Journal of Experimental Child Psychology 260 (2025) 106340

Contents lists available at ScienceDirect

Journal of Experimental Child Psychology

journal homepage: www.elsevier.com/locate/jecp

From social inhibition in childhood to social facilitation in adulthood: How social presence systematically enhances the predominant response strategy in cognitive tasks

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ARTICLE INFO

Keywords:
Developmental trajectory
Response strategies
Social influence
Bimodal RT distributions
Coaction

ABSTRACT

This study investigated the developmental trajectory of social facilitation and inhibition across 207 participants aged 8–22 in numerosity and phonological comparison tasks. Tested alone or in coaction with a familiar age-matched partner, younger participants exhibited social inhibition on reaction times (RT), while a shift toward facilitation occurred around ages 13–14. Analysis of individual RT distributions revealed that social presence modulated predominant response strategies: younger participants used slower, reactive strategies, while older participants employed faster, anticipative ones. By enhancing the strategy predominating in each age group, social presence led to social inhibition in children and early adolescents, but social facilitation in mid-adolescents and adults. There was no influence of the partner's presence on accuracy, suggesting that while social presence modulated this predominant response, the presence of a partner did not impact the task performance in terms of correct answers. Together, these findings challenge Zajonc's "dominant response" theory, suggesting that social presence affects overall decision-making strategies.

Introduction

Social facilitation and inhibition (SFI) effect refers to the positive or negative influence of someone else presence on our own performance. This phenomenon has been described across various basic behaviors (e.g., moving, dressing or eating) and cognitive skills (e.g., perceptual and attentional abilities, decision-making, memory, executive functions), and has been the subject of extensive literature since the late 19th century (Baron et al., 1978; Zajonc, 1965; Zajonc et al., 1969). While studies exploring human behavior in general—and the SFI effect in particular—have historically focused on young adults, primarily university students, there has been a growing recognition of the importance of studying younger populations. At the time of their publication, classic references in the literature, such as Guerin's book (2010) and Bond and Titus's *meta*-analysis (1983), indicated that children and adolescents were underrepresented among studies investigating the effect of social presence. Indeed, only 3 to 6 % of published studies focused on this

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https://doi.org/10.1016/j.jecp.2025.106340
Received 5 December 2024; Received in revised form 23 June 2025;
Available online 3 July 2025
0022-0965/

age group at the time (Guerin, 2010; Bond & Titus, 1983). However, since a decade or so, there has been a growing interest for studying effects of SFI on children and adolescents (Albert et al., 2013; Telzer et al., 2017; Tricoche & Caspar, 2024; van Hoorn et al., 2019). However, this has been specifically directed towards certain behaviors. For example, studies have investigated effects of SFI in contexts which are relevant to combat childhood obesity, such as food consumption (Bevelander, Lichtwarck-aschoff, Anschütz, Hermans, & Engels, 2013a; Bevelander, Meiselman, Anschütz, & Engels, 2013b; Drewett, 2007; Engelmann, Herrmann, & Tomasello, 2015; Lumeng & Hillman, 2007; Salvy, Kieffer, & Epstein, 2008) and active versus sedentary activities (Barkley et al., 2014; Coppinger et al., 2010; Gonzales et al., 2019; Kieffer, 1977; Rittenhouse et al., 2011; Salvy et al., 2009; Siegmund et al., 2014). Together, these studies showed that the presence of others can positively influence consumption habits and physical effort, even if different factors might affect these effects (e.g., type of peer, whether an individual is obese or not…). Other studies have focused on risky decision-making in adolescents to better understand deviant behaviors during this developmental stage (Chein et al., 2011; Gardner & Steinberg, 2005; Hoffmann et al., 2018; Reniers et al., 2017; Smith et al., 2018; Somerville et al., 2019; Telzer et al., 2015, 2017; van Hoorn et al., 2018). Overall, this literature indicates that peer influence is stronger in adolescents than in adults, leading to an increase in risk-taking decisions when others are present, regardless of whether the associated reward is monetary or not. At the neural level, this is reflected in heightened activity in brain regions associated with reward processing, particularly the ventral striatum, in the presence of peers (Chein et al., 2011). Interestingly, social effects on adolescents are observed across various types of social presence but appear to be more pronounced when the presence is that of a peer rather than a parent (van Hoorn et al., 2018). These social effects can even be opposite depending on the type of presence. Indeed, Telzer et al. (2015) showed that the presence of a mother reduced risk-taking and encouraged safer decision-making by decreasing the rewarding nature of risky choices and enhancing activity in brain regions related to self-control (Telzer et al., 2015). Together, these findings reflect the unique developmental stage of adolescence, during which sensitivity to peers is particularly heightened. However, a recent *meta*-analysis found a small size of the effect of peer observation—whether the peer was familiar or not—on risk-taking decisions in adolescents, except when the peer was actively engaged in the decision-making process and expressed a preference for risky choices (Powers et al., 2022). Importantly, this synthesis focused on the SFI effects on choice outcomes (risky or not) rather than on the decision-making process itself, including its underlying neural networks. This distinction is particularly relevant to the present study, as the presence of a partner may influence the cognitive processes leading to a decision (e.g., the time taken or the strategy used to make the decision) without necessarily affecting the decision outcome or overall performance (accuracy).

While the issues discussed above (i.e., childhood obesity, risk taking) have major societal relevance, it is surprising that the effects of social influence on cognitive skills and academic knowledge remain relatively understudied in children (Bouhours et al., 2021; Camarda et al., 2021; Dumontheil et al., 2016; Tricoche et al., 2021; Tricoche et al., 2023a; Wolf et al., 2015), given that children spend most of their daily lives at school where they learn among peers and are heavily influenced by them.

One reason effects of SFI in the context of academic learning are understudied could be that schooling covers a wide developmental

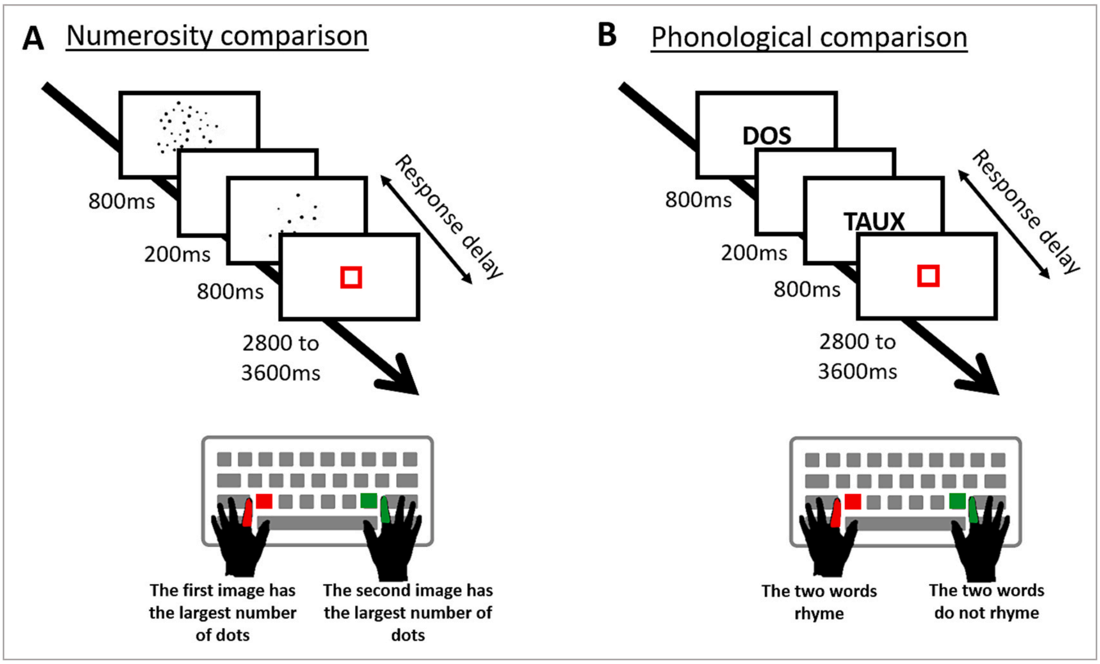


Fig. 1. Trial's temporality for Numerosity comparison (A) and Phonological comparison (B). Stimuli were presented successively during 800 ms with a 200 ms in-between interval. Participants made their decision by pressing one of two possible keys. They could respond as soon as the second stimulus appeared, but before the red square (displayed for a randomized duration) disappeared ('Response delay'). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

