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The metacognitive abilities of children and adults

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ABSTRACT

Metacognition, or the capacity to reflect upon one's own knowledge, is a key trait in our cognitive repertoire which is developed during childhood. Here, a direct comparison of metacognitive ability in children (*N* = 188; 6–9 years old) and adults, (*N* = 47) using a single perceptual task, was made. Results showed that 6–9 years old children have a level of metacognitive access similar to that of adults. Further, a signal detection theory model was applied in order to distinguish metacognitive ability from the propensity towards risk taking, two factors that have so far been confounded in studies. Children presented a sub-optimal tendency towards risky decisions and a natural predisposition to overconfidence that can be partially mitigated by imposing a conservative normative strategy.

1. Introduction

Metacognition is the ability of thinking about what we know, an individual's knowledge about her cognitive processes and how to use this knowledge to control those processes accordingly. It constitutes a key trait in our cognitive repertoire (Dunlosky & Metcalfe 2009; Flavell, 1976; Lockl & Schneider, 2006).

Evaluating this ability is a subtle matter: one typically chooses a base cognitive task (type I task), and then asks participants to report how well they think they have performed it (type II task, confidence report). By relating the responses in both tasks one can then assess the metacognitive ability of the participants. Although metacognition is in principle independent of the skill in the type I task (which can range from a low level perceptual decision to tasks at a higher cognitive level such as memory or problem solving) (Baird, Smallwood, Gorgolewski, & Margulies, 2013; Metcalfe & Finn, 2013; Roebers, von der Linden, Schneider, & Howie, 2007; Zylberberg, Barttfeld, & Sigman, 2012), the direct confidence report can confound these two. For instance, if the type I task is extremely easy, type II reports will show a tendency towards high confidence, which prevents an accurate evaluation of metacognition. Even in a setting in which there is a reasonable range of performance in the type I task, it is not straightforward to extract a single measure from the type I and type II responses that directly quantifies metacognitive ability (Fleming & Lau, 2014; Maniscalco & Lau, 2012). These sort of confounds can lead to erroneous interpretations about

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the participants' metacognitive abilities. A clear example of this kind of incorrect assessments can be found in what used to be the established literature within children's metacognition research, which alleged that metacognitive skills emerge in development late in life, around age of 8 (Veenman, Van Hout-Wolters, & Afferbach, 2006). The main issue among these studies was the reliance on type I tasks that prove to be too demanding for younger children.

The proposal of a delayed emergence of metacognition has been challenged and mostly discarded over the past years by the realization that research relying on self-report or verbally-based experimental methodologies may significantly underestimate the metacognitive and self-regulated performance of young children (Cultice, Somerville, & Wellman, 1983; Schellings & Van Hout-Wolters, 2011; Whitebread et al., 2009; Whitebread, Almeqdad, Bryce, Demetriou, Grau, & Sangster, 2010; Winne & Perry, 2000). For example, Schneider (1985) demonstrated that many early studies, which examined the relationship between metacognition and performance in children, were based merely on the use of self-report techniques as a way of understanding individuals' metacognitive processes (Schneider, 1985). These depend heavily upon the respondents' ability to give reliable reports of their own mental experiences, which for younger children can derive in an underestimation of their regulatory abilities. An underestimation is particularly expected when the natures of the tasks that are used to test metacognition during toddlerhood or early childhood rely heavily on declarative memories and language-based procedures, which children do not master until later in life (for a revision, Whitebread et al., 2010). Nowadays, as a consequence of an increasing number of reports using a variety of age-appropriate methodologies, there is agreement that children as young as 2 years old can already exhibit metacognitive abilities, well before they can produce consistent verbal reports (Hembacher & Ghetti, 2014; Lyons & Ghetti, 2011; Marazita & Merriman, 2004; Ruffman, Garnham, Import, & Connolly; 2001). Furthermore, studies have identified metacognitive and self-regulatory behaviors, such as uncertainty and judgments of learning, in young children (Beran, Decker, Schwartz, & Smith, 2012; Destan, Hembacher, Ghetti, & Roebers, 2014; Ghetti, Hembacher, & Coughlin, 2013).

The use of age-appropriate techniques is necessary for establishing how metacognitive abilities are developed. Regarding to this point, Winne and Perry (2000) have argued that observational methodologies are particularly crucial for establishing metacognitive abilities, because it allows the opportunity to evaluate non-verbal (such as eye gaze shifting, gestures, and pauses) as well as verbal behavior during the tasks (Winne & Perry, 2000). Accordingly, we agree that metacognition assessment in young children should be through tasks that are purely behavioral, nondeclarative, and as language free as possible. One example that began to fill the void in the understanding of early childhood metacognition by using a novel non-verbal metacognition task is the recent work by Vo, Kornell, Pouget, and Cantlon (2014). By introducing a comprehensive set of metacognitive measures to evaluate metacognition they could claim that metacognition is a fundamental domain-dependent cognitive ability in children (Vo et al., 2014).

