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► To cite this version:

Belen Haza, Jawel Mersali, Charlotte Pinabiaux, Laurence Conty. A new psychometric tool for evaluating nonverbal social cue-following: regression-based normative data for children 6 to 10 years old. *Child Neuropsychology*, 2025, 35, pp.1-23. <10.1080/09297049.2025.2484336>. <hal-05017114>

HAL Id: hal-05017114

<https://hal.science/hal-05017114v1>

Submitted on 2 Apr 2025

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**A new psychometric tool for evaluating nonverbal social cue-following:
regression-based normative data for children 6 to 10 years old**

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Short title: Norms for a nonverbal social cue-following test

Number of words: 6369

Number of tables: 5

Number of figures: 3

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Abstract

The ability to follow nonverbal social cues is impaired in several disorders. Our aim was to collect normative data for the first psychometric test (TooN) that assesses this skill in children. The normative sample consisted of 339 typically developing children aged 6 to 10. TooN is a computerized tool that includes 120 trials in which children must press a button as soon as possible when an object appears on the right or left side of the screen. Each object is preceded by a video of a model gazing and/or pointing to the side where the object appears (i.e. congruent condition) or the opposite side (i.e. incongruent condition). Linear regression analyses were conducted for reaction times (RTs) and for gaze and pointing cuing effects (i.e. the difference between RTs in incongruent and congruent conditions). Regression analyses showed that age, sex and parental education significantly predicted RTs. Age and sex, but not parental education, were significant predictors of gaze cuing effects. However, age was the only significant predictor of pointing cuing effects. Based on these analyses, we provided the equations to calculate the z-scores for RTs and cuing effects. Accuracy scores, stratified by age and/or sex, are reported as percentiles. Based on the performances of typically developing children, we present the normative data of a new psychometric tool designed to assess nonverbal social cue-following. This tool can be valuable for evaluating children with neurodevelopmental disorders. To support this claim, its validity should be tested across various clinical populations.

Keywords: Nonverbal social cue-following, social cognition, neuropsychological assessment, normative data, children

Introduction

Joint attention involves coordinating one's attention with that of another person. More precisely, it refers to the ability to follow nonverbal social cues (i.e., another person's gaze, head, and/or pointing gestures) in order to have the same point of reference and share information (Mundy, 2018; Mundy, 2016). This ability emerges early, typically within the first year of life (Farroni et al., 2000, 2004; Scaife & Bruner, 1975), and plays a critical role in the development of later social abilities. Indeed, the early processing of nonverbal social cues is considered a predictor of the typical development of theory of mind (Baron-Cohen, 1995; Brooks & Meltzoff, 2015; Charman et al., 2000; Tomasello, 1995) and language abilities (Brooks & Meltzoff, 2005, 2008, 2015).

The ability to follow nonverbal social cues has been widely investigated using adaptations of the Posner cuing paradigm (Posner, 1980). In this task, participants must detect a target that appears on a computer screen by pressing a button as quickly as possible. A cue indicating either the right or left side appears in the center of the screen, just before the target appears on the side indicated by the cue (i.e., congruent condition) or the opposite side (i.e., incongruent condition). In the early versions of the task, the cue was an arrow (i.e., central cue) or a highlighted square (i.e., peripheral cue). More recently, authors have started to use nonverbal social cues, such as gaze direction, to assess social attention. Using both social and non-social cues, several studies have shown that typically developing individuals are faster at detecting the target in the congruent condition compared with the incongruent condition, which is known as *cuing effect* (for a review, see Frischen et al., 2007).

Interestingly, the cuing effect persists even when participants are informed that gaze direction does not predict the target location (Driver et al., 1999; Friesen et al., 2004; Friesen & Kingstone, 1998). These results show that processing gaze direction is difficult to inhibit,

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likely due to its early emergence in cognitive development (Farroni et al., 2002), and its crucial role in everyday social interactions (Frischen et al., 2007). While much of the research on social cuing has focused on gaze, other nonverbal social cues, such as pointing gestures and head orientation, are also known to elicit cuing effects in typically developing individuals (Belopolsky et al., 2008; Cazzato et al., 2012; Fischer & Szymkowiak, 2004; Langton, 2000; Langton & Bruce, 2000; Sato et al., 2010; Ulloa et al., 2015).