timespan and that the developmental trajectory of SFI effect remains largely unknown. To our knowledge, no study has compared children, adolescents, and adults on a continuum to evaluate the development of this basic form of social influence. Indeed, most studies have focused on a single population. Those having compared two age groups (Bouhours et al., 2021; Camarda et al., 2021; Chein et al., 2011; Dumontheil et al., 2016; Gardner & Steinberg, 2005; Haddad et al., 2014; Rosen et al., 2016; Ross et al., 2016; Somerville et al., 2019; Tricoche et al., 2021, 2023a) have overall reported an increase of SFI in younger participants as compared to adults. However, they assessed the SFI effect of cognitive functions in adolescents (or children: Rosen et al., 2016) compared to adults in many different tasks: risk-taking tasks (Chein et al., 2011; Gardner & Steinberg, 2005; Haddad et al., 2014; Ross et al., 2016; Somerville et al., 2019), problem-solving tasks (Bouhours et al., 2021; Camarda et al., 2021; Dumontheil et al., 2016) or numerosity and phonology tasks (Tricoche et al., 2021, 2023a). Further, these studies widely differed by the types of partner (familiar vs peer vs expert) or partner relationships (simple presence/observation vs coaction vs evaluation/judgement) or by the affective levels engaged (affective arousal). Therefore, the current body of empirical knowledge regarding the effect of age on SFI remains quite restricted and un-conclusive, as well as lacks investigations of the whole developmental trajectory. It is thus crucial to determine how and to what extent SFI effect evolves with age.

In the present study we explored the entire developmental trajectory of effects of SFI on participants from the age of 8 to the age of 22, using two tasks that are relevant in the context of academic learning and require participants to compare the numerosity of sets of dots and the phonology of words (stimuli were sequentially presented in both cases, see Fig. 1). In the numerosity comparison task, participants had to decide which set contained the larger number of dots, and in the phonological comparison task, they had to decide whether the two words rhymed or not. Participants performed these tasks alone or in a coaction situation (i.e., both participants doing the same task at the same time) with a familiar age-matched partner (i.e., friend, sibling, life partner or close colleague). A main goal of the present study was to extend the developmental findings from a previous study conducted in 8- to 10-year-olds and young adults. In that study, similar numerosity and phonological tasks were used and showed a social facilitation in both tasks, though the effect was stronger in children than in adults (Tricoche et al., 2021). Here we proposed to recruit an additional group of participants (adolescents 11- to 19-year-old) and used a complementary analysis method to identify the developmental changes of performance and processes modulated by social presence. Specifically, in the present study we investigated the strategy adopted by participants to make their decision in these tasks, both of which involve the sequential presentation of two stimuli (i.e., the first stimulus–a set of dots or a word–is presented and then disappears before the second one–another set of dots or another word–appears). Indeed, to perform these tasks, individuals were previously found to adopt either an 'anticipative' strategy that was relatively fast or a 'reactive' strategy that was slower (by 500 to 600 ms), without difference in accuracy (Tricoche et al., 2023b). Individuals tended to respond either around 500–600 ms or around 1000–1100 ms, with few responses falling in between, as revealed by a bimodal pattern of the group RT distribution. This substantial gap between the two types of performance suggested two distinct strategies rather than mere variations in response time along a slow-to-fast continuum of individual subjects (unimodal group RT distributions should be seen in this alternative case). More precisely, the reactive or "wait-and-see" strategy may involve a cautious evaluation of past events (in this case, Stim-A) to update and integrate new information (Stim-B) before making a well-informed decision. In contrast, the anticipatory strategy may rely on predicting future events (Stim-B) based on the currently available information (Stim-A), allowing for a faster decision at the cost of increased uncertainty and risk. This anticipatory strategy, with or without social context, was more frequently observed in adults than in children or adolescent (Tricoche et al., 2021, 2023b). Here, we predicted that partner presence might lead to a social facilitation by favoring the adoption of the anticipative strategy in children, helping them to reduce their developmental gap as compared with adults' performance. In fact, in 2021, Tricoche et al., asked children aged 8–10 and adults aged 18–32 to complete numerosity and phonological comparison tasks, and found that participants of both groups, but particularly children, responded faster in a social context (coaction condition) as compared to alone, without any loss in accuracy. For these tasks, mastered around 9–10 years old (Phillips et al., 2008; Starr et al., 2013), the positive social effect on the decision time was found whatever the trial difficulty (easy or hard). More precisely, children were not only faster but also exhibited less variability in response initiation, with a greater proportion adopting an anticipatory strategy. We hypothesized to find similar results in the present study with a social facilitation effect improving the adoption of the fast strategy in children, for both tasks and whatever the trial difficulty. Moreover, a developmental effect was previously found on the preferred strategies adopted by individuals (Tricoche et al., 2023b). If social presence promotes the adoption of an anticipatory strategy regardless of age, then for adolescents—who exhibit a more balanced distribution between the two strategies (Tricoche et al., 2023b)—the proportion of anticipatory profiles should, like children, increase to the detriment of reactive profiles, in the coaction context. Conversely, among adults, who already predominantly use this optimal strategy, the positive effect of social presence should be more limited.

Methods

Participants & sample size justification

Two hundred and seven participants from 8 to 22 years old (113 females, mean age 15.81 years +/- 4.11) were recruited via social network advertising. All participants were native French speakers, without any psychiatric or neurological disorders. The study received approval from the local ethics committee (CPP Sud Est II Ethics Committee) on November 7, 2018 (ClinicalTrials.gov

Identifier: NCT03453216) as well as by the Institutional Review Board of the INSERM (protocol code 15–282-ter, date of approval: 19 December 2018). All participants, or their parents for participants under 18, signed an informed consent. Each participant received a 10 € compensation for their time.

To explore the developmental trajectory of effects of SFI, we divided participants into five age groups: 27 children (8–10 years), 43 young adolescents (11–13 years), 50 middle adolescents (14–16 years), 28 late adolescents (17–19 years), and 58 young adults (20–22 years) (see Table 1 for sample size and demographic information per group). To assign participants to age groups, we adhered to standard classifications (Powers et al., 2022; World Health Organization, n.d), with our focus on defining age groups rather than inferring strict developmental differences between them. Moreover, as detailed in our subsequent analyses, we mainly investigated age as a continuous variable to capture the overall developmental trajectory from 8 to 22 years.

Data from the fifty-eight participants in the young adult group and from eleven participants in the late adolescent group were previously analyzed and contributed to the results reported in Tricoche et al., 2021 (Tricoche et al., 2021). For these participants, the exact age in days was not collected (we only collected their birth year). Thus, we decided to estimate their age in days (a measure for some of our analyses, see below), by using the middle of the year as reference for each participant (e.g., a participant having 20 years: 20.5 years converted in 7483 days; a participant having 21 years: 21.5 years converted in 7848 days, etc.).

Using G*Power, we conducted post-hoc power analyses to determine the achieved statistical power for our sample size of 207 participants with an alpha level (α) of 0.05. Assuming a low-to-medium effect size, which is commonly reported in the literature of SFI effect (see, for instance, Tricoche et al., 2021, with a comparable design), we obtained the following power estimates: 1) 99 % for the Age x Condition x Task x Difficulty within-between ANOVAS ($f = 0.17$ or $\eta_p^2 = 0.03$), 2) 96 % for the segmented regression model analyses ($f^2 = 0.08$), and 3) 62 % for the Chi-square tests ($V = 0.2$, $df = 4$). In our study, effect sizes V for the Chi-square tests ranged between 0.17 and 0.36, then suggesting that these analyses are slightly underpowered.

