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

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## **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 peer, 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 peer 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, peer presence led to social inhibition in children and early adolescents, but social facilitation in mid-adolescents and adults. These findings challenge Zajonc's "dominant response" theory, suggesting that peer presence affects overall decision-making strategies.

**Keywords:** developmental trajectory, response strategies, social influence direction's breakpoint, bimodal RT distributions, coaction

## 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 behaviors, and has been the subject of extensive literature since the late 19<sup>th</sup> century (Baron et al., 1978; R. Zajonc, 1965; R. B. Zajonc et al., 1969). However, similar to the majority of studies conducted to explore human behavior, most of the research investigating the SFI effect has focused on young adults, primarily recruited from pools of university students. Foundational references in this literature, such as Guerin's book (2010) and Bond and Titus's meta-analysis (1983), indicate that children and adolescents are underrepresented, as only 3 to 6% of published studies in this field focus on this age group (Bond & Titus, 1983; Guerin, 2010). Recently, there has been a growing interest for studying effects of SFI on children and adolescents. 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, et al., 2013; Bevelander, Meiselman, et al., 2013; Drewett, 2007; Engelmann et al., 2015; Lumeng & Hillman, 2007; Salvy et al., 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). Other studies have focused on risky decision-making in adolescents to understand and explain 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). While evidently these issues have major societal relevance, it is surprising that the effects of social influence on cognitive skills and academic knowledge remain relatively understudied in children (Camarda et al., 2021; Dumontheil et al., 2016; Tricoche et

al., 2021; Tricoche, PéliSSon, et al., 2023; 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 spreads over a wide developmental 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 focused on a single population, except for a few of them that compared two age groups (Camarda et al., 2021; Chein et al., 2011; Dumontheil et al., 2016; Gardner & Steinberg, 2005; Somerville et al., 2019; Tricoche et al., 2021; Tricoche et al., 2023). Yet, the influence of social presence is not restricted to adults but extends to children and adolescent's immature brains (Breiner et al., 2018; Chein et al., 2011; Dumontheil et al., 2016; Smith et al., 2018; Tricoche et al., 2023; van Hoorn et al., 2018; Van Hoorn et al., 2016). There is also evidence that the social brain continues its development during adolescence (Albert et al., 2013; Blakemore, 2015; Burnett et al., 2011; Rauchbauer & Grosbras, 2020). Therefore, it is crucial to understand 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 Figure 1). Participants performed these tasks alone or in a coaction situation with a familiar peer (i.e., both participants doing the same task at the same time). 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 propose to recruit an additional group of participants (adolescents 11- to 19-year-old) and use a complementary analysis method to identify the developmental changes of performance and processes modulated by social presence. Specifically, we studied the strategy adopted by participants to make their decision in these tasks, which both involve the sequential presentation of two stimuli. 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 600ms). The former was more frequently observed in adults than in children or adolescent (Tricoche et al., 2021; Tricoche et al., 2023). Here, we predicted that peer presence might favor the adoption of the anticipative strategy in children, helping them to reduce their developmental gap as compared with adults’ performance (Tricoche et al., 2021). As a developmental effect was previously found on the preferred strategies adopted by individuals (Tricoche et al., 2023), we also expected to find in the present study a peer presence effect on these response strategies that would vary with age.

## **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). 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).

Our sample size was calculated based on a previous study comparing the peer presence effect in young and old adolescents in a relational reasoning task (Wolf et al., 2015). This study found a lower accuracy in the friend-present condition relative to the experimenter-present condition on easy-relational trials in young adolescents, while old adolescents showed this presence effect across all difficulty levels. An a priori power analysis, based on the effect size obtained by Wolf et al on this Age (Young adolescents, Old adolescents)  $\times$  Condition (Friend, Experimenter)  $\times$  Difficulty (Easy, Hard) interaction ( $\eta_p^2=0.09$ ,  $d=0.6$ ), indicated that we would need a sample size of 40 participants to detect a similar interaction with our five sub-groups ( $\eta_p^2=0.09$ , power=0.95,  $\alpha=0.05$ ). As our analyses required the addition of a fourth factor (i.e., Task), we increased the sample size beyond that indicated by the power analysis.

### **Social context**

Participants were tested in a coaction condition or alone. In the coaction condition, participants were recruited by pairs, as friends, significant others, or siblings. The two familiar peers of each pair were matched in age 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:  $\pm 1.32$ ), which confirmed an overall close relationship. The two peers were seated side by side, each facing a computer screen and a keyboard, and completed the same tasks at the same time. 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.