Several researchers have applied the gaze cuing paradigm to clinical populations often characterized by social deficits, such as schizophrenia (Akiyama et al., 2008; Dalmaso et al., 2013), autism spectrum disorder (ASD; Goldberg et al., 2008; Marotta et al., 2013), and attention-deficit/hyperactivity disorder (ADHD; Marotta et al., 2014). At the group level, these studies reported difficulty in gaze-following, which has also been shown in studies using eye tracking (Airdrie et al., 2018; Asgharpour et al., 2015; Chawarska & Shic, 2009; Jones et al., 2008; Temeltürk et al., 2023). These findings highlight that impairments in following nonverbal social cues are not specific to any single diagnosis but rather reflect a transdiagnostic difficulty that may be linked to broader deficits in social cognition (see Haza et al., 2024; Savla et al., 2013; Velikonja et al., 2019 for meta-analyses specific to each disorder).

Previous studies investigating nonverbal social cue-following in clinical populations based their conclusions on mean performances, without reporting individual effects. However, assessing individual performances is crucial, particularly during childhood, when diagnosis of neurodevelopmental disorders (e.g., ADHD and ASD; Sainsbury et al., 2023) and interventions to improve social skills are often underway (e.g., Storebø et al., 2019). Moreover, not all children with neurodevelopmental disorders exhibit social deficits, and there is a scarcity of psychometric tools designed to detect such deficits during childhood. Therefore, it is essential to identify children who do not spontaneously follow nonverbal social cues with an easy-to-use psychometric tool to help refine cognitive profiles and adapt the intervention strategies.

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In this study, we collected normative data using a new tool, the Tool for evaluating nonverbal social cue-following in Neuropsychological disorders (TooN), in typically developing children aged 6 to 10, which is when interventions to improve social skills are often implemented (e.g., Storebø et al., 2019). These normative data can provide clinicians with a valuable reference point to identify difficulties in nonverbal social cue-following in children.

TooN is designed to measure nonverbal social cue-following as realistically as possible, as most studies to date have used photographs or drawings of faces (Bayliss et al., 2006; Galfano et al., 2012; Marotta et al., 2014; Sato et al., 2016; Tipples, 2008; Ulloa et al., 2018), or pictures or videos of isolated hands with pointing fingers (Belopolsky et al., 2008; Cazzato et al., 2012; Fischer & Szymkowiak, 2004; Gregory et al., 2016; Sato et al., 2010; Ulloa et al., 2015). The cue and the target are usually decontextualized, presented against a black or white background. In contrast, TooN uses videos of real people showing everyday objects in an everyday life environment. With this ecological concern in mind, we manipulated a gaze condition where the model orients their gaze toward the left or the right, and a pointing condition, where the model orients their gaze, head, and arm toward the specific location.

TooN measures both gaze and pointing conditions because these may be affected differently. Indeed, pointing gestures are visually more salient than gaze deviations, leading to a stronger cuing effect, particularly in children (Gregory et al., 2016; but see also Lu & van Zoest, 2023 in adults). Moreover, in everyday contexts, the combination of gaze, head and pointing likely potentiates cuing effects. In line with this view, areas in the superior temporal sulcus, which are specialized in processing nonverbal social cues, show increased activity when several social cues are oriented in the same direction (Perrett et al., 1992). Thus, manipulating gaze and pointing conditions is clinically relevant, as some individuals may respond to pointing but not gaze, while others may not respond to either, suggesting a greater deficit.

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Few studies have explored the developmental trajectories of social cuing effects in children. Neath et al. (2013) showed that 7-year-old children had a gaze cuing effect that decreased with age until 12-13 years old, which is when adult level performance was reached. Kuhn et al. (2011) and Ristic et al. (2002) also found that children aged 3–5 and 10 years presented larger gaze cuing effects compared with adults. Using a saccadic task, Gregory et al. (2016) showed that the pointing cuing effect decreased with age between 3 and 10 years, but did not report such age-related changes for the gaze cuing effect. Still, overall, most of the findings suggest that social cuing effects decrease with age, probably because of the development of executive functions (e.g., inhibition abilities, Kramer et al., 2005) resulting from the maturation of the prefrontal cortex (Moriguchi & Hiraki, 2013). Since we calibrated ToonN in children 6 to 10 years old, our study provides the first data on the developmental trajectory of nonverbal social cue-processing using real-life social stimuli.