Social context

Participants were tested in a coaction condition or alone. In the coaction condition, participants were recruited by pairs, as friends, siblings, life partners or close colleagues. The two members of each pair were matched in age (age difference ≤ 3 years) and gender. They completed the seven-point Inclusion of the Other in the Self (IOS) scale (Gächter et al., 2015) in order to evaluate the subjectively perceived closeness of their relationship. The mean score obtained was of 5.73 (standard deviation: ±1.32), which confirmed an overall close relationship. The members of the duo were seated side by side, each facing a computer screen and a keyboard, and completed the same tasks at the same time. Both members of the duo were included as participants, each one being the familiar partner of the other (coaction situation). As trials order was randomized, the two partners completed a different version of the task. They were instructed to focus on their computer screens throughout the session, and to refrain from speaking and assisting each other.

In the alone condition, participants were tested alone in the experimental room. In both conditions, at the beginning of the experiment, after giving all the instructions, the experimenter left the experimental room. One hundred and twelve participants were tested in the coaction condition and 95 participants were tested in the alone condition. One participant was excluded from the analyses as one of our main measures of interest, age, was not reported in the dataset. Group composition is reported in Table 1

Tasks & stimuli

Participants completed the same two tasks that were previously used in Tricoche et al., 2021 (Tricoche et al., 2021) and based on previous studies (Prado et al., 2011; Prado, Mutreja, & Booth, 2014). The first task was a numerosity comparison task, in which participants decided which of two sequentially displayed dots arrays contained the largest number of dots. The second task was a phonological comparison task, in which participants decided if two words appearing sequentially rhymed or not. These tasks were chosen for several reasons. First, they involve cognitive skills related to school education, specifically numeracy and literacy skills. Moreover, since the two tasks involve different cognitive processes and are mastered at different developmental stages (Ehri et al., 2001; Hyde et al., 2014; Phillips et al., 2008; Prado et al., 2011; Starr et al., 2013), it is important to us to examine whether social presence influences them in the same way. Second, we aimed to replicate the findings from Tricoche et al. (Tricoche et al., 2021) by using the same tasks to ensure consistency and comparability. Finally, the design of these sequential tasks initially allowed to study

Table 1
Number of participants (N) in each age group according to the condition (coaction, alone), as well as their mean age (and standard deviation, sd) and gender repartition. IOS scores are also reported for the Coaction condition.

	Coaction condition				Alone condition		
Age sub-group	**N**	**Mean age ± sd**	**Gender Male − Female**	**Mean IOS score ± sd**	**N**	**Mean age ± sd**	**Gender Male − Female**
8-10y	15	9.06y ± 0.82	9—6	5.87 ± 1.41	12	8.61y ± 0.64	4—8
11-13y	19	12.69y ± 0.65	6—13	5.27 ± 1.67	24	12.62y ± 0.57	12—12
14-16y	32	14.84y ± 0.75	18—14	5.67 ± 1.49	18	14.72y ± 0.80	8—10
17-19y	12	18.08y ± 0.86	7—5	5.83 ± 1.19	16	17.94y ± 0.66	9—7
20-22y	33	20.85y ± 0.70	11—22	5.91 ± 0.98	25	21y ± 0.80	9—16
	= 111				= 95		

decision-making strategies. Thus, we sought to replicate both the social effect on decision-making strategies observed in Tricoche et al., 2021 (Tricoche et al., 2021) and their developmental effect reported in Tricoche et al. (2023b).

The trials time line is shown in Fig. 1. All sub-groups completed the same version of the tasks, each composed by 144 trials.

Dot arrays used for numerosity comparison contained 12, 18, 24 or 36 dots. Differences in cumulative surface areas and distribution of dot sizes were both controlled for each pair of dot arrays (Gebuis & Reynvoet, 2011). Difficulty was varied according to the ratio between the two dots arrays, from easy trials with a ratio comprised between 0.33 (e.g., 12 versus 36 dots) and 0.5 to hard trials with a ratio comprised between 0.67 (e.g., 24 versus 36 dots) and 0.75.

Words used for phonological comparison contained 1 or 2 syllables and 3 to 8 letters, with similar frequency in French language as assessed by the New and Pallier's dictionary (New et al., 2001). Difficulty was varied by manipulating orthography and phonology between the two presented words. In easy trials the two words had congruent orthography and phonology (both same, e.g. dix-six [dis-sis] or both different, e.g. jeu-doux [ʒoe-du]), whereas in hard trials orthography and phonology were incongruent (e.g. dos-taux [do-to] or tapis-iris [tapi-iris]).

Stimuli were presented in a pseudorandomized order, mixing both numerosity and phonological comparison tasks together in the same block of trials (i.e., no more than three successive trials of the same difficulty or task was presented).

Analyses

Frequentist statistical analyses were conducted using RStudio (v.4.0.0). We measured for each task and difficulty level the global accuracy as the proportion of correct responses relative to the total number of decisions (%Corr), then we measured the reaction time of each correct response (RT) as the delay between the second stimulus appearance and the key press. We conducted 5 X 2 X 2 X 2 ANOVAs, with Age (8-10y, 11-13y, 14-16y, 17-19y, 20-22y) and Condition (Coaction, Alone) as between-subject factors, and Task (Numerosity, Phonology) and Difficulty (Easy, Hard) as within-subject factors. Post-hoc comparisons were conducted through two-sample Student's t tests with FDR corrections. Effect sizes were reported using partial eta squared values (η_p^2). Frequentist statistical analyses were complemented by Bayesian statistics, calculating the Bayes Factor inclusion (BF_{incl}), using JASP (v.0.10.2). Extreme, strong, moderate or anecdotal evidence for the null hypothesis (H0) were qualified for a BF_{incl} < 0.001, < 0.01, < 0.33, <1

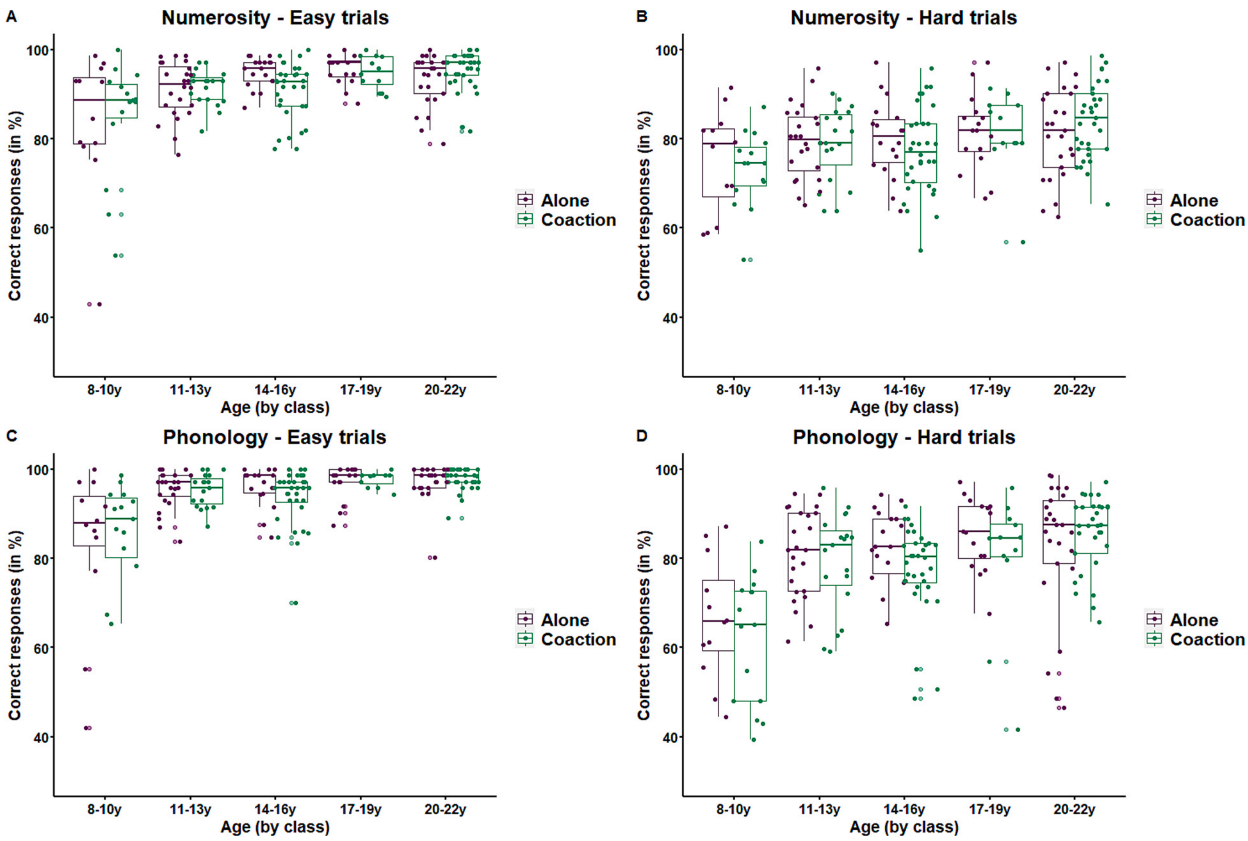


Fig. 2. Accuracy expressed in %Corr according to the Age (by class), Condition (alone in purple, coaction in green), Task (A-B: numerosity; C-D: phonology) and Difficulty (A-C: easy trials; B-D: hard trials). Dots represent individual data, boxes show the medians, lower quartiles, upper quartiles and whiskers (±1.5*Inter-quartile range). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

respectively; whereas extreme, strong, moderate or anecdotal evidence for the alternative hypothesis H1 were qualified for a *BFincl* > 100, > 10, > 3 and > 1 (Keysers et al., 2020; Wagenmakers et al., 2018).