Hence, if children develop metacognitive abilities, this would mean that they can (1) introspect on the current state of their cognitive processes (i.e., metacognitive monitoring) and (2) use the output of metacognitive monitoring to regulate these operations (metacognitive control). On this topic, recent research has shown that young children respond appropriately not only to their own knowledge or the lack of it, but as well as to the reliability on somebody else's knowledge, showing strong preferences towards those who they perceive as trustworthy (see Ghetti et al., 2013 for a review). For example, Koenig and Harris (2005) demonstrated that children as young as 4 years old assess the reliability of the source of information and further use that information to predict future assertions, seek information and even endorse their claims (Koenig & Harris, 2005).

Although the literature on metacognitive development has increased, still much work needs to be done. Particularly, it is not completely understood whether children represent their uncertainty during perceptual discriminations and base their confidence judgments on that uncertainty, and how metacognitive monitoring and control during those processes change during development, if they do.

Besides using age-appropriate tasks when studying children's metacognitive development, current research has argued that most of the available methods used to analyze metacognitive paradigms are inadequate because they are bias by factors such as type 1 sensitivity (Galvin, Podd, Drga, & Whitmore, 2003; Maniscalco & Lau, 2012). Research by Maniscalco and Lau (2012) has proposed that the signal detection theory (SDT) approach for measuring type II task sensitivity because it allows the discrimination the independent contributions of sensitivity and response bias during confidence reports.

Accordingly, with these two ideas on the use of (1) age-appropriate techniques and (2) SDT for the analysis of confidence reports, the aim of the current research is threefold. First, we present a direct comparison of metacognitive performance between young children and adults through the use of a perceptual base task adapted from a task designed for monkeys by Kornell and colleagues (Kornell, Son, & Terrace, 2007). Though comparisons between these different ages were attempted before, they were mostly limited by the fact that, in order to make them more accessible, both the base and/or the metacognitive tasks were simplified when presented to children (Finn & Metcalfe, 2014; Metcalfe & Finn, 2012; Roebers, 2002). For example, in judgment of learning studies, the vocabulary materials used with children during the type 1 task is a comparable cued recall task, but not same, as the one employed for adults (Finn & Metcalfe, 2014).

Second, we aim at assessing metacognitive ability and tendency towards risk independently, since these two factors are generally confounded in the standard treatment of confidence in the literature. In order to achieve this, we apply a signal detection theory (SDT) model in terms of which we analyze our results. This model allows us (1) to treat metacognitive ability and risk attitude independently and (2) to resolve the confound of varying performance in the base task. Study 1 was designed to address these two first aims.

Third, in Study 2 we explored whether the natural tendency towards overconfidence observed can be tempered by imposing a payoff structure that makes rational action conservative. The extent to which this tempering works is studied progressively with age, which we achieve by comparing adults and children in the 6–8 year old range.

We stress however that metacognition is complex and multifaceted, such that developmental trajectories may differ when considering alternative cognitive objects. Here the focus was on a perceptual ability already developed in young children.

2. Study 1

In this first study, we use an age-appropriate task for evaluating metacognition, which, together with an SDT model analysis, allows us to independently assess the difference in metacognitive ability and the tendency towards risk between children and adults through a wagering report.

As it was previously described, during type II tasks, participants' confidence reports can be influenced by type I performance (such that, for instance, an extremely easy type I task would trivially lead to all high confidence responses). This problem has been assessed thoroughly by Maniscalco and Lau (2012), who systematically studied how different measures that are common in the literature as ϕ and © depend on type I performance, and showed further that they confound metacognitive sensitivity and response bias (Maniscalco & Lau, 2012). In order to tackle these issues, these authors proposed a novel SDT model for jointly constructing confidence judgments and type I responses from sensory information (see also Fleming & Lau, 2014; for a review). As their model is most suitable for two alternative forced choice tasks, we chose instead to use the SDT approach directly at the confidence judgment level, in a manner similar to Kukimoto et al. (Kunimoto, Miller, & Pashler, 2001). This approach bears some resemblance with the analysis done in Vo et al. (Vo et al., 2014), where hit and false alarms rates are used to construct an area under the curve (A_{ROC}) measure of metacognitive ability. In our case, by further imposing a model structure, we are able to identify two different aspects of metacognitive judgment: the *metacognitive ability* and the response bias or *criterion*. A high metacognitive ability means being able to correctly judge right or wrong type I responses while low metacognitive ability means that confidence judgments cannot discriminate correct from erred responses. The criterion is related to the policy the subject is choosing concerning risk. Two participants can have the same metacognitive ability while one can be very conservative (with lower confidence responses) and the other more risk seeking (higher confidence). These factors all contribute to the construction of the confidence report collected, and we employ the SDT model in order to resolve them.