While several studies have reported stronger gaze cuing effects in women relative to men using a Posner-like paradigm (Alwall et al., 2010; Bayliss et al., 2005; Deaner et al., 2006; McCrackin & Itier, 2019), others have found no such sex differences (Chacón-Candia et al., 2020; Narison et al., 2020). To our knowledge, no study has investigated this issue in children, and the effect of sex on processing pointing gestures has not been examined in any population. In addition, no study has examined the effect of education on gaze and pointing cuing effects. Here, we analyzed the effects of age, sex, and parental education on social cuing effects to determine whether these variables should be considered in the normative data.

In summary, the main aim of our study was to provide normative data for the first psychometric tool, named ToonN, designed to help clinicians assess whether a child has difficulty in following nonverbal social cues. This should help them refine the child's cognitive profile and guide the adaptation of intervention strategies. For this purpose, we calculated regression-based normative data in typically developing children aged 6 to 10 years old. Using

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stimuli representative of daily life, these data allow us to investigate: (1) the differences in attentional orientation between gaze cues alone (gaze condition) and a combination of gaze, head, and pointing gestures (pointing condition) in school-aged children and (2) the effects of age, sex and parental education on the ability to follow nonverbal social cues in typically developing children.

Method

Participants

To develop normative data on TooN, a total of 438 children from 15 elementary schools in Ile-de-France participated in this study. For each participant, the age (in months) and the average years of education of the two parents were recorded. This information was coded from the first year of elementary education in France (1) to the doctorate level (20). If one of the parents did not report their level of education, only the level of education reported by the other parent was taken into consideration.

Among the 438 children, 81 were excluded for different reasons: (1) the child had a neurological, psychiatric, or neurodevelopmental disorder reported by their parents; (2) there were computer problems during the test; (3) the parents did not answer the child questionnaire; (4) the child had uncorrected vision problems; (5) the test was interrupted due to fatigue or other observable factors (e.g., children standing up or expressing unwillingness to continue); (6) the child had repeated a school year; (7) the child did not understand the instructions; and (8) the child was over 10 or under 6 years old.

Among the remaining 357 children, 18 were excluded based on their data (see statistical analyses for reasons of exclusion). The remaining 339 children had perfect or corrected-to-perfect vision, were fluent in French and had no history of brain injury or other neurological or

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psychiatric disorders. All parents of the children were informed of the goal of the study and provided written informed consent, according to institutional ethics committee guidelines. The procedure was approved by the Ethics Committee of the Department of Psychology of Paris Nanterre University (ID: 2020-12-01).

Materials

The Tool for evaluating nonverbal social cue-following in Neuropsychological disorders (TooN) was developed in Python language by Jawel Mersali, an independent computer engineer. It is based on Posner's paradigm but uses videos of real people sitting at a desk and gazing and/or pointing at everyday objects in a realistic environment.

Videos

Eight models (4 women, aged 21 to 45, $M = 31.7$, $SD = 9.2$) were selected from a pre-test (see Supplementary Material). They were individually filmed sitting at a desk and facing the camera under controlled conditions (i.e. black t-shirt, hair tied, neutral facial expression) and uniform lighting. The background featured a room with a window, a dark background, white walls, wooden ceiling, and a plant. Each model appeared in four videos: two in which the model turned their gaze to the right (Gaze Right) or left (Gaze Left), and two in which the model pointed to one side of the desk while also turning their head and gaze in the same direction (Pointing Right, Pointing Left). The videos were edited to capture 1.5 seconds before and 4.5 seconds after the movement's onset.

Objects

Eight commonly used objects (stapler, notebook, pair of scissors, glasses, watch, mobile phone, pen, and scotch tape) were selected from a pre-test (see Supplementary Material). In the Gaze condition, the object was positioned near the model's head, while in the Pointing

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condition, it appeared on the desk. Object sizes were adjusted to maintain natural proportions relative to the scene.