We also analyzed, separately for each task and each difficulty level, the relation between %Corr and Age (measured in days) as well as between RT of correct trials and Age, combining all sub-groups of participants in two superimposed scatter plots (coaction and alone condition). We then estimated the linear trend-lines ($y = bx + a$) for each condition (coaction and alone) using the least squares method. As reported in the Results part (for RT particularly), all 4 scatter plots (2 tasks x 2 difficulty levels) showed that the linear trend-lines intersected, indicating an age where the direction of the coaction effect changed. We adjusted to the %Corrr and RT data a segmented regression model (%Corr ~ Age*Condition and RT ~ Age*Condition) to estimate these age-breakpoints means and confidence intervals at 95 % (*CI*95) and to investigate if there was a significant difference in the relation between the %Corr or RT and the Age according to the Condition ('segmented' package on R). This segmented regression model analysis was justified as it allows to identify potential nonlinear and complex relationships between variables (Age and Condition), that cannot be assessed by ANOVAs which focus on average effects. It also provides a nuanced view of developmental transitions in SFI effect by identifying breakpoints. By conducting both analyses—one treating age as a categorical variable and the other as a continuous variable—we were able to compare the results and gain insights into the relevance of each approach. This combination allowed us to leverage the strengths of both methods: ANOVAs provided a structured overview of age group differences and interactions, consistent with prior research methodologies and facilitating their comparison; while the regression models captured more fine-grained, continuous age-related changes.

Finally, we computed the RT distributions of correct responses for each subgroup and each task, comparing the two conditions using a Kolmogorov-Smirnov (K-S) test. For the sake of clarity, we combined easy and hard trials, as our analyses revealed similar social effects. As we mainly obtained bimodal RT distributions at group level indicating two discrete strategies, we calculated the proportion of participants in each profile (fast or slow responders) using the method previously developed (Tricoche et al., 2021, 2023b) and detailed in Appendix A. We then conducted Chi-square tests with Yates continuity correction, comparing the proportion of fast and slow responders between the alone and coaction conditions, for the different ages and tasks separately. In addition to the X^2, we reported the Bayes Factor 10 (BF_{10}) and the effect sizes as estimated using Cramer's V (Cramér, 1946). Significance level was set at $p < 0.05$ for all frequentist analyses.

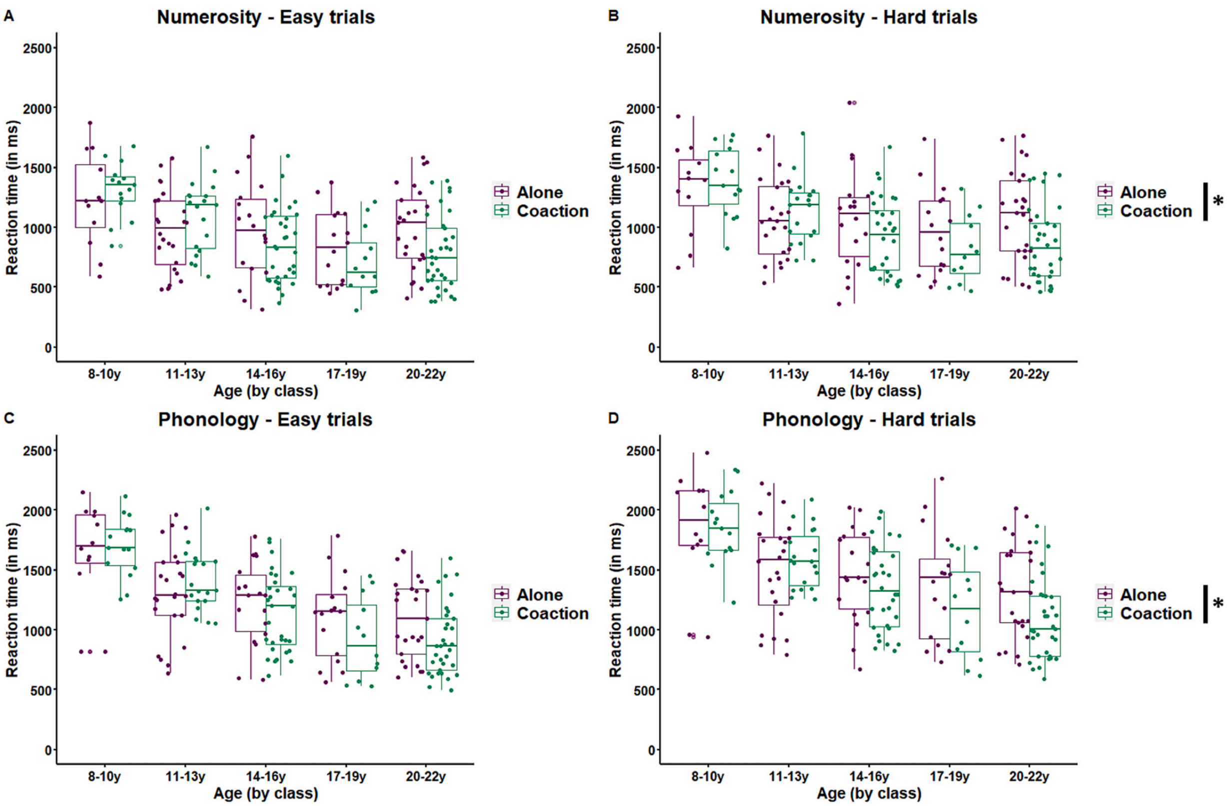


Fig. 3. RT expressed in ms according to the Age (by class), Condition (alone in purple, coaction in green), Task (A-B: numerosity; C-D: phonology) and Difficulty (A-C: easy trials; B-D: hard trials). Same conventions as in Fig. 2. A significant social facilitation was found by comparing alone (purple) and coaction (green) conditions, for hard trials (*: p = 0.01). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Results

Social effect on accuracy and RT

Accuracy

As illustrated in Fig. 2, the Condition x Age x Task x Difficulty ANOVA revealed a main effect of Age ($F(4, 196) = 22.37$, $p < 0.001$, $\eta_p^2=0.31$, $BF_{incl}>100$), Task ($F(1, 588) = 4.52$, $p = 0.03$, $\eta_p^2=0.008$, $BF_{incl}>100$) and Difficulty ($F(1, 588) = 742.07$, $p < 0.001$, $\eta_p^2=0.56$, $BF_{incl}>100$), but no Condition effect ($F(1,196) = 1.14$, $p = 0.29$, $BF_{incl}=0.05$). We also observed two significant interactions: Age by Task ($F(4, 588) = 7.47$, $p < 0.001$, $\eta_p^2=0.05$, $BF_{incl}>100$) and Difficulty by Task ($F(1, 588) = 6.57$, $p = 0.01$, $\eta_p^2=0.01$, $BF_{incl}=2.74$).