*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.*

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

## Tasks & Stimuli

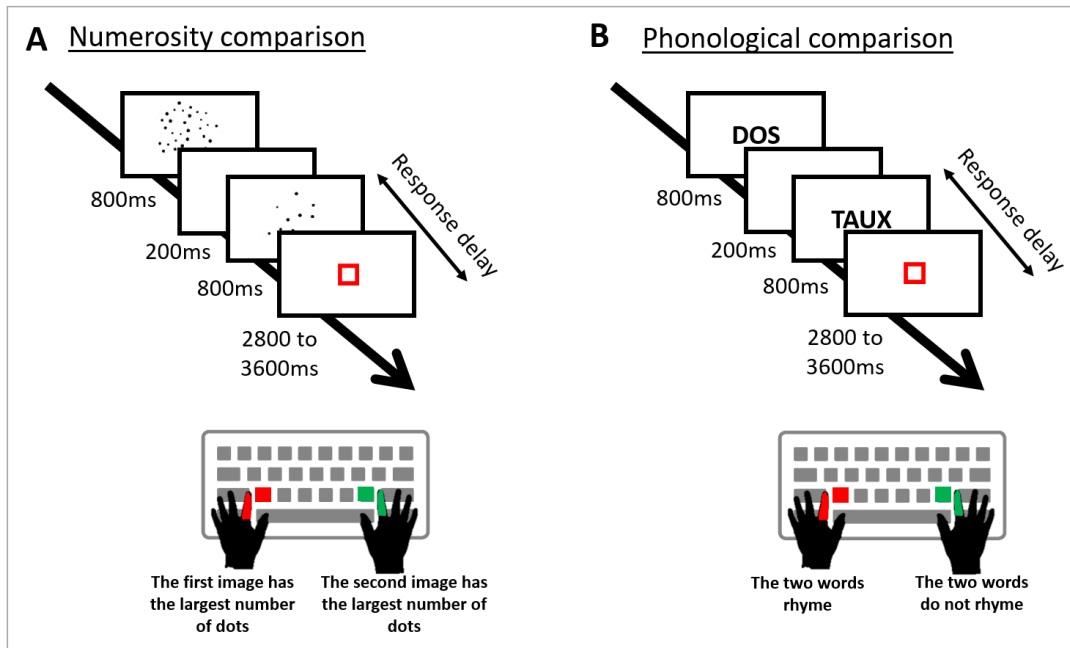


Participants completed the same two tasks that were previously used in Tricoche et al., 2021 (Tricoche et al., 2021) and based on previous studies (Prado et al., 2011, 2014). The first task was a numerosity comparison task, in which participants decided which of two sequentially displayed dots arrays 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. The trials time line is shown in Figure 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 B. 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 [zoe-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).



*Figure 1: Trial's temporality for Numerosity comparison (A) and Phonological comparison (B). Stimuli were presented successively during 800ms with a 200ms 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').*

## **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 ( $\eta_p^2$ ). 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  $BF_{incl} < 0.001$ ,  $< 0.01$ ,  $< 0.33$ ,  $< 1$  respectively; whereas extreme, strong, moderate or anecdotal evidence for the alternative hypothesis H1 were qualified for a  $BF_{incl} > 100$ ,  $> 10$ ,  $> 3$  and  $> 1$  (Keysers et al., 2020; Wagenmakers et al., 2018).

We also analyzed, separately for each task and each difficulty level, the relation between RT and Age (measured in days), 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, 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 RT data a segmented regression model ( $RT \sim \text{Age} * \text{Condition}$ ) 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 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. For the accuracy data, which did not show any social effect with ANOVAs, the results of this segmented regression model analysis are reported in **Appendix A**.

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; Tricoche et al., 2023) and detailed in **Appendix B**. 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 (Cramer, 1946). Significance level was set at  $p < 0.05$  for all frequentist analyses.

## Results

### Social effect on accuracy and RT

#### *Accuracy*

As illustrated in Figure 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 $\pm$ SEM = 93.2% $\pm$ 0.4 when averaging numerosity and phonology comparisons) than hard trials (79.5% $\pm$ 0.5 when averaging numerosity and phonology comparisons). In line with a number of previous studies, accuracy was also higher for numerosity (85.9% $\pm$ 0.5 when averaging easy and hard trials) than phonology comparison (86.9% $\pm$ 0.7 when averaging easy and hard trials) (Prado et al.,

2011, 2014; Tricoche et al., 2021; Tricoche, Meunier, et al., 2023; Tricoche, Pélisson, et al., 2023). 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 are given in **Appendix C**.