2.1. Method

2.1.1. Participants

Twenty-nine adults (22 men and 7 women; mean age: 29 years and 1 month, ranging from 20 to 40 years old) and 110 children (49 boys and 61 girls, mean age: 7 years and 9 months, ranging from 6 years and 4 months to 9 years and 9 months) participated. The sample size was determined by previous experiments with children and adults and was fixed before starting data analysis. All participants were from medium-high socioeconomic status.

Recruitment letters were sent to several schools in Buenos Aires and different appointments were made. The adults were recruited via e-mails aimed at university staff members and students.

The study was approved by the *Centro de Educación Médica e Investigaciones Clínicas "Norberto Quirno"* (CEMIC)'s Ethical Committee. Children recruited attended two different private schools in Buenos Aires, where the study was conducted. Both schools approved the research and all children's parents or legal guardians gave signed voluntary consent. The consent form was presented to the caregivers supplemented with a note which explained the procedure. All adult participants gave written informed consent.

2.1.2. Design

Fig. 1A illustrates the task presented to the participants in Study 1. The protocol was adapted from the paradigm introduced by Kornell et al. (Kornell et al., 2007). The base or type I task was perceptual and consisted in identifying the largest among 9 black circles of varying size. The type II task involved a confidence judgment produced by the participants.

Participants were told to choose the *Green Tick* button if they were sure about their prior choice of circles (high confidence), and the *Red Cross* button if they were uncertain about it (low confidence). Choices were rewarded with a payoff scheme, such that the task amounted to a wagering procedure: 3 points were awarded for a high confidence rating on a correct type I response, −3 points for a high confidence rating on an incorrect type I response, and 1 point for a low confidence wager, independent of correctness on the type I response. This payoff structure is identical to the one used by Kornell et al. (Kornell et al., 2007). The number of accumulated points was displayed as colored balls on the metacognitive report screen. When participants earned 9 points, they advanced to the next level and the counter was reset. The experiment continued until participants completed 10 levels. The level structure was introduced in order to keep children engaged with the task. Prior to testing, children learnt and were familiarized with the metacognitive wagering paradigm. Briefly, an experimenter explained the rules to a child (or adult): '*We are going to play a game; first you have to find the largest circle among 9 black circles and then choose between two buttons... if you are confident/sure that you picked the largest circle, then you should press the Green Tick, but if you are uncertain about it, then you could press the Red Cross. Remember, if you press the Green Tick and*

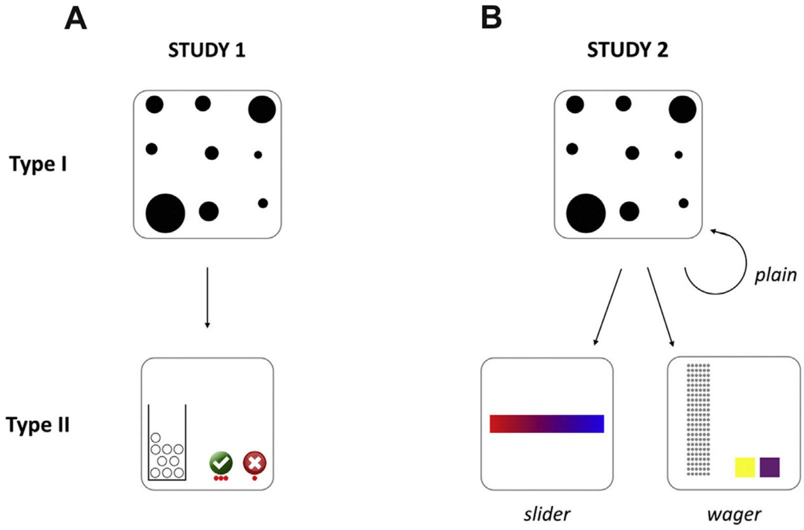

Fig. 1. Schematic design of task structure in Studies 1 and 2.

you had correctly chosen the largest circle, you win 3 points, but if you had not, you loose 3 points. If you press the Red Cross, you always win 1 point, no matter whether you had chosen the largest circle or not'.

In order to make sure that both children and adults understood how to choose the circles, how to use the wagering buttons and how the points system worked, the experimenter demonstrated with different examples, ((1) with a large circle among 8 small ones and (2) with 9 circles with the exact same size). During the presentation of the examples, if the participants had questions about how to play, the experimenter would explain the protocol again in full detail. No feedback other than the point system was given to the participants during type I or type II tasks in the study.

Type I task difficulty was controlled through a QUEST procedure (Watson & Pelli, 1983) which varied the sizes of the circles in order to fix performance at a value of about 0.75. Due to the limited number of trials, certain variability in participants' performance was nonetheless observed.