As expected, accuracy was higher on easy trials (mean %Corr ± SEM = 93.2 %±0.4 when averaging numerosity and phonology comparisons) than hard trials (79.5 %±0.5 when averaging numerosity and phonology comparisons). Contrary to previous studies, accuracy was a bit lower for numerosity (85.9 %±0.5 when averaging easy and hard trials) than phonology comparison (86.9 %±0.7 when averaging easy and hard trials) (Prado et al., 2011; Prado, Mutreja, & Booth, 2014; Tricoche et al., 2021, 2023a, 2023b). Overall, older participants were more accurate than younger participants (8-10y: 76.4 %±1.6; 11-13y: 86.5 %±0.8; 14-16y: 86.1 %±0.8; 17-19y: 89.3 %±1.0; 20-22y: 89.8 %±0.7). All post-hoc comparisons, including all interactions, are reported in Appendix B. Such post-hoc comparisons revealed that the Task by Difficulty interaction was driven by a difference in easy trials only; with no difference in hard trials. By considering a model without the Task factor (i.e., conducting ANOVAs for each task separately) we found results that are comparable to our single ANOVA including Task as a factor (see Appendix C).

Substantiating the absence of main Condition effect, no interaction was found with this factor, suggesting no social effect on accuracy.

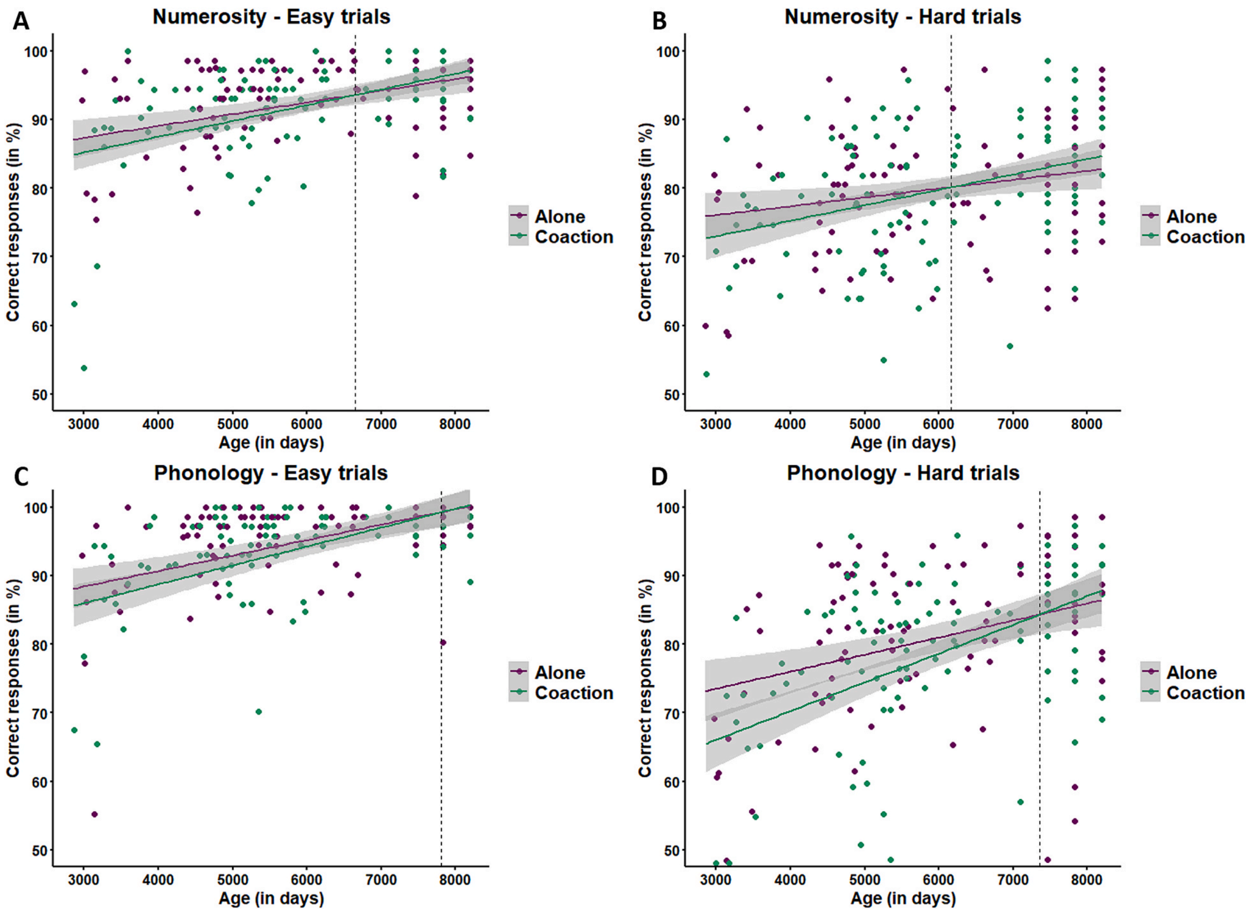


Fig. 4. Relation between the Age (in days) and the accuracy (in % of correct responses) according to the Condition (alone in purple, coaction in green), Task (A-B: numerosity; C-D: phonology) and Difficulty (A-C: easy trials; B-D: hard trials). The breakpoints estimated by the model are indicated (dashed lines). However, the segmented regression models showed no significant effect in each of the 4 situations, suggesting that the effect of Age on the %Corr is not modulated by the Condition. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

RT

As shown in Fig. 3, we found a significant main effect of Age ($F(4, 196) = 15.42$, $p < 0.001$, $\eta_p^2=0.31$, $BF_{incl}>100$), Task ($F(1, 588) = 1306.22$, $p < 0.001$, $\eta_p^2=0.69$, $BF_{incl}>100$) and Difficulty ($F(1, 588) = 285.99$, $p < 0.001$, $\eta_p^2=0.33$, $BF_{incl}>100$) on the RTs. Condition effect did not reach the conventional threshold for significance, and Bayesian analyses indicated anecdotal evidence toward H0 ($F(1, 196) = 3.86$, $p = 0.051$, $\eta_p^2=0.02$, $BF_{incl}=0.59$). Three interactions were significant: Age by Task ($F(4, 588) = 30.62$, $p < 0.001$, $\eta_p^2=0.17$, $BF_{incl}>100$), Difficulty by Task ($F(1, 588) = 46.48$, $p < 0.001$, $\eta_p^2=0.07$, $BF_{incl}>100$), and Condition by Difficulty ($F(1, 588) = 4.09$, $p = 0.04$, $\eta_p^2=0.007$, $BF_{incl}=0.61$).

In line with the accuracy results, easy trials elicited faster responses (1079.1 ms ± 19.7) than hard trials (1225.7 ms ± 21.8), and numerosity trials showed lower RTs (995.7 ms ± 18.0) than phonology trials (1309.0 ms ± 21.1). Older participants were faster than younger participants (8-10y: 1540.3 ms ± 39.2; 11-13y: 1258.2 ms ± 29.4; 14-16y: 1109.2 ms ± 28.1; 17-19y: 998.9 ms ± 38.1; 20-22y: 1004.6 ms ± 24.2). All post-hoc comparisons, including all interactions, are reported in Appendix B (except those involving the Condition factor which are reported in the following paragraph). These post-hoc comparisons revealed that the Task by Difficulty interaction corresponded to a higher RT difference between easy and hard trials for phonology than numerosity comparison. The Age by Task interaction suggested a later acquisition of phonological comparison (RT differences not reaching significance only between 17 and 22 years old participants) compared to numerosity comparison (RT differences not reaching significance between 14, 17 and 22 years old participants). By considering a model without the Task factor (i.e., conducting ANOVAs for each task separately) we found results that are comparable to our single ANOVA including Task as a factor (see Appendix C).

Concerning the main objective of our study, the Condition effect, despite not reaching statistical significance, was directed toward a social facilitation (coaction: 1111.2 ms ± 19.8; alone: 1200.5 ms ± 22.4). The interaction with the Difficulty factor was due to this social facilitation reaching significance only for hard trials, as revealed by post-hoc comparisons (easy: $p = 0.10$; hard: $p = 0.01$).

