0.763	6.596	0.000
Scola & Vauclair (2010b) 2	0.691	0.604	0.766	4.126	0.000
Scola & Vauclair (2010b) 3	0.625	0.468	0.760	1.564	0.118
Sieratzki & Woll (2004)	0.733	0.550	0.861	2.450	0.014
Suter et al. (2007)	0.656	0.479	0.798	1.737	0.082
Turnbull & Bryson (2001)	0.750	0.610	0.852	3.296	0.001
Turnbull & Lucas (1991)	0.463	0.348	0.582	-0.610	0.542
Turnbull & Lucas (1996) 1	0.778	0.680	0.852	4.941	0.000
Turnbull & Lucas (1996) 2	0.620	0.480	0.743	1.680	0.093
Turnbull et al. (2001) 1	0.829	0.722	0.900	4.968	0.000
Turnbull et al. (2001) 2	0.757	0.644	0.843	4.079	0.000
van der Meer & Husby (2006) (Adults)	0.721	0.679	0.761	9.112	0.000
Vauclair & Donnot (2005)	0.675	0.608	0.735	4.907	0.000
Vauclair & Scola (2008)	0.704	0.624	0.773	4.718	0.000
Vauclair & Scola (2009)	0.711	0.599	0.801	3.550	0.000
Weatherill et al. (2004)	0.630	0.549	0.704	3.108	0.002
	0.692	0.664	0.719	12.163	0.000

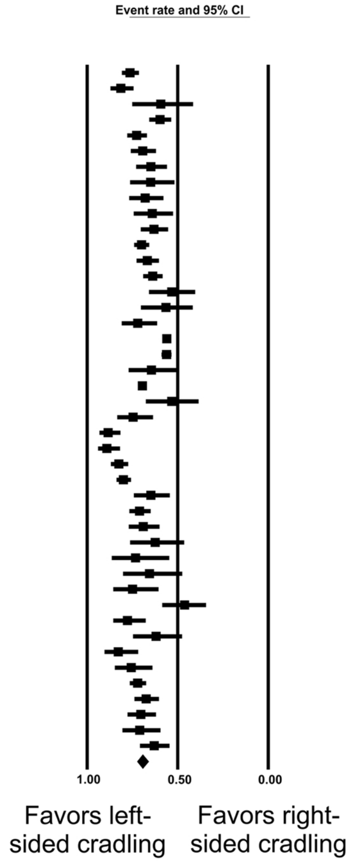


Fig. 2. Forest plot depicting the lateralization of cradling in the general population across 45 independent samples. The 95% confidence interval for each study is represented by a horizontal line and the point estimate is represented by a square. The diamond shape represents the point estimate of the overall mean effect and its horizontal lines represent the confidence interval across all studies.

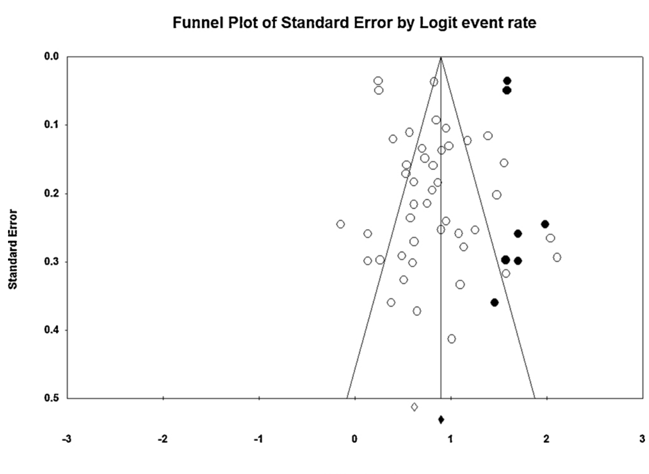


Fig. 3. Funnel plot of standard error by logit event rate for observed left-cradlers compared to the overall sample. White dots indicate observed data points from individual studies whereas black dots represent imputed studies.

males (OR = 1.49, CI = [1.17, 1.89], $Z = 3.25$, $p = .001$, see Fig. 9). We furthermore calculated a simple proportion using the combined odds ratio and the formula FMLC = MLC*OR/[1 + MLC(OR-1)] where FMLC represents the number of female left cradlers and MLC indicates the number of male left cradlers. Here, the probability of females cradling to the left is 1.49 times higher than in males. Based on the observed 64% left cradles in males, the probability of females cradling to the left would therefore be at 73%. Publication bias did not reach significance in studies comparing males and females ($t(17) = 0.54$, $p = .60$, Fig. 10). However, using Duval and Tweedie's trim and fill method for bias correction for the random effects model one data sets was "filled" to the left of the plot to make it symmetrical. When recalculating the odds ratio including these studies, this resulted in OR = 1.52, CI = [1.20, 1.93].

3.2.4.2. Moderator variables analysis. As for the previous analyses, we looked for task design as a moderator in analysis 3. A mixed-effects model did not demonstrate significant heterogeneity between child cradling and doll cradling ($Q(1) = 0.44$, $p = .593$, Fig. 11).