2.1.3. Data analysis

A SDT model is used to analyze the data which allows us to separate the contributions of metacognitive ability and risk aversion to the participants' wagers. The SDT model sorts participants' responses into four categories, using SDT nomenclature [19]; *hit*: correct type I, high confidence, *miss*: correct type I, low confidence; incorrect type I, *false alarm*: high confidence; *correct rejection*: incorrect type I, low confidence. Here, is assumed that the participants' confidence report (high/low) arises from thresholding an internal metacognitive signal at a certain level, the criterion (c), which is different for each subject. Further, we take this signal to be sampled from one of two normal distributions, one corresponding to the type I decision being correct, and the other to it being wrong. Both Gaussians have the same variance and differ in their means, the one corresponding to type I correct choices producing typically higher metacognitive signals (and hence producing high confidence reports more frequently). The normalized distance between the two Gaussians is, using again SDT terms, d'.

From empirical counts of hits, false alarms, misses and correct rejections, we can compute for each subject their d' and their criterion c according to the following formulae (Macmillan & Creelman, 2005):

$$d' = z(h) = z(f) \quad (1)$$

$$c = -\frac{1}{2}(z(h) + z(f)) \quad (2)$$

where z is the inverse cumulative normal distribution, h is the proportion of high confidence answers given a correct type I response (the *hit rate*), and f is likewise the proportion of high confidence answers given an incorrect type I response (the *false alarm rate*).

In this way, we distinguish between metacognitive ability, indexed by d', and the level of risk avoidance, indexed by c such that the lower its value, the more risk seeking the behavior. Importantly, the model allows us not only to discern these two aspects of the metacognitive response, but also to do so independently of performance in the type I task. The quantities produced by our model cannot however be computed whenever a subject produces no responses in one of the four categories, which was actually the case for some of our participants due to the high level of confidence reported (particularly by children). We thus choose to analyze our data both in more direct terms, such as type I performance and confidence level, and in terms of the easily interpretable d' and c whenever possible. Given that the model requires a finite amount of counts in all four categories, we disregarded participants who had no responses in at least one of them (17 children and 2 adults). An alternative procedure, which takes into account the resolution in the number of counts, would be to replace

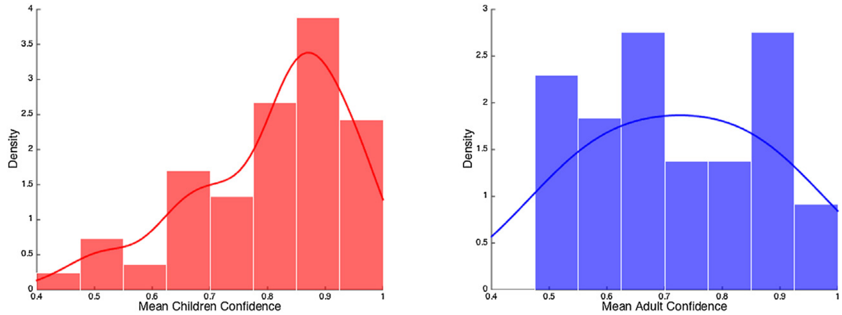

Fig. 2. Mean confidence distribution for children (red) and adults (blue) in Study 1. Solid lines are kernel density estimations for the data. Children respond with higher confidences than adults. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the cases with zero frequency with 1/2N; that is, the average between 0 and the minimum resolved frequency of 1/N, with N being the total number of counts. Applying this procedure yielded similar results to those presented below.

Finally, we introduce another aspect of the analysis made possible by the model. In the wager trials, the fact that there is a payoff associated with each type of response (3 for hits, −3 for false alarms and 1 for misses and correct rejections), allows us to compute, given a level of metacognitive access *d*', the optimal criterion c_{opt} that maximizes expected payoff through the following formula:

$$c_{opt} = \frac{1}{d'} \ln\left(2\frac{N_{wrong}}{N_{right}}\right) \quad (3)$$

where N_{right} and N_{wrong}) are the number of the subject's correct and wrong type I responses respectively. This allows us to compute how far participants are from an equally "*metacognitively able*" agent using an optimal risk policy, which, as we will see, makes for a crucial aspect of our results.

Together, *d*' and $(c - c_{opt})$ give us a complete perspective of a subject's metacognitive behavior. While *d*' tells us how accurate she is in assessing the correctness of her type I responses, $c - c_{opt}$ speaks of how she deviates from the optimal risk policy given her *d*'. A more detailed explanation of the model together with calculations leading to formulas (1), (2) and (3) can be found in the Supplementary material.

2.2. Results

First, we evaluated confidence reports as the proportion of high confidence (green tick) responses for both children and adults. Confidence is greater for children than for adults ($t\,(137) = 2.85$, $p < 0.005$, *2 sample t-test*, Fig. 2). Performances (controlled in the experiment) are in the same range for children and adults. The pattern of higher confidence in children could however be due to poor metacognition or to low risk aversion. We then turn to the analysis of the results through the use of the model introduced in the previous section to tear these effects apart.