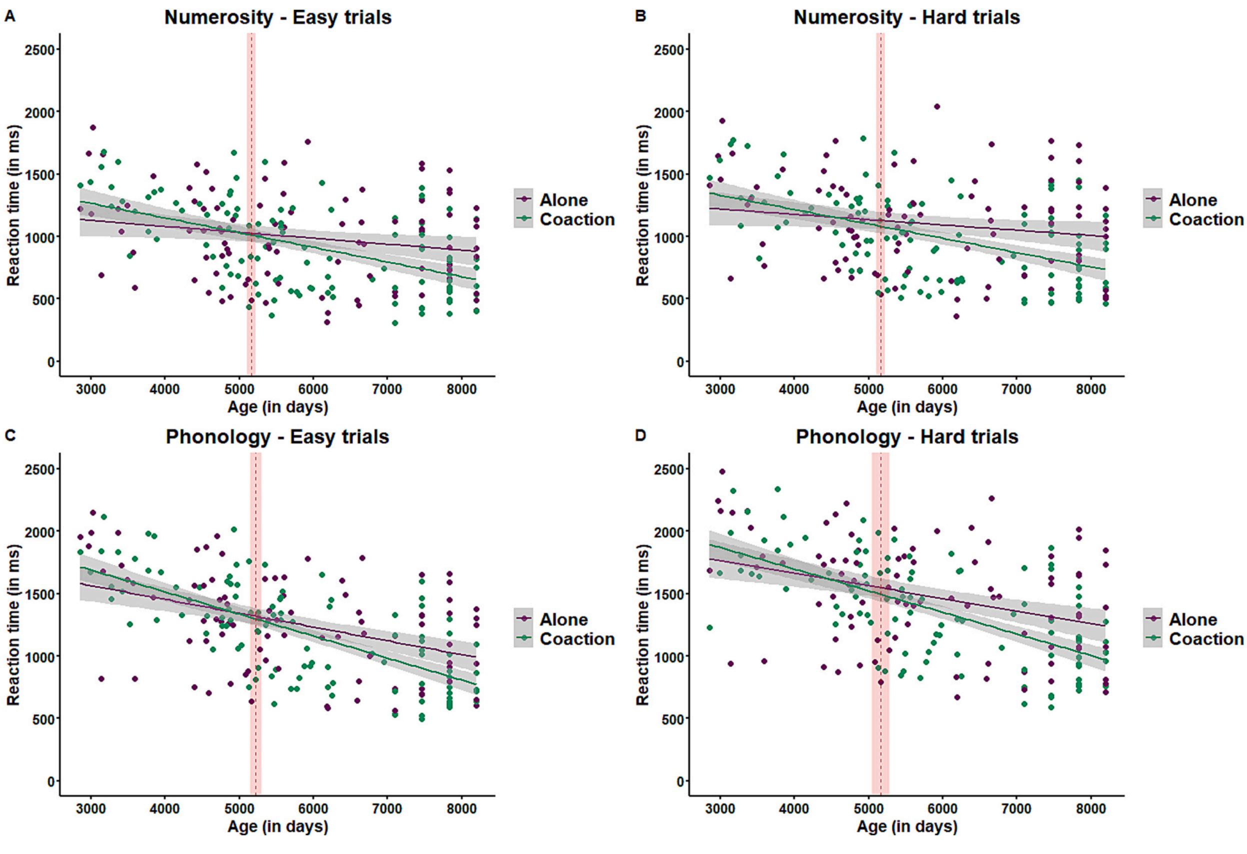


Fig. 5. Relation between the Age (in days) and the RT (in ms) according to the Condition (alone in purple, coaction in green), Task (A-B: numerosity; C-D: phonology) and Difficulty (A-C: easy trials; B-D: hard trials). The segmented regression models indicated a significant Age by Condition effect in each of the 4 situations, showing that the effect of Age on the RT is modulated by the Condition. Further, the direction of the social effect (inhibition/facilitation) changed around 5100–5200 days, as revealed by the estimated breakpoints (red dashed lines, with confidence intervals at 95 %). Note that the slight difference between the observed graphical intersection of the curves and the statistically determined values of breakpoint can be explained by the fact that the latter is affected by precision of statistical modeling, contrary to the former. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Analyses conducted for each task separately led to marginal Condition effect and interaction by Difficulty (see Appendix C).

The direction of social effect is modulated by age

Accuracy

We then investigated the relation between %Corr and age according to the social context. As illustrated in Fig. 4, the estimated segmented regression models did not show significant Age by Condition effects, irrespective of the task and the difficulty (t's = [1.37:1.77], p's = [0.08:0.17]). This suggests that the effect of Age on the %Corr was not modulated by the social Condition. This result corroborates the frequentist analyses, which revealed no social effect on %Corr.

RT

When investigating the relation between RT and age according to the social context, we found a developmental change in the direction of the social effect. As illustrated in Fig. 5, linear trend-lines intersected around 13–14 years old. This pattern indicates a social inhibition before 13–14 years (longer RTs in coaction than alone condition) and a social facilitation after this period (shorter RTs in coaction than alone condition), for both tasks and both trial difficulties. Applying a segmented regression model to the data for each task and difficulty level allowed us to estimate breakpoints falling in a narrow age-range [5150—–5220 days] for all 4 cases (Numerosity-Easy: 5159 days, *CI*95: ±56.35; Numerosity-Hard: 5159 days, *CI*95: ±57.69; Phonology-Easy: 5220 days, *CI*95: ±76; Phonology-Hard: 5159 days, *CI*95: ±118.3). Finally, contrasting with the ANOVA results reported above, the results of the segmented regression models indicated a significant Age by Condition effect (t's = [-2.53:-2.21], p's = [0.01:0.03]). Thus, this analysis which does not require pooling participants into different sub-groups, showed that the effect of Age on RT was modulated by the Condition, whatever the Task and Difficulty. Overall, we conclude that children under 13–14 years old were socially inhibited whereas older children were socially facilitated.

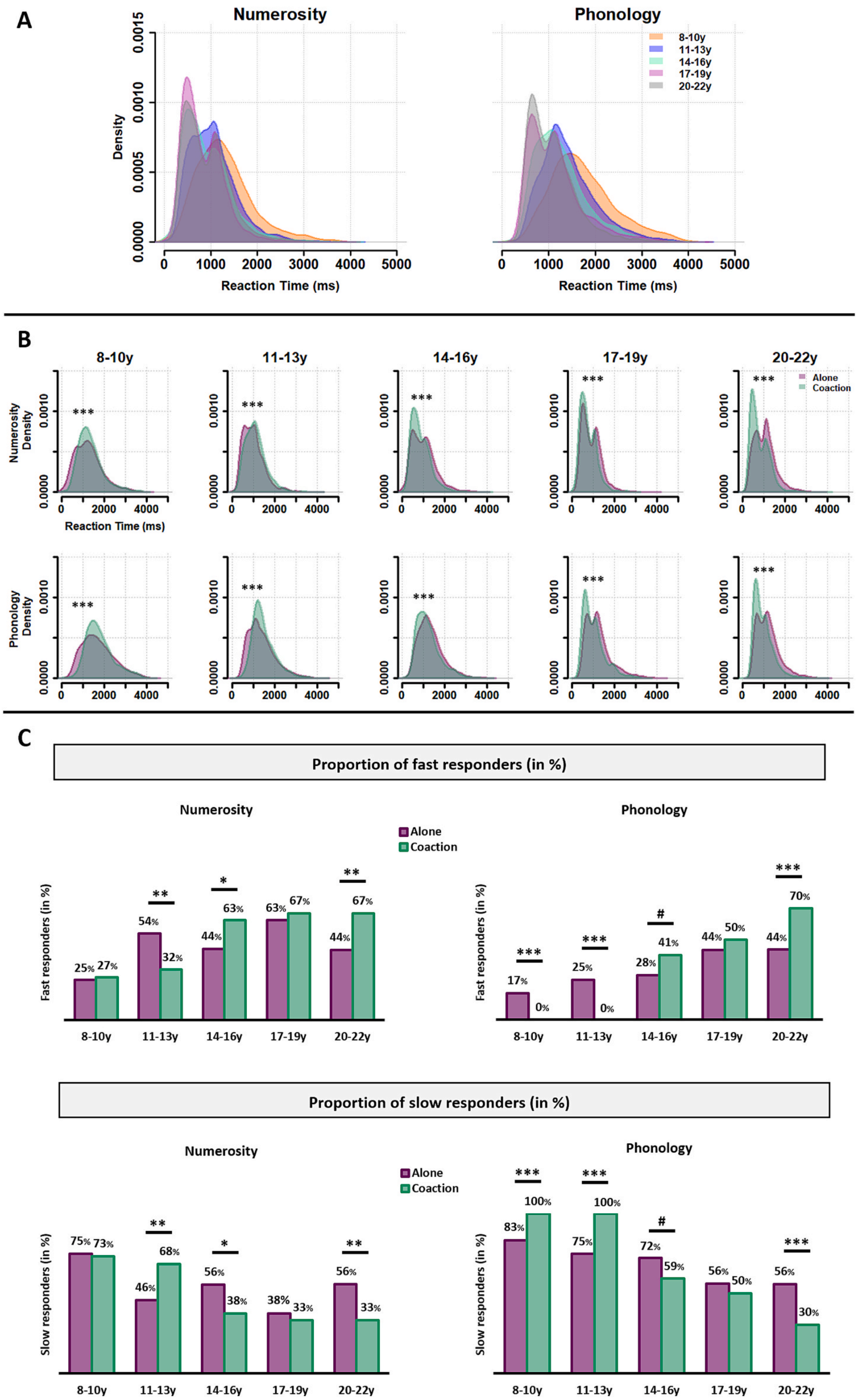
The social context improves the preferred strategy