4. Discussion

The aim of the present study was to quantify the extent of the cradling bias and identify if factors such as handedness and sex are moderating the lateral cradling bias found widely in the contemporary literature on infant holding. We first used classical null hypothesis testing to determine asymmetrical distributions in the general population. Overall, the evidence towards a left-side cradling bias was significant with 69% of the population demonstrating a left-side preference. We furthermore investigated whether handedness or sex moderated the cradling bias. For both phenotypes, null hypothesis tests revealed significant differences. Left-handers were more inclined to cradle on the right side compared to right-handers (while still maintaining a left-side bias overall). For sex, both males and females demonstrated a significant left-side bias with females being more lateralized to the left than males. Using meta-analyses, we could identify the same findings on the overall population bias and the differences based on handedness and sex in infant cradling.

4.1. Comparison between null hypothesis testing and meta-analyses

In general, we found highly comparable results using classical

Group by Doll_child	Study name	Event rate	Lower limit	Upper limit	Z-Value	p-Value
1.00	Alzahrani (2012)	0.764	0.718	0.805	9.589	0.000
1.00	Bogren (1984)	0.815	0.747	0.867	7.325	0.000
1.00	Bruser (1981)	0.598	0.540	0.653	3.290	0.001
1.00	Dagenbach et al. (1988)	0.727	0.674	0.775	7.528	0.000
1.00	Donnot & Vauclair (2007)	0.694	0.624	0.756	5.135	0.000
1.00	Donnot & Vauclair (2011)	0.649	0.563	0.726	3.355	0.001
1.00	Donnot (2007)	0.650	0.522	0.759	2.287	0.022
1.00	Donnot et al. (2008)	0.680	0.583	0.764	3.516	0.000
1.00	Ginsburg et al. (1979)	0.641	0.529	0.739	2.456	0.014
1.00	Harris & Fitzgerald (1985)	0.632	0.557	0.701	3.400	0.001
1.00	Harris et al. (2000)	0.700	0.661	0.737	9.154	0.000
1.00	Harris et al. (2001)	0.668	0.607	0.724	5.206	0.000
1.00	Harris et al. (2006)	0.638	0.587	0.687	5.139	0.000
1.00	Manning & Denman (1994)	0.561	0.544	0.578	6.966	0.000
1.00	Manning (1991)	0.562	0.538	0.585	5.086	0.000
1.00	Nakamichi & Takeda (1995)	0.696	0.680	0.711	22.544	0.000
1.00	Reissland (2000)	0.533	0.389	0.672	0.447	0.655
1.00	Reissland et al. (2009)	0.747	0.640	0.830	4.181	0.000
1.00	Saling & Cooke (1984)	0.885	0.820	0.928	7.674	0.000
1.00	Salk (1960)	0.826	0.777	0.865	9.999	0.000
1.00	Salk (1973)	0.800	0.762	0.834	11.984	0.000
1.00	Scola & Vauclair (2010a)	0.649	0.548	0.738	2.843	0.004
1.00	Scola & Vauclair (2010b) 1	0.712	0.654	0.763	6.596	0.000
1.00	Scola & Vauclair (2010b) 2	0.691	0.604	0.766	4.126	0.000
1.00	Scola & Vauclair (2010b) 3	0.625	0.468	0.760	1.564	0.118
1.00	Sieratzki & Woll (2004)	0.733	0.550	0.861	2.450	0.014
1.00	Turnbull & Lucas (1996) 1	0.778	0.680	0.852	4.941	0.000
1.00	Vauclair & Scola (2008)	0.704	0.624	0.773	4.718	0.000
1.00	Vauclair & Scola (2009)	0.711	0.599	0.801	3.550	0.000
1.00	Weatherill et al. (2004)	0.630	0.549	0.704	3.108	0.002
1.00		0.695	0.662	0.726	10.601	0.000
2.00	Bourne & Todd (2004)	0.594	0.419	0.747	1.054	0.292
2.00	Harris et al. (2010)	0.533	0.408	0.655	0.516	0.606
2.00	Huggenberger et al. (2009)	0.565	0.421	0.700	0.882	0.378
2.00	Lucas et al. (1993)	0.721	0.617	0.805	3.948	0.000
2.00	Matheson & Turnbull (1998)	0.646	0.502	0.767	1.991	0.047
2.00	Saling & Tyson (1981)	0.892	0.822	0.936	7.177	0.000
2.00	Suter et al. (2007)	0.656	0.479	0.798	1.737	0.082
2.00	Turnbull & Bryson (2001)	0.750	0.610	0.852	3.296	0.001
2.00	Turnbull & Lucas (1991)	0.463	0.348	0.582	-0.610	0.542
2.00	Turnbull & Lucas (1996) 2	0.620	0.480	0.743	1.680	0.093
2.00	Turnbull et al. (2001) 1	0.829	0.722	0.900	4.968	0.000
2.00	Turnbull et al. (2001) 2	0.757	0.644	0.843	4.079	0.000
2.00	van der Meer & Husby (2006) (Adults)	0.721	0.679	0.761	9.112	0.000
2.00	Vauclair & Donnot (2005)	0.675	0.608	0.735	4.907	0.000
2.00		0.685	0.623	0.741	5.574	0.000
Overall		0.693	0.664	0.720	11.973	0.000