In order to apply the model we require that, for every participant, there are nonzero counts in every entry of the table (*hits, false alarms, misses* and *correct rejections*). We thus limited the following analysis to the 93 children and 27 adults that satisfied this condition. We further tested a different version of the model replacing the zeros in the table for 1/2 in order to make it applicable to all participants, obtaining similar results.

Children's and adults' distribution of *d*' and the difference between the criterion employed by each subject and the optimal criterion for an agent with the same *d*' $(c - c_{opt})$ was evaluated next (Fig. 3). No significant differences in *d*' were found between the two age groups ($t\,(55) = 0.43$, $p = 0.66$, 2 samples, *2* tailed *t-test)*, showing that children and adults have similar metacognitive ability. This result is consistent when more traditional measures of metacognition such as ϕ and γ are used for the analysis of metacognitive abilities, which showed no differences between the two groups. Using ϕ, we computed $\phi_{children} = 0.3672$ and $\phi_{adults} = 0.3670$ ($t(68) = 0.006$, $p = 0.995$, 2 samples, 2 tailed *t-test*), whereas for γ we obtained $\gamma_{children} = 0.7136$ and $\gamma_{adults} = 0.7314$ ($t(111) = 0.417$, $p = 0.678$, 2 samples, 2 tailed *t-test*).

When we evaluated the differences in criterion, however, a clear difference appears: children tend to use a more negative criterion than adults do, meaning that they appear to be more risk seeking than adults ($t(118) = 2.16$, $p = 0.033$, 2 samples, 2 tailed *t-test*). The fact that children and adults, use criteria that are smaller than the optimal, suggests that they are both choosing betting policies which are suboptimally risky (children: $t(92) = 9.61$; $p < 1\text{E-}06$; adults $t(26) = 2.90$; $p = 0.008$, 2 tailed *t-tests*).

To summarize, we have shown that the metacognitive ability extracted through the model from the confidence judgments is similar in children and adults. However, there is a marked difference in the decision criteria: while both tend to be suboptimally overconfident, this tendency is exacerbated in children.

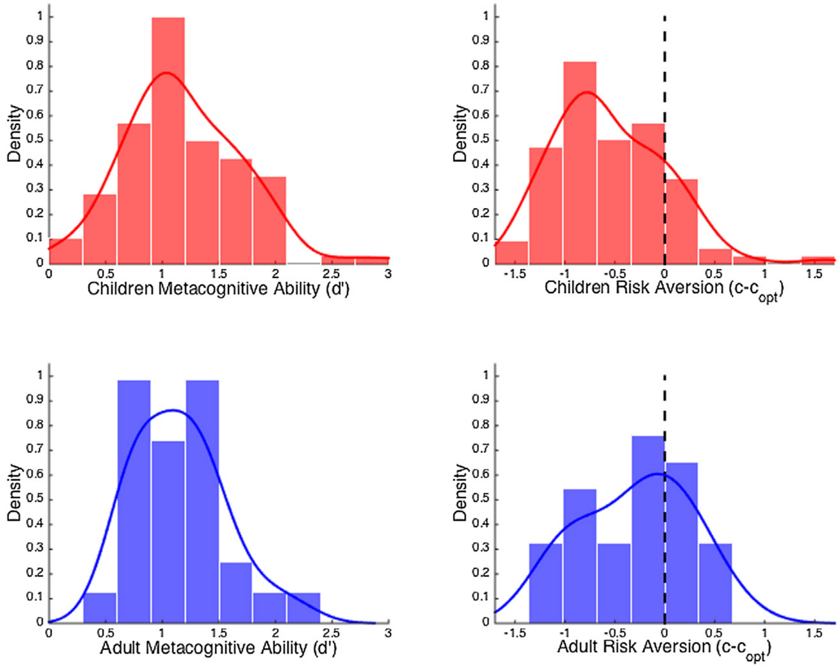

Fig. 3. Metacognitive ability (as indexed by *d*') and risk aversion (as indexed by the value of *c* with respect to the optimal criterion, c_{opt}) for children (red) and adults (blue) in Study 1. Solid lines are kernel density estimations for the data. Vertical dashed line: optimal criterion, c_{opt}. While children and adults display a similar metacognitive ability, children are more risk avid than adults. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Study 2

Study 1 showed that, as previously describe in the literature, not only are children highly overconfident in their responses, but also that this suboptimal tendency may not be due to a poor metacognitive access (*d*'), which appears to be similar in children and adults, but instead to a difference in the decision criterion (*c*) used to make their choices. To explore whether the natural tendency towards overconfidence observed could be modified, in Study 2 we introduce an alternative response method for confidence. Alongside wagering, thus, we introduced a second type of trial in which participants reported their level of confidence on their prior type I circle choice on a continuous slider without a "winning or loosing" points system. By not having a payoff, any criterion that they employed would be equally reasonable in this trial type. This new protocol was evaluated in both age groups, adults and children in the 6–8 years old range.