To evaluate whether the strategies potentially used by participants could change according to age, tasks, or conditions, we plotted the RT distributions of correct responses in each age group and for both tasks. First, to focus on the developmental effect, we pooled the two social conditions together (Fig. 6A). These distributions were all bimodal (i.e., two peaks of density). This pattern, which is in line with previous studies (Tricoche et al., 2021, 2023b), is particularly conspicuous for older participants. Based on these bi-modal distributions at the group level, participants were classified in two profiles according to their individual RT distribution: participants who responded relatively fast (mean RT around 600 ms) and participants who responded relatively slowly (around 1,100 ms) (Appendix A). This distinction between fast responders around 600 ms and slow responders around 1,100 ms replicated previous results, as well as the observed developmental trajectory (Tricoche et al., 2021, 2023b). Indeed, while the youngest participants adopted preferentially the slow strategy, the number of fast responders increased with age, such that it becomes the predominant strategy in the 17 years old group (Fig. 6A).

Then, to test whether there was an effect of Condition, we plotted for each sub-group and each task, the ''alone'' versus "coaction'' distributions. Conducting K-S tests, we found that the ''alone'' distributions differed from the ''coaction'' distributions for all sub-groups in both tasks (D's = [0.10: 0.23], all p's < 0.001) (Fig. 6B). Using the method previously developed (Tricoche et al., 2021, 2023b) and detailed in Appendix A, we calculated the proportion of participants in each profile (fast responders, slow responders), and investigated for each task separately, if this proportion differed with the Condition according to the Age (Chi-square tests). For Numerosity, we found a significant effect of Condition on the proportion of fast and slow responders for the 11-13y ($X^2 = 9$, p = 0.003, V = 0.21, BF_{10}=1.04), 14-16y ($X^2 = 6.1$, p = 0.01, V = 0.17, BF_{10}=0.69) and 20-22y ($X^2 = 9.8$, p = 0.002, V = 0.22, BF_{10}=1.35). For Phonology, this Condition effect was found for the 8-10y ($X^2 = 16.46$, p < 0.001, V = 0.29, BF_{10}=1.91), 11-13y ($X^2 = 26.33$, p < 0.001, V = 0.36, BF_{10}=7.49) and 20-22y ($X^2 = 12.75$, p < 0.001, V = 0.25, BF_{10}=2.1), while being marginal for the 14-16y ($X^2 = 3.19$, p = 0.07, V = 0.13, BF_{10}=0.49) (Fig. 6C). Interestingly, and as illustrated in Fig. 6B&C, the direction of this social effect seemed to differ according to the sub-groups, favoring the slow strategy in younger participants (8 to 13 years), while improving the fast strategy in older ones (>14 years).

Discussion

In this study, we investigated the developmental trajectory of social presence effects in two judgment tasks (numerosity or phonology) involving a comparison of two items presented sequentially. We compared five age sub-groups, from childhood to adulthood, tested either alone or in a coaction condition with a familiar age-matched partner. Partners could be friends, siblings, life partners, or close colleagues. Duos had an equivalent level of closeness, as indicated by the IOS scale results. While partners type may influence social effect on behavioral outcomes differently, particularly in adolescents, existing literature suggests that such differences are more often linked to the type of the presence (e.g., mother vs. peer, familiar vs. unfamiliar, audience vs. evaluation) rather than the nature of the relationship with an age-matched partner (e.g., friend, sibling, colleague, life partner) (Bouhours et al., 2021; Powers et al., 2022; Salvy et al., 2008; Telzer et al., 2015; van Hoorn et al., 2018, 2019; Wolf et al., 2015). Notably, Tricoche et al. (2021),



(caption on next page)

Fig. 6. A: RT distributions of correct responses superimposed for the different Age sub-groups (colors) separately for Numerosity (left) and Phonology (right). B: RT distributions of correct responses superimposed for the alone (purple) and coaction (green) Conditions separately for the Age sub-groups (left-to-right) and for Numerosity (upper row) and Phonology (lower row). Two profiles of participants can be seen: fast (first peak of density around 600 ms) and slow (second peak of density around 1,100 ms) responders, with a developmental trajectory from the slow to the fast strategy. C: Proportion of fast (upper row) and slow (lower row) responders in the alone (purple) and coaction (green) condition, ranked according to the Age sub-groups separately for Numerosity (left) and Phonology (right). Even though the proportion of slow responders complements that of fast responders, both graphs are displayed for enhanced visual clarity. While the slow strategy dominates in younger participants (8 to 13 years), the fast strategy increases in older ones (>14 years) (#: $p < 0.08$; *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

using the same paradigm, found no significant difference in results based on the nature of the partner relationship (Tricoche et al., 2021).