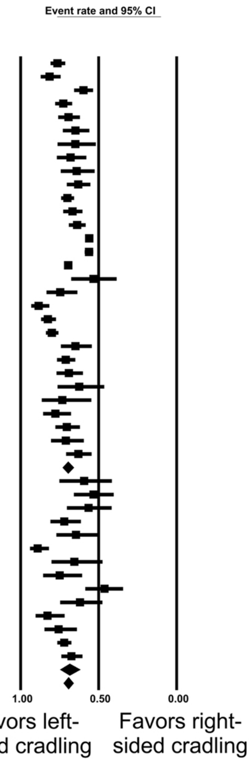


Fig. 4. Forest plot depicting the lateralization of cradling divided by child cradling (1) or doll cradling (2). The structure of the plot is identical to Fig. 1.

hypothesis testing and a meta-analytical approach. However, as evident from the large sample sizes in individual groups, using a simple data aggregate across studies is strongly reliant on very few highly powered studies to the point of completely neglecting results from studies with a low number of test participants. As meta-analyses weight the impact of these studies more nuancedly (Borenstein et al., 2011), they provide a more accurate picture of the actual effect as they are not driven by individual studies. Furthermore, the size of the effects using simple data aggregates might be systematically overestimated as heterogeneity among studies is not considered. This is particularly evident in case of sex and handedness differences as null hypothesis testing using data aggregates provides very strong effects of sex whereas the results of the meta-analyses are of a weaker effect. Therefore, simple tests for asymmetrical distributions should be viewed with caution.

4.2. Influence of handedness on the cradling bias

Both analysis types revealed a difference between left- and right-handers with right-handers having a more lateralized left-side cradling bias. Therefore, handedness clearly influences the asymmetry in infant holding, albeit to a much smaller degree compared to what is postulated by van der Meer and Husby (2006). They found an almost reversed cradling bias in left- and right-handers and therefore concluded that the dominant hand is used to perform tasks requiring accurate hand and arm movements. However, when the entire literature on cradling is considered, this bias diminishes drastically and does not

Study name	Odds ratio	Lower limit	Upper limit	Z-Value	p-Value
Bogren (1984)	0.710	0.214	2.354	-0.560	0.575
Dagenbach et al. (1988)	0.271	0.124	0.592	-3.273	0.001
Harris et al. (2000)	0.521	0.293	0.928	-2.216	0.027
Harris et al. (2001)	0.768	0.403	1.462	-0.805	0.421
Nakamichi & Takeda (1995)	0.798	0.586	1.087	-1.431	0.153
Salk (1960)	0.724	0.295	1.782	-0.702	0.483
Scola & Vauclair (2010a)	0.561	0.183	1.714	-1.015	0.310
Scola & Vauclair (2010b) 1	0.384	0.175	0.843	-2.387	0.017
Sieratzki & Woll (2004)	0.167	0.022	1.282	-1.721	0.085
Turnbull & Bryson (2001)	0.250	0.051	1.223	-1.711	0.087
Turnbull & Lucas (1996) 1	0.836	0.204	3.434	-0.248	0.804
Turnbull & Lucas (1996) 2	0.721	0.167	3.106	-0.439	0.661
Turnbull et al. (2001) 1	1.244	0.300	5.165	0.300	0.764
Turnbull et al. (2001) 2	0.542	0.119	2.465	-0.793	0.428
van der Meer & Husby (2006) (Adults)	0.147	0.084	0.257	-6.703	0.000
Vauclair & Donnot (2005)	0.682	0.307	1.513	-0.942	0.346
Vauclair & Scola (2008)	0.940	0.273	3.237	-0.099	0.921
Vauclair & Scola (2009)	0.265	0.054	1.299	-1.638	0.101
Weatherill et al. (2004)	2.308	0.599	8.895	1.215	0.224
	0.539	0.389	0.745	-3.735	0.000

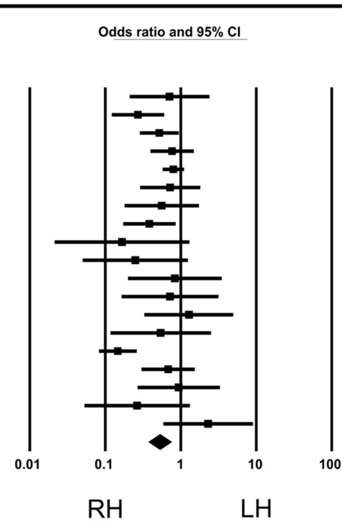


Fig. 5. Forest plot depicting the difference in lateralization of cradling between left-handers (LH) and right-handers (RH) across 19 studies. The x-axis represents the odds ratio of the cradling bias between left-handers and right-handers. If the odds of left-handers and right-handers cradling to the left are equal, the odds ratio would be 1. An odds ratio of above 0 and less than 1 favors a stronger lateralization of right-handers compared to left-handers whereas an odds ratio of more than 1 favors a stronger lateralization of left-handers compared to right-handers. Here, the odds ratio of less than 1 indicates that right-handers cradle more often on the left than left-handers.