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

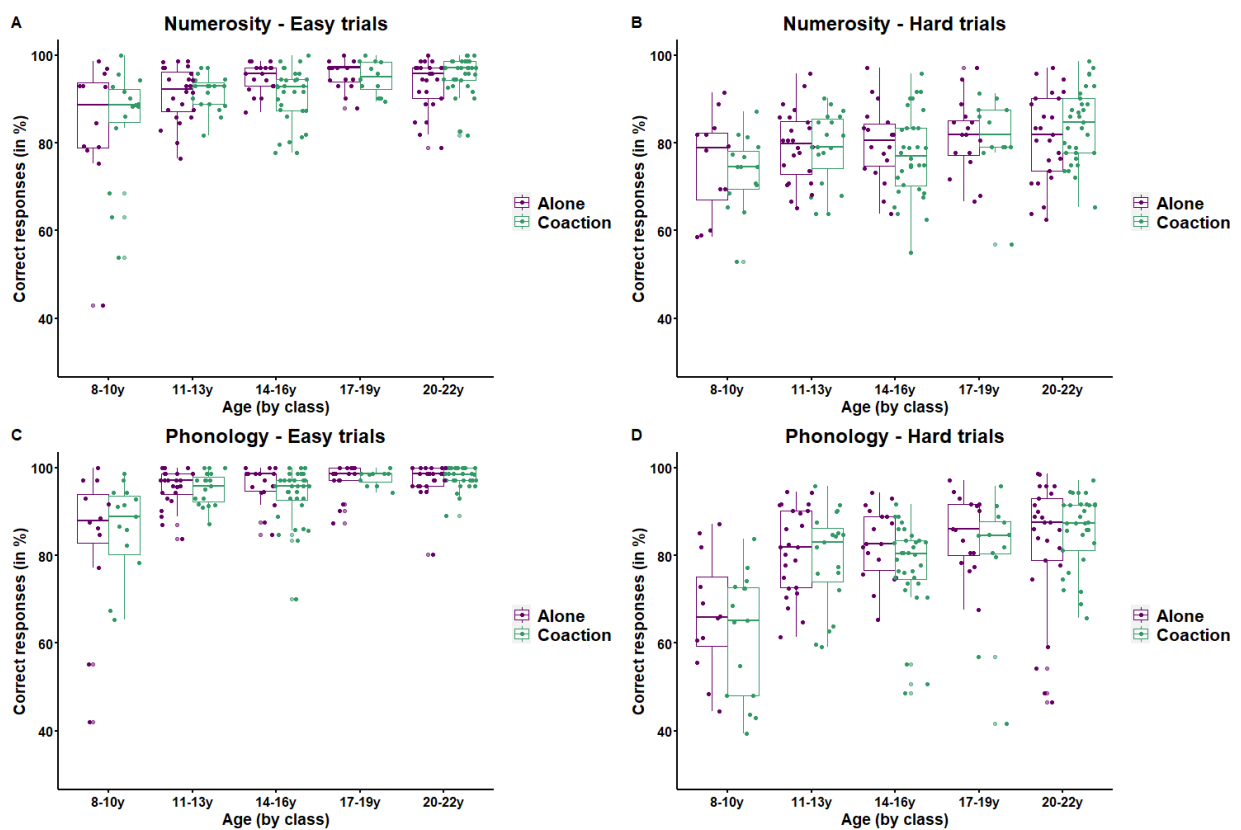


Figure 2: Accuracy expressed in %Corr according to the Age (by class), Condition (alone in purple, coaction in green), Task (A-B: numerosity; C-D: phonology) and Difficulty (A-C: easy trials; B-D: hard trials). Dots represent individual data, boxes show the medians, lower quartiles, upper quartiles and whiskers ( $\pm 1.5 \times$  Inter-quartile range).

## *RT*

As shown in Figure 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. The Condition effect also reached significance, but Bayesian analyses indicated anecdotal evidence toward  $H_0$  ( $F(1, 196)=3.86, p=0.05, \eta_p^2=0.02, BF_{incl}=0.59$ ). 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 ( $1079.1\text{ms}\pm 19.7$ ) than hard trials ( $1225.7\text{ms}\pm 21.8$ ), and numerosity trials showed lower RTs ( $995.7\text{ms}\pm 18.0$ ) than phonology trials ( $1309.0\text{ms}\pm 21.1$ ). Older participants were faster than younger participants (8-10y:  $1540.3\text{ms}\pm 39.2$ ; 11-13y:  $1258.2\text{ms}\pm 29.4$ ; 14-16y:  $1109.2\text{ms}\pm 28.1$ ; 17-19y:  $998.9\text{ms}\pm 38.1$ ; 20-22y:  $1004.6\text{ms}\pm 24.2$ ). All post-hoc comparisons are given in **Appendix C**. Concerning the main objective of our study, results indicated that the significant main Condition effect was directed toward a social facilitation (coaction:  $1111.2\text{ms}\pm 19.8$ ; alone:  $1200.5\text{ms}\pm 22.4$ ). 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:  $p=0.01$ ).