3.1. Method

3.1.1. Participants

Eighteen adults (9 men and 9 women, mean age: 25 years and 2 months, ranging from 21 to 35 years old) and 78 children (38 boys and 40 girls, mean age: 6 years and 5 month, ranging from 5 years to 8 years and 2 months) participated.

Six children did not complete the experiment and were thus left out of the analysis. The sample size was determined by previous experiments with children and adults and was fixed before starting data analysis. None of the children in this study had participated in the Study 1. Participant recruitment, the sample's gender, mean age and socioeconomic background were the same as in Study 1.

3.1.2. Design

The metacognition task used was similar to that of Study 1. Fig. 1B illustrates the task presented to the participants; this protocol was also adapted from the paradigm presented by Kornell et al. (Kornell et al., 2007). The base or type I task was perceptual and consisted in identifying the largest among 9 black circles of different sizes. However, the type II task had a fixed number of 114 trials. Of these trials, 20 were *plain* trials in which no metacognitive report was asked, 40 were *wager* trials in which the participants report on the correctness of their type I response with the same payoffs as in Study 1, and 40 were *slider* trials in which a continuous value of confidence was reported by clicking on a colored slider bar. The order of these trials was randomized. Notice that in this study there are only 40 wager trials per participant, which are too few to render the STD model applicable. The remaining 14 trials were periodic controls in which the difficulty of the type I task was either very high or very low. Game instructions (how to choose the circles, use buttons or the slider and how the points

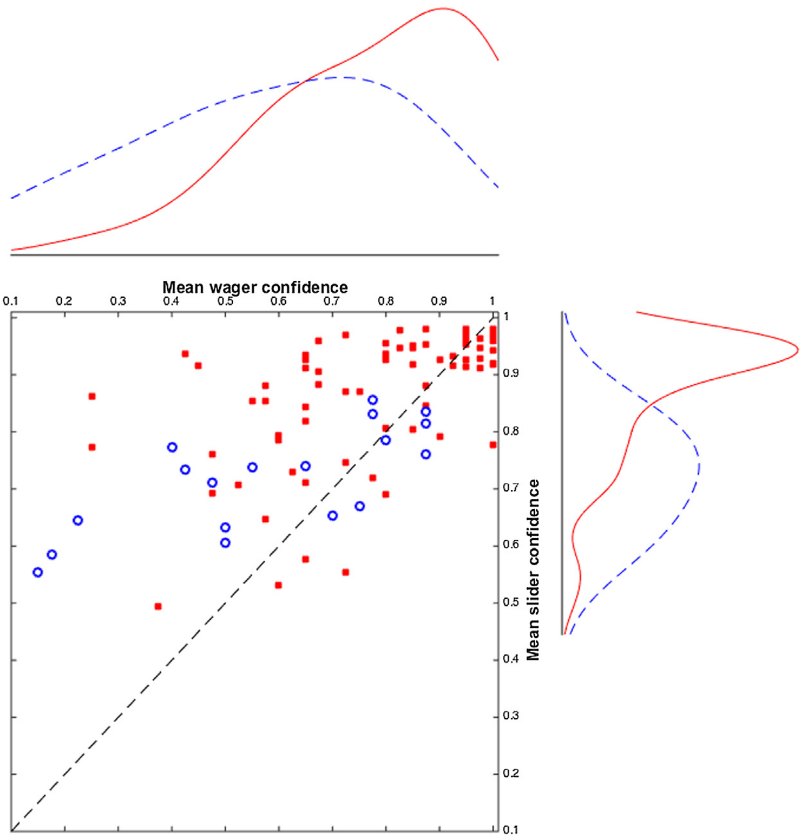

Fig. 4. Mean confidence for *wager* and *slider* trails in Study 2. Children (red filled squares, solid line); adults (blue empty circles, dashed line). Confidence reports are correlated in both input modalities for both children and adults. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

system worked) were presented by an experimenter and different examples were used to ensure that children (and adults) understood the game, in the same way as in Study 1. Also, during the presentation of the examples, if the participants had questions about how to play, the experimenter explained the protocol again in full detail. No feedback other than the point system for the *wager* trials was given to the participants during type I or type II tasks.

Children and adults first became familiar with the game and then the testing phase began. The varying type of metacognitive report proved enough to keep children motivated, so the level structure was discarded, and the point counter, which was never reset, was displayed only in *wager* trials. Further, in this type of trials, the green tick and red cross were replaced by less suggestive plain yellow and violet squares respectively.