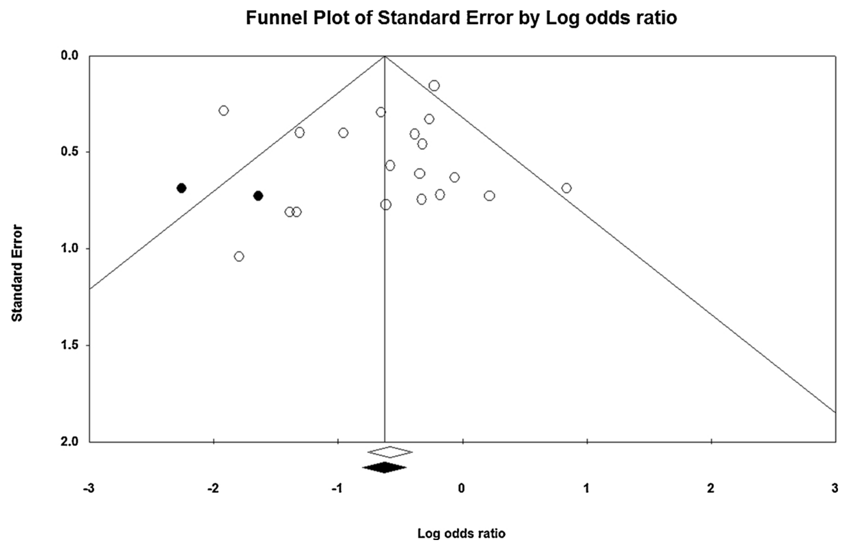


Fig. 6. Funnel plot of standard error by logit event rate for studies comparing left- and right-handers.

show a reversed pattern. Left-handers in general do not prefer the right hand as the overall bias was still left-sided in this group. A potential explanation why van der Meer and Husby (2006) found such a strong difference between left- and right-handers might be due to the cradling of a doll instead of an actual child. While task design (child cradling vs. doll cradling) did not demonstrate any influence as a moderating variable, they actually used a beanbag doll weighing 1.5 kg with a soft body and hard head opposed to other studies (*e.g.*, Huggenberger, Suter et al., 2009) using more lifelike dolls offering participants a more realistic experience of the haptics cradling an actual child. Thus, while complex motor movements with the dominant arm might contribute to the preferred use of the left hand, it only accounts for a moderate shift in behavior and probably does not fully explain the cradling bias. Moreover, such a clear pattern of complementary hemispheric specialization (*i.e.* left-handers cradling on the right and right-handers cradling on the left side) has rarely been reported for laterality phenotypes. While there is evidence that visuospatial attention is clearly predominantly processed by the subdominant hemisphere for language (Cai et al., 2013), such an explicit division of labour between hemispheres seems to be an exception rather than the rule. For example, it has been shown that there is a lesser extent of left-hemispheric language lateralization, but no reversal of hemispheric specialization for language in left-handers compared to right-handers (Somers et al., 2015). This pattern is comparable with the handedness effects in cradling bias revealed here. Future research will establish whether a common biological mechanism underlies different forms of lateral biases such as language lateralization and the cradling bias.

Another finding indicating that handedness is a contributing, but not fully explanatory, variable in determining the cradling bias stems from the observation of the cradling bias in non-human primates. Especially for great apes such as chimpanzees, which have also been found to be biased towards the left side during cradling (Manning and Chamberlain, 1990; Manning et al., 1994), a population bias in handedness has been identified (Hopkins, 2006; MacNeilage et al., 1987). This indicates that the cradling bias in primate species could at least partly be determined by their respective handedness. Interestingly however, non-human primates conduct midline cradles in roughly 20% of the observations (Manning and Chamberlain, 1990; Manning et al., 1994), a finding that could not be observed in human participants in the scope of this meta-analysis (midline cradles comprised less than 0.2% of the reported data). Such a result could potentially be attributed to population level asymmetries in handedness of non-human primates being highly task specific (Regaiolli et al., 2016) and not universal as they are in humans. To achieve a comprehensive understanding of similarities and differences in cradling between humans and non-human primates, more comparative research is needed however as the study

Group by Handedness measure	Study name	Statistics for each study: Odds ratio	Lower limit	Upper limit	Z-Value	p-Value
1.00	Bogren (1984)	0.710	0.214	2.354	-0.560	0.575
1.00	Nakamichi & Takeda (1995)	0.798	0.586	1.087	-1.431	0.153
1.00	Salk (1960)	0.724	0.295	1.782	-0.702	0.483
1.00	Sieratzki & Woll (2004)	0.167	0.022	1.282	-1.721	0.085
1.00	Turnbull & Lucas (1996) 1	0.836	0.204	3.434	-0.248	0.804
1.00	Turnbull & Lucas (1996) 2	0.721	0.167	3.106	-0.439	0.661
1.00	Turnbull et al. (2001) 1	1.244	0.300	5.165	0.300	0.764
1.00	Turnbull et al. (2001) 2	0.542	0.119	2.465	-0.793	0.428
1.00	Weatherill et al. (2004)	2.308	0.599	8.895	1.215	0.224
1.00		0.800	0.619	1.035	-1.701	0.089
2.00	Dagenbach et al. (1988)	0.271	0.124	0.592	-3.273	0.001
2.00	Harris et al. (2000)	0.521	0.293	0.928	-2.216	0.027
2.00	Harris et al. (2001)	0.768	0.403	1.462	-0.805	0.421
2.00	Scola & Vauclair (2010a)	0.561	0.183	1.714	-1.015	0.310
2.00	Scola & Vauclair (2010b) 1	0.384	0.175	0.843	-2.387	0.017
2.00	Turnbull & Bryson (2001)	0.250	0.051	1.223	-1.711	0.087
2.00	van der Meer & Husby (2006) (Adults)	0.147	0.084	0.257	-6.703	0.000
2.00	Vauclair & Donnot (2005)	0.682	0.307	1.513	-0.942	0.346
2.00	Vauclair & Scola (2008)	0.940	0.273	3.237	-0.099	0.921
2.00	Vauclair & Scola (2009)	0.265	0.054	1.299	-1.638	0.101
2.00		0.414	0.270	0.635	-4.044	0.000
Overall		0.672	0.539	0.837	-3.543	0.000