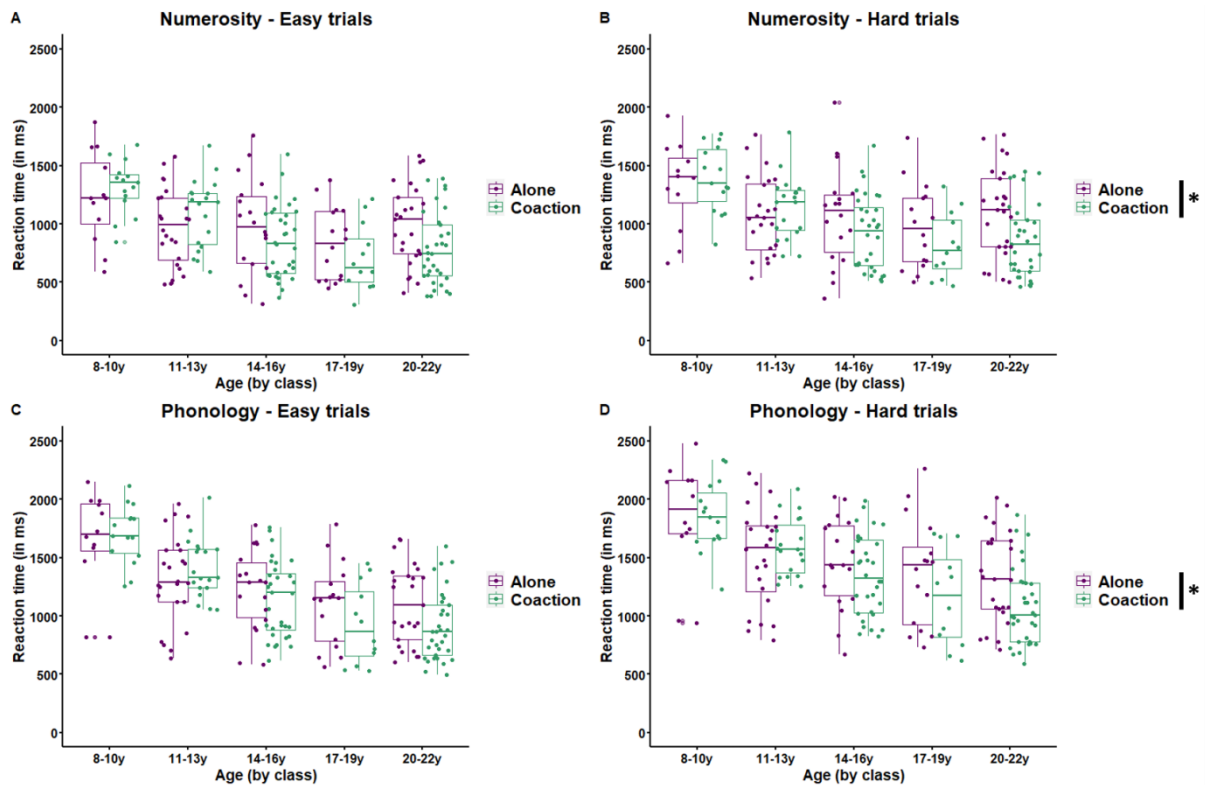


Figure 3: RT expressed in ms according to the Age (by class), Condition (alone in purple, coaction in green), Task (A-B: numerosity; C-D: phonology) and Difficulty (A-C: easy trials; B-D: hard trials). Same conventions as in Figure 2. A significant social facilitation was found by comparing alone (purple) and coaction (green) conditions, for hard trials (\*:  $p=0.01$ ).

### The direction of social effect is modulated by age

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 Figure 4, 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,  $CI95: \pm 56.35$ ; Numerosity-Hard: 5159 days,  $CI95: \pm 57.69$ ; Phonology-Easy: 5220 days,  $CI95: \pm 76$ ; Phonology-Hard: 5159 days,  $CI95: \pm 118.3$ ). 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.

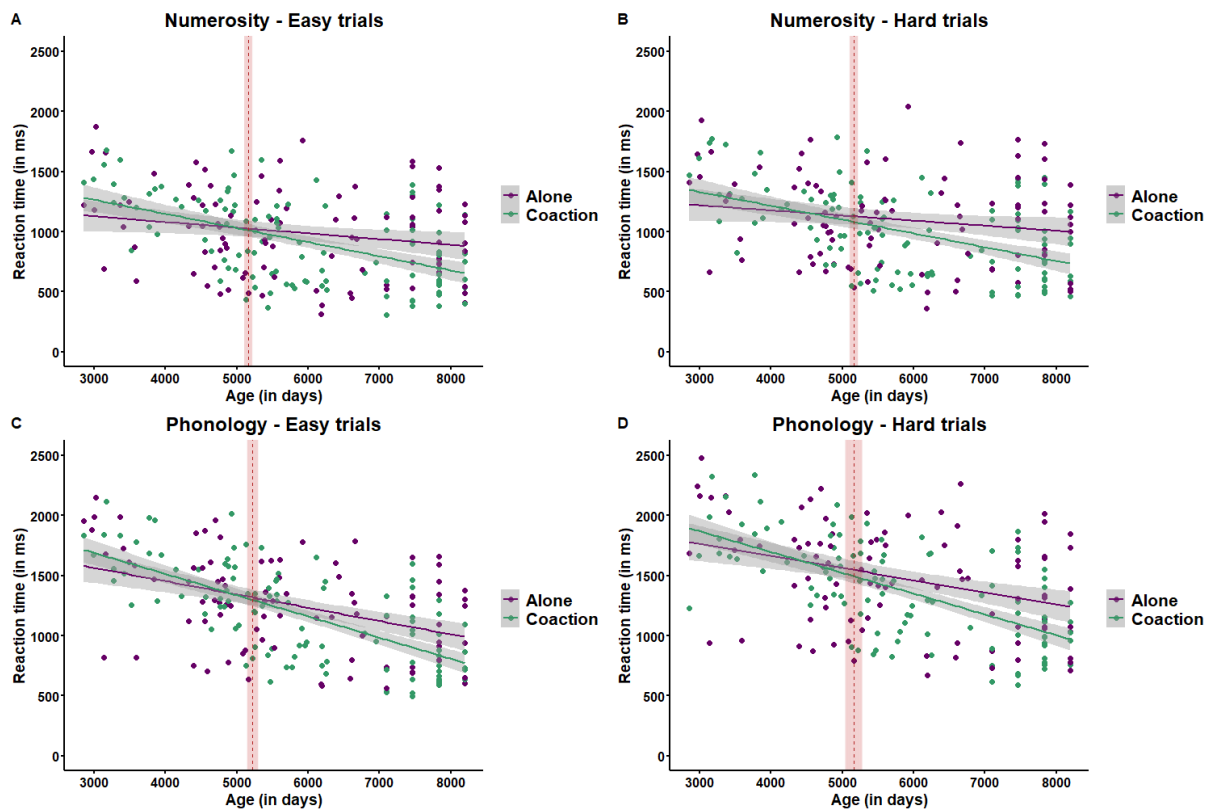


Figure 4: Relation between the Age (in days) and the RT (in ms) according to the Condition (alone in purple, coaction in green), Task (A-B: numerosity; C-D: phonology) and Difficulty (A-C: easy trials; B-D: hard trials). The segmented regression models indicated significant an Age by Condition effect in each of the 4 situations, showing that the effect of Age on the RT