When analyzed at the group level, without considering developmental differences, the coaction condition led in both tasks to a social facilitation on RT (but not on accuracy) for the hard trials. These findings only partially replicated findings from a previous study in the youngest and oldest subjects groups (Tricoche et al., 2021), then not fully supporting our hypotheses. Indeed, we previously found a social facilitation in these tasks for both groups of participants, and for both trial types (including easy trials). However, in our previous study, some of the children completed a simplified version of the tasks (i.e., less number of dots or less controlled stimuli in numerosity comparison). This might explain why, at the group level, they were facilitated by social presence across all trials. In contrast, in the present study, all participants completed a more difficult version of the task. This may have led to a more heterogeneous performance at first: while some participants (essentially the older participants) might have been mature enough to succeed at the required level, others (essentially the youngest participants) might not have fully developed the necessary skills. Consequently, the effect of social presence on RTs may have fluctuated between facilitation and inhibition depending on the participants' individual skill levels, which could not be fully captured in a group-level analysis. Thus, these results at the group level must be considered cautiously, especially as the segmented regression analysis of the effect of age (in days) and condition on RT led to a more nuanced pattern. Indeed, this analysis indicated that the social effect on RT was modulated by age, with a switch between social inhibition and social facilitation around 13–14 years old. This finding suggests an important age-dependent inter-individual variability: while the youngest participants are inhibited, older participants are facilitated by social presence. Camarda and collaborators (2021) also found a similar pattern of social influence on a creativity task, with a social inhibition in early adolescents (11 years old) and a social facilitation in middle adolescents (15 years old) (Camarda et al., 2021), suggesting that a switch can occur in several cognitive tasks. This age-dependent variability may be further amplified when considering different contexts that could modulate the observed effects. For example, Bouhours et al. (2021) demonstrated that an evaluative presence leads to greater attentional distraction in adolescents compared to adults during an emotional Stroop task, ultimately resulting in better inhibitory control (Bouhours et al., 2021). This indicates, in line with other studies, that both the type of task and the nature of the presence interact with the developmental time-course of social influence. Therefore, the shift observed in the present study may occur at different ages depending on the context in which performance is measured. In particular, for adolescents, the presence of evaluators or parents could have stronger effects—either enhancing or impairing performance. This is supported by a report from Wolf et al., indicating that performance in a relational reasoning task is influenced by the participant's age (younger vs. older adolescents vs. adults), the type of presence (evaluation by a friend vs. an experimenter), and the task complexity (low vs. high reasoning level) (Wolf et al., 2015). Additionally, research by Telzer and colleagues highlights specific neural activity modulations depending on whether the presence is that of a parent, a close peer, or whether the individual is alone, ultimately leading to performance changes (Telzer et al., 2015; van Hoorn et al., 2018). Moreover, while the question of how different familiar figures—such as siblings versus friends—might differentially modulate social influences is indeed relevant, the literature on this issue remains scarce, particularly in younger age groups. Among the few studies that have addressed this question, a systematic review found no consistent difference of social influence between siblings and friends in the context of eating behavior (Ragelien & Grønhøj, 2020). That review also reported mixed findings—both positive and negative influences—even within the same category of social presence, making it difficult to generalize conclusions across different behaviors or forms of social influence. Similarly, another study suggested that the influence of siblings and peers on substance use in adolescents may vary depending on cultural background, with effects that can be either similar or distinct (Rowan, 2016). However, these studies were mainly concerned with interactive forms of social influence involving direct social interactions. To our knowledge, no study has specifically investigated the distinction between siblings, friends, or other relevant partners in the context of SFI effect. In the present study, the heterogeneous and uneven distribution of partner types prevented us from controlling for this factor or evaluating it systematically. Further studies will be necessary to systematically examine the interaction of these factors and their relative influence across development. Ultimately, this will contribute to a deeper understanding of social learning environments in schools and the impact they may have on the acquisition of academic skill. Moreover, a notable limitation of this study is the precision of age measurement for participants over 20 years old (as well as a few participants aged 18–19). For this subgroup—initially recruited for a previous study—we only recorded their birth year and subsequently estimated their age in days (see Method section). This approach reduced variability within the subgroup and partially altered the overall age distribution, potentially introducing measurement error in our analyses, particularly in breakpoint estimation. Nonetheless, we opted to include this age category because it enhances the representativeness of the sample by spanning the full developmental curve and capturing its overall trends. This method also provided preliminary evidence warranting further investigation. Future studies should ideally collect precise age data across all groups, which would allow for a more accurate identification of the specific age range at which the transition from social inhibition to social facilitation occurs.

Another limitation worth noting is that participants in the coaction condition were paired with familiar partners, which may introduce a degree of similarity between dyad members—for instance in terms of cognitive abilities, motivation, or response style. Such similarity could potentially reduce variability within dyads and lead to clustering effects that were not accounted for in the present analyses. While the IOS scale confirmed comparable closeness across pairs, future studies should consider modeling potential dyadic dependencies statistically (e.g., with multilevel approaches) or include control conditions with randomly paired individuals.

Furthermore, a critical contribution of our study, based on the analysis of RT distributions, is that the difference in the direction of the social effect might be due to an improvement in the participants' predominant response strategy. Based on our previous findings, we initially predicted that the social context in our task would facilitate performance by promoting the adoption of the anticipative strategy—optimal for its faster responses without cost on accuracy—across all age groups. However, our results revealed that social presence could influence both strategies, particularly reinforcing the one that is predominant for each age group. Nonetheless, the sensitivity analysis we conducted indicated that the Chi-square tests (leading to effect sizes ranging between 0.17 and 0.36) may have been slightly underpowered (power estimate = 62 %), and these results should be interpreted with some caution and require replication in future studies. For the youngest participants, the predominant strategy was to produce relatively slow responses, whereas older participants adopted the optimal fast strategy. (Tricoche et al., 2023b). Social presence may drive the cognitive system and lead participants to focus on the most appropriate way to succeed in the task. Our proposal is that by improving the predominant strategy used by participants, partner presence led to social inhibition in children and young adolescents (<13–14 years) and to social facilitation in mid-adolescents and adults. This interpretation aligns with and complements Zajonc's seminal theory therein social presence increases the probability of the dominant response, which is the most probable or common response during the performed task (Zajonc, 1965; Zajonc et al., 1969). While Zajonc's physiological perspective primarily focuses on an arousal modulation origin of social facilitation/inhibition effects, our findings suggest a broader perspective of social influence. Instead of simply inducing moderate changes of the reaction time (~a few tens of msec) of dominant responses through increased arousal, we revealed a global change in the participants' response strategy, and hence of the decision-making process, ultimately resulting in a substantial modification of response time up to several hundred milliseconds. This suggests a more comprehensive strategic adjustment due to social context rather than a mere reflexive response driven by heightened arousal. In Tricoche et al., 2023b, it was proposed that the fast strategy could be associated with an anticipatory process which develops with age in relation with the growing capacities of working memory (Adam et al., 2012; Chen et al., 2007; Swensson & Edwards, 1971); it was also argued that young children, on the other hand, adopted a more reactive and cautious strategy, waiting for the second stimulus appearance before making a decision with a high degree of certainty (see also Hedge et al., 2019). The lower working memory abilities in individuals before thirteen years old (Van Duijvenvoorde et al., 2012) could be a potential explanation of why they preferentially adopted the reactive strategy. Thus, this developmental factor may also help to account for the presently-observed inhibition before this period of age and switch to facilitation later on.

Interestingly and contrary to the present results, it was previously found that social presence helped children to adopt the fast strategy, allowing them to become more ''adult-like'' in their behavior (Tricoche et al., 2021). This difference between the two studies could be explained by the adapted difficulty in this previous study where children completed a simplified version of the task, in numerosity comparison particularly. This adaptation possibly enhanced their ability to adopt a fast strategy for this very well mastered task. More specifically, both task versions (the simpler one used previously, with fewer dots and less controlled stimuli, and the more complex version used here) included both easy and hard trials, defined by the ratio between the two dot arrays. However, previous findings indicate that trial difficulty within the task does not influence the adopted strategy (Tricoche et al., 2023b). Participants seem to choose their strategy at the start and maintain it throughout the task, regardless of fluctuations in difficulty. In the previous study, where the overall task was simpler, children may have found it easier to develop an anticipative strategy early on, feeling more confident in their ability to master the task. In contrast, the present study, with its increased complexity—particularly due to the doubled number of dots—may have made it harder for them to rely on anticipation. Future studies will have to better explore these postulated different effects on the chosen strategy between the global task difficulty and the single trials difficulty, considering the self-confidence of individuals to complete these tasks.

To our knowledge, no other study has been conducted to investigate the social influence on these decision-making strategies, preventing us from comparing our findings with the existing literature. Moreover, it is important to keep in mind that these conclusions are only valid for these specific sequential comparative judgment tasks and cannot yet be extended to other forced-choice tasks or general decision-making abilities. Nonetheless, our findings open the door to a better understanding of the social influence effect on the traditionally known "dominant response." They also aim to highlight the importance of considering age as a continuous variable over than a categorical factor, and analyzing performance at the individual level to accurately capture variations in SFI effects across development and map its precise trajectory.

Ethical approval

The study received approval from the local ethics committee (CPP Sud Est II Ethics Committee) on November 7, 2018 (ClinicalTrials.gov Identifier: NCT03453216) as well as by the Institutional Review Board of the INSERM (protocol code 15–282-ter, date of approval: 19 December 2018).

CRediT authorship contribution statement

Leslie Tricoche: Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Amélie Reynaud:** Writing – review & editing, Formal analysis, Data curation. **Denis Pélisson:** Writing – review & editing, Supervision, Project administration, Conceptualization. **Jérôme Prado:** Writing – review & editing, Funding acquisition, Conceptualization. **Martine Meunier:** Supervision, Funding acquisition, Conceptualization.

Funding

This research was funded by the Fondation Neurodis and by the Agence Nationale de la Recherche (ANR-20-CE37-0021 to M. Meunier and ANR-17-CE28-0014 to J. Prado).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We thank the Fondation Neurodis and the Agence Nationale de la Recherche for funding this project. We thank Eric Koun for helping designing the study, and Marion Royer d'Halluin for helping conducting experiments. The OpenAI ChatGPT was used to check for syntax and grammatical mistakes.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2025.106340.

Data availability

Data are made available on OSF (https://osf.io/n2v43/).

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