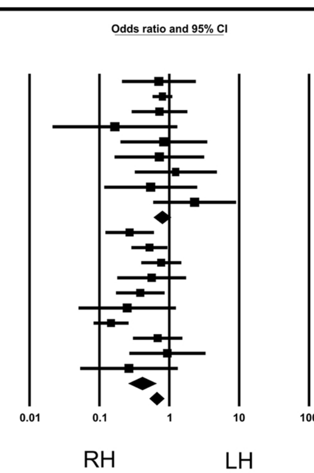
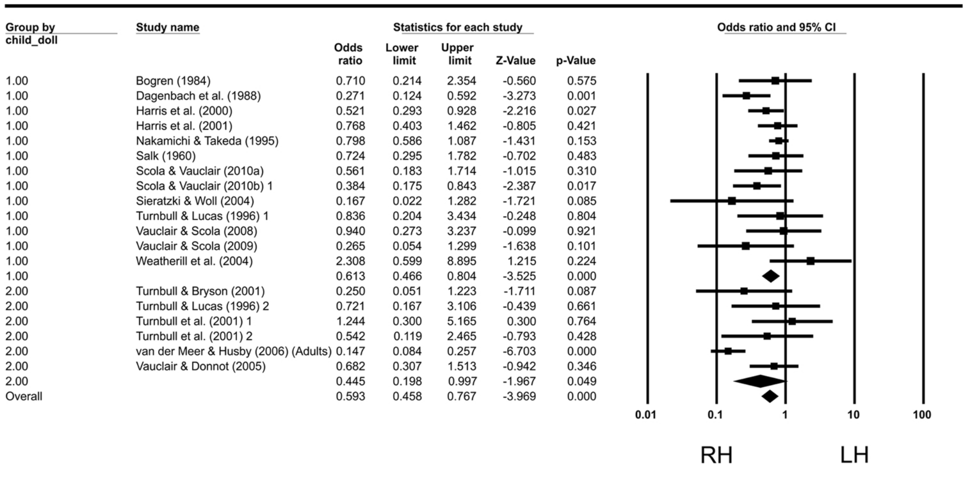
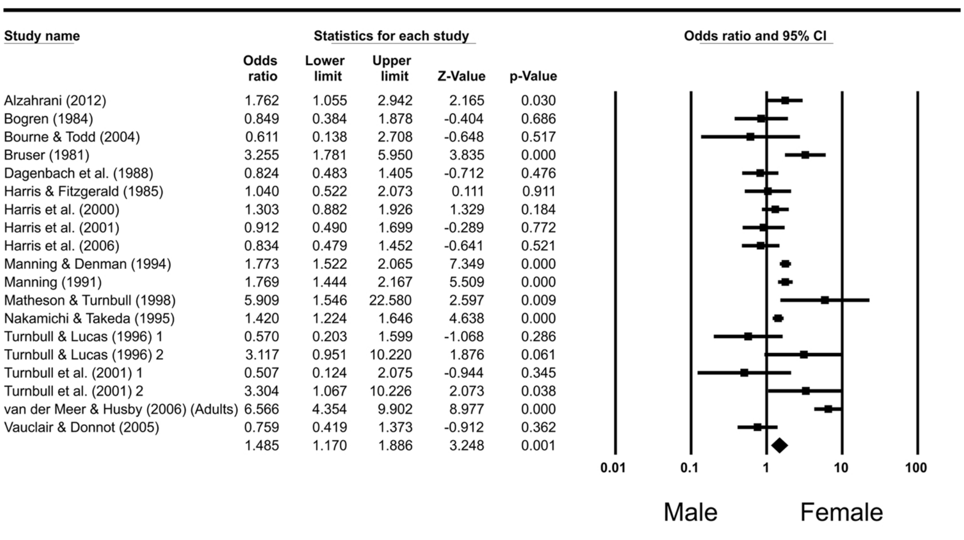


Fig. 7. Forest plot depicting the difference in lateralization of cradling between left- and right-handers divided by self-report (1) or questionnaire (2) assessment of handedness. The structure of the plot is identical to Fig. 5.