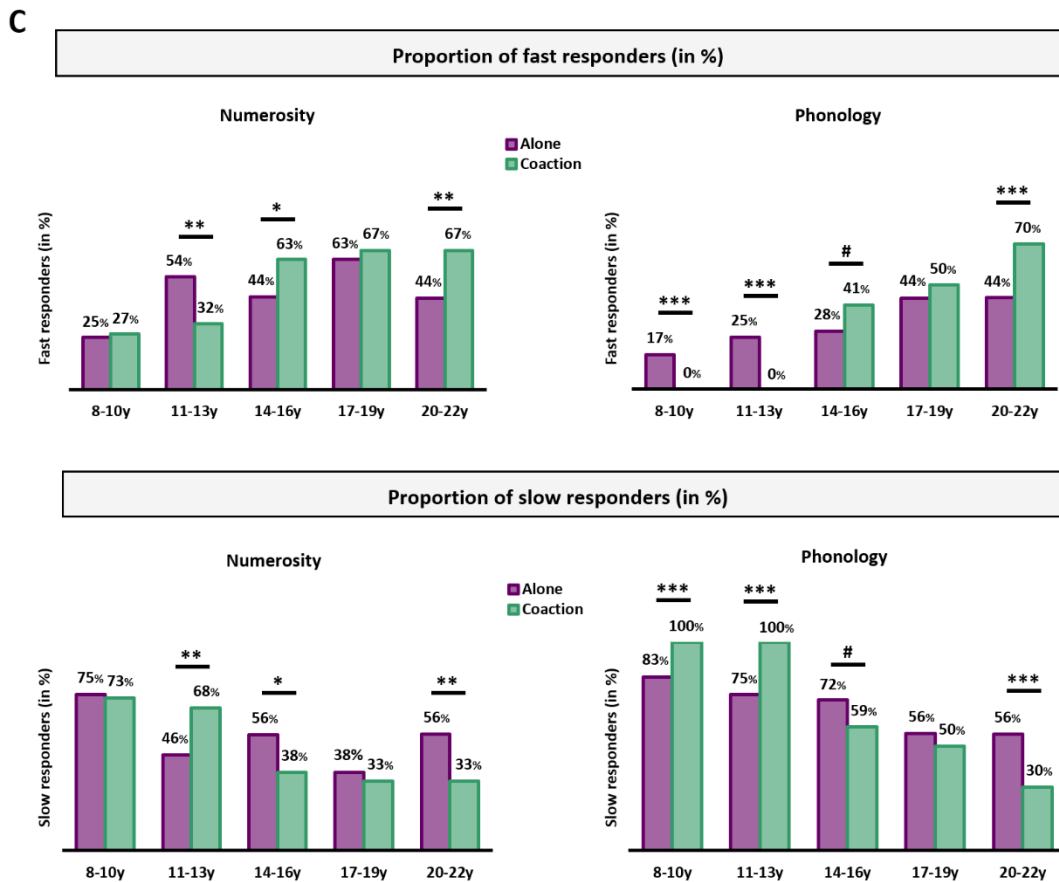
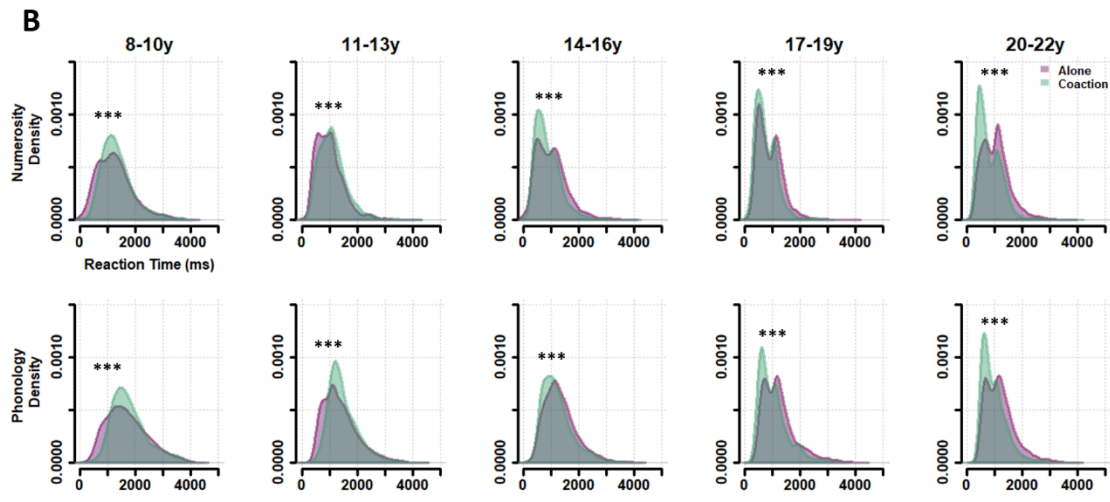
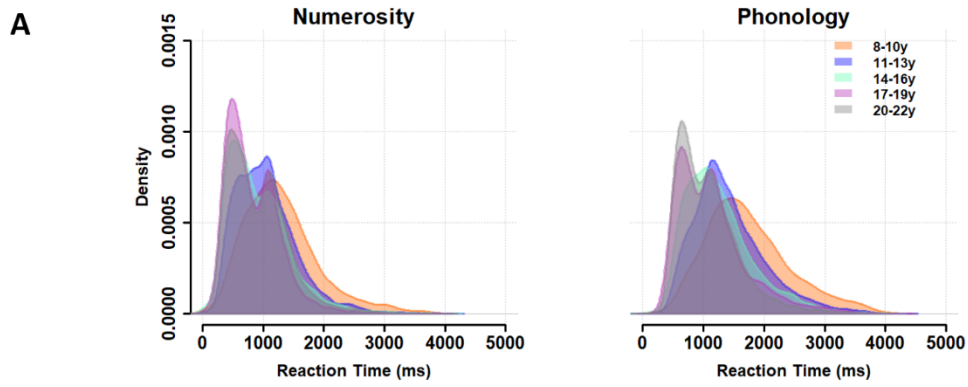
*is modulated by the Condition. Further, the direction of the social effect (inhibition/facilitation) changed around 5100-5200 days, as revealed by the estimated breakpoints (red dashed lines, with confidence intervals at 95%). Note that the slight difference between the observed graphical intersection 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.*

### **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 (Figure 5A). These distributions were all bimodal (i.e., two peaks of density). This pattern, which is in line with previous studies (Tricoche et al., 2021; Tricoche et al., 2023) 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 600ms) and participants who responded relatively slowly (around 1,100ms) (**Appendix B**). This distinction between fast responders around 600ms and slow responders around 1,100ms replicated previous results, as well as the observed developmental trajectory (Tricoche et al., 2021; Tricoche et al., 2023). 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 (Figure 5A).