Type I task difficulty was also controlled through a QUEST procedure (Watson & Pelli, 1983) which varied the sizes of the circles in order to fix performance at a value of about 0.75.

3.2. Results

To explore whether the tendency towards overconfidence observed in Study 1 could be modified imposing a different payoff structure in both age groups; we evaluated first the relation between mean confidence for wager and slider trials for adults and children (Fig. 4). Confidences for both trials types are significantly correlated for adults ($r = 0.75$, $p < 1E\text{-}03$) and 6–8 year old children ($r = 0.51$, $p < 1E\text{-}04$). This result suggests that participants that tend to place high wagers also report higher confidences in the slider bar.

Next, we compare confidence ratings across *input modality* (wager and slider trials) and *age group* (adults and 6–8 year olds) through a two-way *ANOVA*. We found significant effects of both input modality ($F(1191) = 13.75$, $p < 1E\text{-}03$) and age group ($F(1191) = 33.36$, $p < 1E\text{-}03$). However no significant interaction of these two factors was found.

As expected, children report higher confidences than adults in both trial types. This reinforces our previous findings that, despite both age groups being overconfident, children are more so than adults, and this result is not due to the wager payoff structure, but instead to a more general effect in reporting confidence.

Comparing input modality, we found that confidence reports in slider trials are higher than those in wager trials for both adults ($t(34) = 2.24$, $p = 0.032$, paired samples *t-test*) and children in the 6–8 year old range ($t(154) = 3.45$, $p < 1E\text{-}03$, paired samples *t-test*). This leads us to the conclusion that the general tendency towards overconfidence can be partially mitigated by setting payoffs for the metacognitive task that make high confidence unprofitable.

The extent to which payoffs can mitigate overconfidence seems to be progressive with age. The relation of the confidence reduction from slider to wager trials is slightly larger in adults than in 6–8 year old children (although not significantly so, $t(94) = 1.13$, $p = 0.26$, 2 samples *t-test*). We suggest that this progression indexes the development of a trait related to metacognitive control, as is discussed below.

4. Discussion

In the present work, we compared the metacognitive abilities of children and adults using the same perceptual type I task and type II task. The protocol and tasks were built to be age-appropriate for both groups. This was crucial given that we aimed to measure metacognitive differences between the two groups and not differences in their cognitive performance. In doing so, we strengthen the result that metacognition, as measured through our perceptual metacognitive task, is already developed in young children, as well as the notion that children are overconfident. In addition, we show here that this tendency may not be due to a poor metacognitive access (*d*'), which is not significantly different from adults, but instead to a difference in the decision criteria (*c*) employed to make their choices. Our results suggest that when middle childhood begins, metacognitive access is already at an adult level; however, the output of metacognitive monitoring to regulate these operations, metacognitive control, may not be fully developed yet. Furthermore, the results from the adult group seem to indicate that an optimal level of metacognitive control may never be achieved, given that they still present a tendency to be suboptimally overconfident.

Although prior work has addressed the development of metacognition in childhood, much work needs to be done yet. Ghetti, Withebread and others (Beran et al., 2012; Ghetti, Qin, & Goodman, 2002; Lyons & Ghetti, 2011; Schneider, 1998; Whitebread et al., 2009; Smith, Shields, & Washburn, 2003), have actively addressed this issue by introducing new experimental protocols based on age-appropriate tasks. This studies set out to overcome the previous confound between Type I and Type II tasks, where difficulties in Type 1 task domains where children were not yet developed would disturb the assessment of performance in the Type II tasks, like that observed in studies that relied heavily on language based procedures or memory (Balcomb & Gerken, 2008; Karmiloff-Smith, 1986; Lovett & Flavell, 1990). Although this new body of work addresses the issue, as the authors point out, it is still limited in that it focuses mostly on the young children's ability to experience uncertainty and act appropriately (Lyons & Ghetti, 2011; Ghetti et al., 2013).

On the other hand, only a few attempts have been made to address metacognition jointly in children and adults (Ackil & Zaragoza, 1998; Finn & Metcalfe, 2014; Metcalfe & Finn, 2012; Roebers et al., 2007; Roebers, 2002). However, many of these studies focused not on metacognitive ability, but on the degree to which participants can be biased by introducing suggestive questioning. Further, most of these studies employed memory tasks (event recall, false memories and eyewitness memories), and might thus be affected by developmental differences between the age groups in domains other than the metacognitive. For example, the work by Metcalfe and Finn (Metcalfe & Finn, 2012) showed that children exhibit a high confidence error hypercorrection effect just as young adults do. But the questionnaire the authors use to evaluate this effect, however, is not the same for children and adults (Metcalfe & Finn, 2011; Metcalfe & Finn, 2012).