Group by child_doll	Study name	Odds ratio	Lower limit	Upper limit	Z-Value	p-Value
1.00	Bogren (1984)	0.710	0.214	2.354	-0.560	0.575
1.00	Dagenbach et al. (1988)	0.271	0.124	0.592	-3.273	0.001
1.00	Harris et al. (2000)	0.521	0.293	0.928	-2.216	0.027
1.00	Harris et al. (2001)	0.768	0.403	1.462	-0.805	0.421
1.00	Nakamichi & Takeda (1995)	0.798	0.586	1.087	-1.431	0.153
1.00	Salk (1960)	0.724	0.295	1.782	-0.702	0.483
1.00	Scola & Vauclair (2010a)	0.561	0.183	1.714	-1.015	0.310
1.00	Scola & Vauclair (2010b) 1	0.384	0.175	0.843	-2.387	0.017
1.00	Sieratzki & Woll (2004)	0.167	0.022	1.282	-1.721	0.085
1.00	Turnbull & Lucas (1996) 1	0.836	0.204	3.434	-0.248	0.804
1.00	Vauclair & Scola (2008)	0.940	0.273	3.237	-0.099	0.921
1.00	Vauclair & Scola (2009)	0.265	0.054	1.299	-1.638	0.101
1.00	Weatherill et al. (2004)	2.308	0.599	8.895	1.215	0.224
1.00		0.613	0.466	0.804	-3.525	0.000
2.00	Turnbull & Bryson (2001)	0.250	0.051	1.223	-1.711	0.087
2.00	Turnbull & Lucas (1996) 2	0.721	0.167	3.106	-0.439	0.661
2.00	Turnbull et al. (2001) 1	1.244	0.300	5.165	0.300	0.764
2.00	Turnbull et al. (2001) 2	0.542	0.119	2.465	-0.793	0.428
2.00	van der Meer & Husby (2006) (Adults)	0.147	0.084	0.257	-6.703	0.000
2.00	Vauclair & Donnot (2005)	0.682	0.307	1.513	-0.942	0.346
2.00		0.445	0.198	0.997	-1.967	0.049
Overall		0.593	0.458	0.767	-3.969	0.000

Fig. 8. Forest plot depicting the difference in cradling bias between left- and right-handers divided by child cradling (1) or doll cradling (2). The structure of the plot is identical to Fig. 5.



Study name	Odds ratio	Lower limit	Upper limit	Z-Value	p-Value
Alzahrani (2012)	1.762	1.055	2.942	2.165	0.030
Bogren (1984)	0.849	0.384	1.878	-0.404	0.686
Bourne & Todd (2004)	0.611	0.138	2.708	-0.648	0.517
Bruser (1981)	3.255	1.781	5.950	3.835	0.000
Dagenbach et al. (1988)	0.824	0.483	1.405	-0.712	0.476
Harris & Fitzgerald (1985)	1.040	0.522	2.073	0.111	0.911
Harris et al. (2000)	1.303	0.882	1.926	1.329	0.184
Harris et al. (2001)	0.912	0.490	1.699	-0.289	0.772
Harris et al. (2006)	0.834	0.479	1.452	-0.641	0.521
Manning & Denman (1994)	1.773	1.522	2.065	7.349	0.000
Manning (1991)	1.769	1.444	2.167	5.509	0.000
Matheson & Turnbull (1998)	5.909	1.546	22.580	2.597	0.009
Nakamichi & Takeda (1995)	1.420	1.224	1.646	4.638	0.000
Turnbull & Lucas (1996) 1	0.570	0.203	1.599	-1.068	0.286
Turnbull & Lucas (1996) 2	3.117	0.951	10.220	1.876	0.061
Turnbull et al. (2001) 1	0.507	0.124	2.075	-0.944	0.345
Turnbull et al. (2001) 2	3.304	1.067	10.226	2.073	0.038
van der Meer & Husby (2006) (Adults)	6.566	4.354	9.902	8.977	0.000
Vauclair & Donnot (2005)	0.759	0.419	1.373	-0.912	0.362
	1.485	1.170	1.886	3.248	0.001

Fig. 9. Forest plot depicting the difference in lateralization of cradling between males and females. The x-axis represents the odds ratio of the cradling bias between males and females. If the odds of males and females cradling to the left are equal, the odds ratio would be 1. An odds ratio of less than 1 favors a stronger lateralization of males compared to females whereas an odds ratio of more than 1 favors a stronger lateralization of females compared to males. Here, an odds ratio of greater than 1 indicates that females demonstrate more left-sided cradles than males.

count on the cradling bias in species other than humans is too low to draw final conclusions or conduct meaningful meta-analyses.

In summary, there is strong evidence that hand preferences play a role in cradling preferences as seventeen out of nineteen investigated studies demonstrated a stronger degree of lateralization in right-handers. However, the relationship between handedness and cradling bias is not monocausally driven by hand preference for fine-tuned motor task as suggested by van der Meer and Husby (2006).