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  $p's<0.001$ ) (Figure 5B). Using the method previously developed (Tricoche et al., 2021;2023) and detailed in **Appendix B**, 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 ( $X^2=3.19$ ,  $p=0.07$ ,  $V=0.13$ ,  $BF_{10}=0.49$ ) (Figure 5C). Interestingly, and as illustrated in Figure 5B&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).



*Figure 5: 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 600ms) and slow (second peak of density around 1,100ms) 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) (#:  $p < 0.08$ ; \*:  $p < 0.05$ ; \*\*:  $p < 0.01$ ; \*\*\*:  $p < 0.001$ ).*

## **Discussion**

In this study, we investigated the developmental trajectory of peer 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 peer.

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 our previous study in the youngest and oldest subjects groups (Tricoche et al., 2021). 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. 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 peer 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.

Furthermore, another 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. For the youngest participants, the predominant strategy was to produce relatively slow responses, whereas older participants

adopted a more optimal strategy allowing faster responses without cost on accuracy (Tricoche, Meunier, et al., 2023). Peer 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, peer 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 wherein social presence increases the probability of the dominant response, which is the most probable or common response during the performed task (R. Zajonc, 1965; R. B. 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, Meunier, et al., 2023, 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. This adaptation possibly enhanced their ability to adopt a fast strategy for this very well mastered task. 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."

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**Authors contribution:** L.T designed the study, analyzed data and wrote the manuscript; A.R conducted experiments and analyzed data; D.P conceptualized the study and supervised; J.P conceptualized the study and acquired funding, M.M conceptualized the study, acquired funding and supervised. All the authors except M.M read and edited the manuscript.

**Data availability:** Data are made available on OSF (<https://osf.io/n2v43/>).

**Supplementary Material:** Appendix are made available on OSF (<https://osf.io/n2v43/>).

**Declaration of competing interest:** The authors declare no competing interest.

## References

- Adam, R., Bays, P. M., & Husain, M. (2012). Rapid decision-making under risk. *Cognitive Neuroscience*, 3(1), 52–61.
- Albert, D., Chein, J., & Steinberg, L. (2013). The Teenage Brain: Peer Influences on Adolescent Decision Making. *Current Directions in Psychological Science*, 22(2), 114–120. <https://doi.org/10.1177/0963721412471347>
- Barkley, J. E., Salvy, S. J., Sanders, G. J., Dey, S., Von Carlowitz, K. P., & Williamson, M. L. (2014). Peer influence and physical activity behavior in young children: An experimental study. *Journal of Physical Activity and Health*, 11(2), 404–409. <https://doi.org/10.1123/jpah.2011-0376>
- Baron, R. S., Moore, D., & Sanders, G. S. (1978). Distraction as a source of drive in social facilitation research. *Journal of Personality and Social Psychology*, 36(8), 816–824. <https://doi.org/10.1037//0022-3514.36.8.816>
- Bevelander, K. E., Lichtwarck-aschoff, A., Anschutz, D. J., Hermans, R. C. J., & Engels, R. C. M. E. (2013). Imitation of snack food intake among normal-weight and overweight children. 4(December), 1–7. <https://doi.org/10.3389/fpsyg.2013.00949>
- Bevelander, K. E., Meiselman, H. L., Anschutz, D. J., & Engels, R. C. M. E. (2013). Television watching and the emotional impact on social modeling of food intake among children q. *Appetite*, 63, 70–76. <https://doi.org/10.1016/j.appet.2012.12.015>



- Blakemore, S. J. (2015). Development of the social brain in adolescence. *Self-Regulation in Adolescence*, 193–211. <https://doi.org/10.1017/CBO9781139565790.010>
- Bond, & Titus, L. J. (1983). Social facilitation: a meta-analysis of 241 studies. *Psychological Bulletin*, 94(2), 265–292. <https://doi.org/https://doi.org/10.1037/0033-2909.94.2.265>
- Breiner, K., Li, A., Cohen, A. O., Steinberg, L., Bonnie, R. J., Scott, E. S., Taylor-Thompson, K., Rudolph, M. D., Chein, J., Richeson, J. A., Dellarco, D. V., Fair, D. A., Casey, B. J., & Galván, A. (2018). Combined effects of peer presence, social cues, and rewards on cognitive control in adolescents. *Developmental Psychobiology*, 60(3), 292–302. <https://doi.org/10.1002/dev.21599>
- Burnett, S., Sebastian, C., Cohen Kadosh, K., & Blakemore, S. J. (2011). The social brain in adolescence: Evidence from functional magnetic resonance imaging and behavioural studies. *Neuroscience and Biobehavioral Reviews*, 35(8), 1654–1664. <https://doi.org/10.1016/j.neubiorev.2010.10.011>
- Camarda, A., Bouhours, L., Osmont, A., Le Masson, P., Weil, B., Borst, G., & Cassotti, M. (2021). Opposite Effect of Social Evaluation on Creative Idea Generation in Early and Middle Adolescents. *Creativity Research Journal*, 33(4), 399–410. <https://doi.org/10.1080/10400419.2021.1902174>
- Chein, J., Albert, D., Brien, L. O., Uckert, K., & Steinberg, L. (2011). Peers increase adolescent risk taking by enhancing activity in the brain's reward circuitry. *Developmental Science*, 14(2), 1–10. <https://doi.org/10.1111/j.1467-7687.2010.01035.x>.Peers
- Chen, J., Hale, S., & Myerson, J. (2007). Predicting the size of individual and group differences on speeded cognitive tasks. *Psychonomic Bulletin & Review*, 14(3), 534–541. <https://doi.org/10.3758/bf03194103>