In order to add to this body of evidences, we adapted a protocol for metacognitive evaluation previously used in monkeys (Kornell et al., 2007). Recently, Vo et al. used a similar paradigm to show that children can report their uncertainty nonverbally by at least the age of 6 years and suggested that a paradigm such as wagering could be used in metacognitive interventions with preschool children (Vo et al., 2014). The minimization of language dependence and the intrinsic simplicity of the game allowed us to make a direct comparison between children and adults, employing the same paradigm for all age groups. With this protocol, we were able to recover prior results showing that both children and adults have a tendency towards overconfidence (Livingston, 1997) and go further.

While confidence reports and metacognitive ability have been often considered as one and the same, they are in fact different. Metacognitive ability is not directly indexed by confidence reports, which confound the participants' attitudes towards risk. We were able to resolve these two factors through the use of a SDT model, which allowed us to show that the difference between children and adults is not one of metacognitive ability but of response criterion instead.

It seems relevant to digress at this point on the reach and limitations of our model. Mainly based on the degree to which subjects bet proportionally to their trial-by-trial accuracy, it may seem that alternative views of the observed behavior are possible, such as probability matching. This last strategy consists on, given a fixed performance rate, betting on the high and low options at a matching rate. If this was the strategy followed by the participants, however, we would observe much smaller values of *d*', since the assignment of high and low confidences, being random, would not largely correspond to correct and incorrect trials as we see in the data.

Another potential explanation of the behavioral pattern observed is related to the use of task I response times (RT) as a source for confidence wagering. RTs correlate negatively with confidence, thus, a potential mechanism for producing a type II report would consist in basing it on the time it takes for one to produce a type I response. This, provided one has direct access to these times, is indeed a plausible mechanism for confidence reporting and thus metacognition. It is however a more mechanistic explanation of behavior than the one we provide here, which stays at a higher level of abstraction. Discerning whether RT evaluation is suitable as a global mechanism for metacognition constitutes an interesting subject for further study, and has been tackled by various authors in relation with neural signals (see for example the recent work by Kiani, Corthell, & Shadlen, 2014).

Our result separating metacognitive access and risk aversion from Study 1 can be further combined with that of our second study, which exposes an even greater tendency towards overconfidence in children and adults by way of eliminating the optimal criterion. This leads us to the claim that a normative conservative behavior, imposed in our experiments through the payoff structure, tempers the natural tendency of humans towards overconfidence (for a review see Lichtenstein et al., 1977; see also Finn & Metcalfe, 2014; Schneider, 1998 as an example in children overconfidence). It is interesting to note that despite becoming more conservative, participants still fail to behave optimally.

The stronger tendency towards overconfidence that we observe in children can be associated with Piaget's concept of *wishful thinking* (Piaget, 1930), which postulates that young children are not able to differentiate between their wishes and their expectations. According to his hypothesis, children overestimate their performance not because they do not have access to it, but because they report how well they wish they performed instead (Bjorklund, 1997). In the same line, Schneider and colleagues suggest that children are capable of making accurate predictions about another child's performance, even while showing overconfidence in their own (Schneider, 1998; Stipek, 1984). In a way, the overconfidence that children display in our game may be an expression of hope for a better performance in the next trial. Similarly, it has been previously proposed that children may remain overly optimistic with a task even after a negative feedback as a protective pattern against loss of motivation (Lipko, Dunlosky, & Merriman, 2009; Lipko, Dunlosky, Lipowski, & Merriman, 2012; Shin, Bjorklund, & Beck, 2007; Bjorklund, 1997). Recent findings by Sharot et al. also show that the level of optimism of adult participants correlates negatively with their capacity to track their errors (Sharot, 2011; Sharot, Korn, & Dolan, 2011). Taking these previous findings together with our results, we venture the proposal that young children may have a metacognitive access similar to those of adults, but they could show an increased tendency towards overconfidence as a result of a feature likely related to their natural optimism.

The progression we found for the tempering of overconfidence along the two age groups also suggests that young children might be capable of evaluating the current state of their cognitive operations (metacognitive monitoring), while they might be still developing the skills for regulating their behavior from the output of this process (metacognitive control). This is in agreement with previous findings of Schneider and collaborators (2000), who support the idea that developmental trends in children's procedural metacognition, in particular metamemory, are not due to differences in basic monitoring skills but attributable to developmental changes (Schneider, Visé, Lockl, & Nelson, 2000). This also in agreement with Destan and collaborators' results, who found that children as young as 5-years old present an emerging ability to monitor and control their learning behavior successfully in a judgment of learning and confidence judgments study (Destan et al., 2014). Suggesting that children's metacognition may develop during early and middle-childhood. Nevertheless, more research needs to be done, and future investigation should study thoroughly the mechanisms behind the emergence of metacognitive monitoring and control mechanisms. In particular, metacognition is not a monolithic construct, and as such should be evaluated across a range of base tasks. The comparison of this ability in children and adults in a higher cognitive domain remains a challenge.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cogdev.2016.08.009.

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