4.3. *Influence of sex on the cradling bias*

We found an effect of sex on cradling lateralization since males are less left-lateralized compared to females during infant holding. This effect could be related to a specific emotional bond of mothers to their newborn children. A recent study by our group investigating the lateralization of embraces, another form of social touch, found that emotional state alters the laterality of embraces (Packheiser et al., 2018). This study indicated a right-hemispheric dominance in emotional processing on the behavioral level as participants performed more left-sided embraces in emotional conditions (*e.g.* farewells or reunions) compared to neutral conditions (*e.g.* greetings), a result that could potentially be explained by assuming that emotional and motor networks are highly interconnected which has been indicated in humans (Borod, 1993) and other animal species (Siniscalchi et al., 2010). A similar explanation might apply to the stronger lateralization of females compared to males during cradling. Packheiser et al. (2018) also found an effect of sex in their study, namely that males feel uncomfortable embracing other males ultimately influencing the lateralization of the embrace. It could be speculated that the reduced asymmetry in males is due to them being more uncomfortable holding a child, especially in experiments involving a doll rather than their own child. Indeed, de Château (1983) found that males who are inexperienced with children have a less pronounced preference to cradle on the left than fathers indicating that the parental emotional bond contributes to the cradling bias. Another possible explanation is that the sex difference was mediated by less experience overall in males compared to females since females are likely to cradle children more often. However, experience with children and infants has been investigated by van der Meer and Husby (2006) and they found no effect on the lateral bias in cradling indicating against this possibility. The sex difference could also be an epiphenomenon of a sex difference in handedness as males are 23% more likely to be left-handed than females (Papadatou-Pastou et al., 2008; Martin et al., 2010). The effects of handedness moderating the sex difference could unfortunately not be further analyzed as almost no study reported handedness itemized by sex of the participants. Regarding the emotional bias, no proper meta-analysis

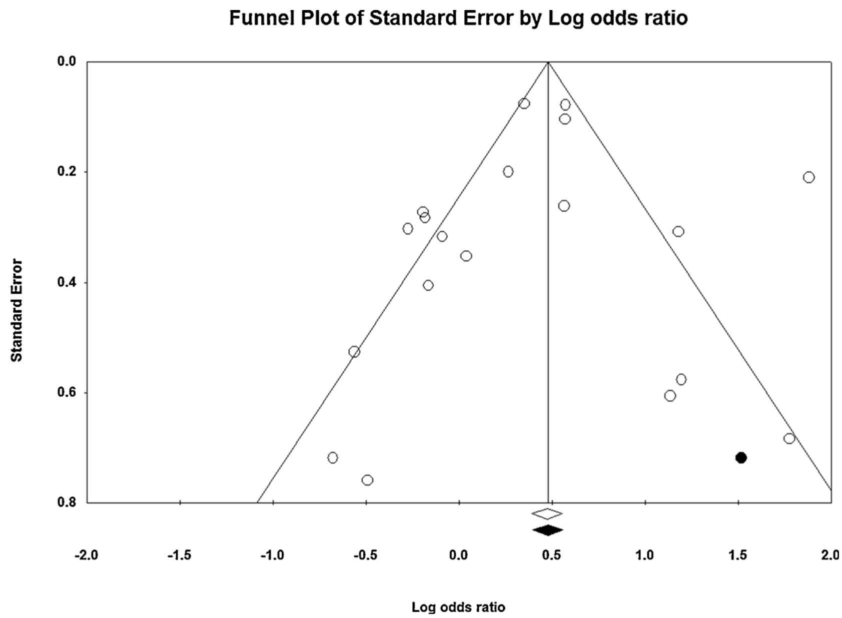


Fig. 10. Funnel plot of standard error by logit event rate for studies comparing males and females.

could be performed due to the low number of studies investigating this phenomenon. Future studies should aim at a systematic manipulation of the emotional context to reveal effects of affectivity influencing the cradling bias.

4.4. Further moderating variables and limitations

We found no difference using the task design (child cradling vs. doll cradling) indicating that the cradling bias can be reliably assessed using a doll. However, the doll should be designed as lifelike as possible (*e.g.*, regarding weight and haptics) given the results by van der Meer and Husby (2006). Of note, the power of the moderating variables analysis within a meta-analysis is a function of the number of included studies, similarly to the fact that the power of primary studies is a function of its sample size. Therefore, a potential moderating effect might not have been detected due to low power. A significant moderator regarding differences between left- and right-handers could be found in the measurement of hand preference. Here, studies using a self-report could not demonstrate a significant difference whereas studies using a standardized questionnaire could show a stronger left cradling bias in right-handers. As left-handers are mismatched in 13.5% of the cases when using self-report (Papadatou-Pastou et al., 2013), this could have confounded the results in this subgroup. Future studies should therefore use hand preference measures beyond simple self-report in order to properly assess the participants' handedness.

There are limitations in this study as all effects demonstrate significant heterogeneity, but we only found one significant moderating variable explaining some of the differences between studies. Potential other moderators could not be properly analyzed as there were either too few studies, for example in the case of ethnicity differences (the grand majority of studies were conducted in Western societies), or the studies did not report key variables such as the participants' age. While sex and handedness were reported in enough studies to warrant a moderator variables analysis, not all studies broke down their data using these categories. We therefore urge researchers to provide these important data in future studies to explain the variability in cradling bias research.