- Coppinger, T., Jeanes, Y. M., Dabinett, J., Vögele, C., & Reeves, S. (2010). Physical activity and dietary intake of children aged 9-11 years and the influence of peers on these behaviours: A 1-year follow-up. *European Journal of Clinical Nutrition*, *64*(8), 776–781. <https://doi.org/10.1038/ejcn.2010.63>
- Cramér, H. (1946). *Mathematical Methods of Statistics* (Princeton). Princeton University Press.
- Drewett, R. F. (2007). The social facilitation of food intake. *Archives of Disease in Childhood*, *92*(5), 377. <https://doi.org/10.1136/adc.2006.108332>
- Dumontheil, I., Wolf, L. K., & Blakemore, S.-J. (2016). Audience effects on the neural correlates of relational reasoning in adolescence. *Neuropsychologia*, *87*, 85–95. <https://doi.org/10.1016/j.neuropsychologia.2016.05.001>
- Engelmann, J. M., Herrmann, E., & Tomasello, M. (2015). The effects of being watched on resource acquisition in chimpanzees and human children. *Animal Cognition*. <https://doi.org/10.1007/s10071-015-0920-y>
- Gächter, S., Starmer, C., & Tufano, F. (2015). Measuring the closeness of relationships: A comprehensive evaluation of the “inclusion of the other in the self” scale. *PLoS ONE*, *10*(6), 1–19. <https://doi.org/10.1371/journal.pone.0129478>
- Gardner, M., & Steinberg, L. (2005). Peer influence on risk taking, risk preference, and risky decision making in adolescence and adulthood: An experimental study. *Developmental Psychology*, *41*(4), 625–635. <https://doi.org/10.1037/0012-1649.41.4.625>
- Gebuis, T., & Reynvoet, B. (2011). Generating nonsymbolic number stimuli. *Behavior Research Methods*, *43*(4), 981–986. <https://doi.org/10.3758/s13428-011-0097-5>
- Gonzales, T., Jackson, M. L., & Nicolson, A. (2019). The Effects of Peer Presence on

Variables Maintaining Moderate-to-Vigorous Physical Activity in Children. *Behavior Modification*, 014544551985074. <https://doi.org/10.1177/0145445519850748>

Guerin, B. (2010). *Social facilitation*. Cambridge University Press.

Hedge, C., Vivian-Griffiths, S., Powell, G., Bompas, A., & Sumner, P. (2019). Slow and steady? Strategic adjustments in response caution are moderately reliable and correlate across tasks. *Consciousness and Cognition*, 75(July), 1–17.

<https://doi.org/10.1016/j.concog.2019.102797>

Hoffmann, F., Puetz, V. B., Viding, E., Sethi, A., Palmer, A., & McCrory, E. J. (2018). Risk-taking, peer-influence and child maltreatment: A neurocognitive investigation. *Social Cognitive and Affective Neuroscience*, 13(1), 124–134.

<https://doi.org/10.1093/scan/nsx124>

Keyesers, C., Gazzola, V., & Wagenmakers, E. J. (2020). Using Bayes factor hypothesis testing in neuroscience to establish evidence of absence. *Nature Neuroscience*, 23(7), 788–799. <https://doi.org/10.1038/s41593-020-0660-4>

Kieffer, L. F. (1977). The Relationship of Trait Anxiety, Peer Presence, Task Difficulty, and Skill Acquisition of Sixth Grade Boys. *Middle School Research Selected Studies*, 1–3(1), 107–115. <https://doi.org/10.1080/08851700.1977.11670190>

Lumeng, J. C., & Hillman, K. H. (2007). Eating in larger groups increases food consumption. *Archives of Disease in Childhood*, 92(5), 384–387.

<https://doi.org/10.1136/adc.2006.103259>

New B., Pallier C., Ferrand L., & Matos R. (2001). Une base de données lexicales du français contemporain sur internet: LEXIQUE. *L'Année Psychologique*, 101((3)), 447–462.

<http://www.lexique.org>

- Prado, J., Mutreja, R., & Booth, J. R. (2014). Developmental dissociation in the neural responses to simple multiplication and subtraction problems. *Developmental Science*, 17(4), 537–552. <https://doi.org/10.1111/desc.12140>
- Prado, J., Mutreja, R., Zhang, H., Mehta, R., Desroches, A. S., Minas, J. E., & Booth, J. R. (2011). Distinct representations of subtraction and multiplication in the neural systems for numerosity and language. *Human Brain Mapping*, 32(11), 1932–1947. <https://doi.org/10.1002/hbm.21159>
- Rauchbauer, B., & Grosbras, M. H. (2020). Developmental trajectory of interpersonal motor alignment: Positive social effects and link to social cognition. *Neuroscience and Biobehavioral Reviews*, 118, 411–425. <https://doi.org/10.1016/j.neubiorev.2020.07.032>
- Reniers, R. L. E. P., Beavan, A., Keogan, L., Furneaux, A., Mayhew, S., & Wood, S. J. (2017). Is it all in the reward? Peers influence risk-taking behaviour in young adulthood. *British Journal of Psychology*, 108(2), 276–295. <https://doi.org/10.1111/bjop.12195>
- Rittenhouse, M., Salvy, S. J., & Barkley, J. E. (2011). The effect of peer influence on the amount of physical activity performed in 8- to 12-year-old boys. *Pediatric Exercise Science*, 23(1), 49–60. <https://doi.org/10.1123/pes.23.1.49>
- Salvy, S., Kieffer, E., & Epstein, L. H. (2008). *Effects of social context on overweight and normal-weight children 's food selection*. 9, 190–196. <https://doi.org/10.1016/j.eatbeh.2007.08.001>
- Salvy, S., Roemmich, J. N., Bowker, J. C., Romero, N. D., Stadler, P. J., & Epstein, L. H. (2009). Effect of Peers and Friends on Youth Physical Activity and Motivation to be Physically Active. *Journal of Pediatric Psychology*, 34(2), 217–225. <https://doi.org/10.1093/jpepsy/jsn071>