Group by Doll_child	Study name	Statistics for each study				
		Odds ratio	Lower limit	Upper limit	Z-Value	p-Value
1.00	Alzahrani (2012)	1.762	1.055	2.942	2.165	0.030
1.00	Bogren (1984)	0.849	0.384	1.878	-0.404	0.686
1.00	Bruser (1981)	3.255	1.781	5.950	3.835	0.000
1.00	Dagenbach et al. (1988)	0.824	0.483	1.405	-0.712	0.476
1.00	Harris & Fitzgerald (1985)	1.040	0.522	2.073	0.111	0.911
1.00	Harris et al. (2000)	1.303	0.882	1.926	1.329	0.184
1.00	Harris et al. (2001)	0.912	0.490	1.699	-0.289	0.772
1.00	Harris et al. (2006)	0.834	0.479	1.452	-0.641	0.521
1.00	Manning & Denman (1994)	1.773	1.522	2.065	7.349	0.000
1.00	Manning (1991)	1.769	1.444	2.167	5.509	0.000
1.00	Nakamichi & Takeda (1995)	1.420	1.224	1.646	4.638	0.000
1.00	Turnbull & Lucas (1996) 1	0.570	0.203	1.599	-1.068	0.286
1.00		1.365	1.133	1.644	3.273	0.001
2.00	Bourne & Todd (2004)	0.611	0.138	2.708	-0.648	0.517
2.00	Matheson & Turnbull (1998)	5.909	1.546	22.580	2.597	0.009
2.00	Turnbull & Lucas (1996) 2	3.117	0.951	10.220	1.876	0.061
2.00	Turnbull et al. (2001) 1	0.507	0.124	2.075	-0.944	0.345
2.00	Turnbull et al. (2001) 2	3.304	1.067	10.226	2.073	0.038
2.00	van der Meer & Husby (2006) (Adults)	6.566	4.354	9.902	8.977	0.000
2.00	Vauclair & Donnot (2005)	0.759	0.419	1.373	-0.912	0.362
2.00		1.994	0.774	5.136	1.429	0.153
Overall		1.384	1.153	1.662	3.487	0.000

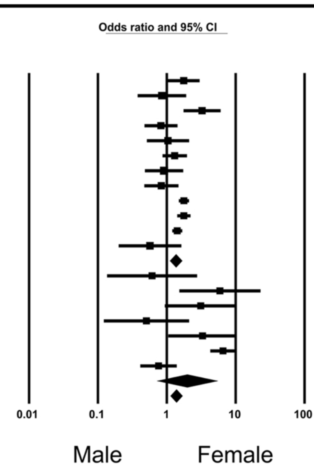


Fig. 11. Forest plot depicting the difference in cradling bias between males and females divided by child cradling (1) or doll cradling (2). The structure of the plot is identical to Fig. 9.

4.5. Concluding remarks

Cradling represents a crucial bonding mechanism between parent and child. As such, it is of central importance for human development and socialization (Jones, 2017). Therefore, understanding the biological determinants of cradling is of pivotal interest both for understanding the nature of human social behavior and the influence of social touch as well as for research on functional lateralization. Getting reliable and replicable data on the basic distribution of left and right cradling preferences and factors influencing such preferences is key for correctly interpreting results of all studies investigating this phenomenon since neuroscience and psychology continue to suffer from a massive replication crisis (Button et al., 2013). Especially in laterality research, progress has been markedly slow to achieve a comprehensive understanding of the neural mechanism of functional asymmetries such as handedness and language lateralization due to severely underpowered studies. Cradling research has been demonstrated to suffer from the identical methodological shortcomings resulting in problems of replication or overestimation of spurious effects due to low sample sizes. Using meta-analysis, we were able to illuminate research questions that have been investigated for almost 60 years, but never conclusively been answered indicating the power of meta-analytic approaches.

The finding of the relationship between handedness and cradling lateralization being akin to the relationship between handedness and language lateralization is of particular interest. To this day, the ontogenetic factors determining asymmetries of the nervous system remain poorly understood (Güntürkün and Ocklenburg, 2017; Ocklenburg and Güntürkün, 2018). This gap in knowledge has been addressed recently by investigating the genetic and neural basis of handedness and language lateralization (de Kovel and Francks, 2019; Ocklenburg et al., 2014; Schmitz, Metz, Güntürkün, and Ocklenburg, 2017; Schmitz, Lor, Klose, Güntürkün, and Ocklenburg, 2017), but the lack of data on this topic is still striking. A thorough understanding of the associated genetic and epigenetic basis of cradling laterality could potentially illuminate on this research question as it provides a phenotype that has so far been neglected in neuroscientific research on the ontogenesis of functional asymmetries.

4.6. Summary and outlook

We could verify and accurately estimate the extent of the left-side cradling bias within the population (ranging between 66% and 72%). Furthermore, handedness and sex could be demonstrated to be significant factors influencing the cradling bias with males and left-handers exhibiting a lesser bias compared to females and right-handers, respectively. Future studies should focus on other potential contributing factors such as the emotional context of the cradling dyad as well as genetic factors influencing the cradling bias. Furthermore, more comparative research should be conducted in non-human primates to achieve a comprehensive understanding of the underlying mechanisms of the cradling bias.

Acknowledgements

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