- Siegmund, L. A., Naylor B., J. B., Santo S., A. S., & Barkley E., J. E. (2014). The effect of a peer on VO<sub>2</sub> and game choice in 6-10 year old children. *Frontiers in Physiology*, 5 JUN(June), 1–10. <https://doi.org/10.3389/fphys.2014.00202>
- Smith, A. R., Rosenbaum, G. M., Botdorf, M. A., Steinberg, L., & Chein, J. M. (2018). Peers influence adolescent reward processing, but not response inhibition. *Cognitive, Affective and Behavioral Neuroscience*, 18(2), 284–295. <https://doi.org/10.3758/s13415-018-0569-5>
- Somerville, L. H., Haddara, N., Sasse, S. F., Skwara, A. C., Moran, J. M., & Figner, B. (2019). Dissecting “Peer Presence” and “Decisions” to Deepen Understanding of Peer Influence on Adolescent Risky Choice. *Child Development*, 90(6), 2086–2103. <https://doi.org/10.1111/cdev.13081>
- Swensson, R. G., & Edwards, W. (1971). Response strategies in a two-choice reaction task with a continuous cost for time. *Journal of Experimental Psychology*, 88(1), 67–81. <https://doi.org/10.1037/h0030646>
- Telzer, E. H., Ichien, N. T., & Qu, Y. (2015). Mothers know best: Redirecting adolescent reward sensitivity toward safe behavior during risk taking. *Social Cognitive and Affective Neuroscience*, 10(10), 1383–1391. <https://doi.org/10.1093/scan/nsv026>
- Telzer, E. H., Rogers, C. R., & Van Hoorn, J. (2017). Neural Correlates of Social Influence on Risk Taking and Substance Use in Adolescents. *Current Addiction Reports*, 4(3), 333–341. <https://doi.org/10.1007/s40429-017-0164-9>
- Tricoche, L., Meunier, M., Hassen, S., Prado, J., & Pélisson, D. (2023). Developmental Trajectory of Anticipation: Insights from Sequential Comparative Judgments. *Behavioral Sciences*, 13(8). <https://doi.org/10.3390/bs13080646>

- Tricoche, L., Monfardini, E., Reynaud, A. J., Epinat-Duclos, J., Pélişson, D., Prado, J., & Meunier, M. (2021). Peer Presence Effect on Numerosity and Phonological Comparisons in 4th Graders: When Working With a Schoolmate Makes Children More Adult-Like. *Biology*, *10*(902). <https://doi.org/10.3390/biology10090902>
- Tricoche, L., Pélişson, D., Longo, L., Koun, E., Poisson, A., Prado, J., & Meunier, M. (2023). Task-independent neural bases of peer presence effect on cognition in children and adults. *NeuroImage*, *277*(120247). <https://doi.org/https://doi.org/10.1016/j.neuroimage.2023.120247>
- Van Duijvenvoorde, A. C. K., Jansen, B. R. J., Bredman, J. C., & Huizenga, H. M. (2012). Age-related changes in decision making: Comparing informed and noninformed situations. *Developmental Psychology*, *48*(1), 192–203. <https://doi.org/10.1037/a0025601>
- van Hoorn, J., McCormick, E. M., Rogers, C. R., Ivory, S. L., & Telzer, E. H. (2018). Differential effects of parent and peer presence on neural correlates of risk taking in adolescence. *Social Cognitive and Affective Neuroscience*, *13*(9), 945–955. <https://doi.org/10.1093/scan/nsy071>
- Van Hoorn, J., Van Dijk, E., Gürođlu, B., & Crone, E. A. (2016). Neural correlates of prosocial peer influence on public goods game donations during adolescence. *Social Cognitive and Affective Neuroscience*, nsw013. <https://doi.org/10.1093/scan/nsw013>
- Wagenmakers, E. J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Selker, R., Gronau, Q. F., Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E. J., van Doorn, J., Šmíra, M., Epskamp, S., Etz, A., Matzke, D., ... Morey, R. D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin and Review*, *25*(1), 58–76. <https://doi.org/10.3758/s13423->

017-1323-7

Wolf, L. K., Bazargani, N., Kilford, E. J., Dumontheil, I., & Blakemore, S. J. (2015). The audience effect in adolescence depends on who's looking over your shoulder. *Journal of Adolescence*, *43*, 5–14. <https://doi.org/10.1016/j.adolescence.2015.05.003>

Zajonc, R. (1965). Social facilitation. *Science*, *149*, 269–274.  
<https://doi.org/10.1126/science.149.3681.269>

Zajonc, R. B., Heingartner, A., & Herman, E. M. (1969). Social enhancement and impairment of performance in the cockroach. *Journal of Personality and Social Psychology*, *13*(2), 83–92. <https://doi.org/10.1037/h0028063>