Procedure

Each child was seated individually in a quiet room of their school to avoid auditory and/or visual distractions. ToonN was administered on different portable computers. In each test, the computer was centered relative to the median of the participant's body and the distance between the child and the screen was measured for each computer so that the objects appeared at approximately the same visual angle in the periphery.

ToonN presents two sequences of 60 trials, in an order randomly chosen by the program. Each sequence lasts approximately 5 min. Each trial started with a blue fixation circle presented for 500 milliseconds (ms). Then, a video appeared in one of the four conditions (Gaze Right, Gaze Left, Pointing Right, Pointing Left). Afterwards, an object appeared on the target side of the gaze or pointing finger (i.e., congruent trials) or on the opposite side (i.e., incongruent trials). Thus, four conditions were tested: Gaze Congruent, Gaze Incongruent, Pointing Congruent, Pointing Incongruent (see Figure 1 for an illustration of the four conditions and Figure 2 for an illustration of the time course of an experimental trial in the Gaze and Pointing conditions). The object appeared 2.4 seconds after the video's onset in the Gaze condition and 2.8 seconds after the video's onset in the Pointing condition.

-----Figure 1 about here-----

-----Figure 2 about here-----

In each sequence, there were 48 trials with objects and 12 without objects. Among the 48 trials with objects, 32 were congruent and 16 were incongruent (with half of the trials pointing/gazing to the right and half to the left). Thus, there were 16 congruent trials and eight

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incongruent trials for each cuing condition (Gaze and Pointing). The eight models and the eight objects were seen twice in each congruent condition (once on the left and once on the right) and once in each incongruent condition (half of the objects and models on the left and half on the right). An additional 12 trials without objects were added (i.e., catch trials) to make sure participants waited for the object to appear to press the button. For the catch trials, each model was presented again one or two times, in a randomly picked condition, so that every four conditions (*2 Cues (Gaze / Pointing) x 2 Fields (Left / Right)*) were seen three times. The distribution of the trials was based on an algorithm close to the Fisher–Yates, to ensure there would not be more than two catch trials in a row, and that the models were uniformly distributed.

The children’s task was to press the space bar as fast as possible when an object appeared, or, if none appeared, to not answer. They pressed the space bar with their dominant hand. Once the answer was given or after the video’s offset, the next trial began. The order of appearance of the trials in each sequence was random and changed for each participant.

In addition to TooN, children completed the French Version of the Self-Report Strengths and Difficulties Questionnaire (SDQ; Capron et al., 2007; Goodman et al., 1998, 2003) and the visual attention test of the NEPSY-I (Korkman, 1998). These tests were administered between the two sequences to control time (~10 minutes) and to provide an activity similar to that presented during neuropsychological testing. For further details on the materials and procedures, see Supplementary Material.

Statistical analyses

Data exclusions

We computed the Percentage of Correct Responses (%CR) and the Reaction Times (in ms) of the correct responses in trials with objects (RTs). RTs inferior to 200 ms and exceeding 3

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standard deviations above the mean (per subject and per condition) were rejected (0.76% of the total number of trials). Of the 357 children who participated, 18 were excluded from all the analyses: 15 had abnormally small %CR (%CR reaching 3 standard deviations below the group mean) and the remaining three children had abnormally long RTs (RTs exceeding 3 standard deviations from the group mean).

Preliminary analyses

Statistical analyses were conducted in the R environment (version R-4.4.1, R Core Team, 2024). First, we assessed the reliability of TooN across all the participants by estimating the internal consistency of RTs for each condition using a permutation-based splithalf approach (Parsons, 2021) with 20000 random splits.

Gaze and Pointing cuing effects were calculated by determining the difference between congruent and incongruent trials (RTs for Incongruent trials – RTs for Congruent trials). To analyze these cuing effects, we conducted an analysis of variance with Cue (Gaze vs. Pointing) as the within-subject factor and Age (6 years vs. 7 years vs. 8 years vs. 9 years vs. 10 years) as the between-subject factor. When an effect was significant, the partial eta squared (η^2_p) values were indicated as effect size indexes and post-hoc tests with Bonferroni correction were performed. For each age group (6 years vs. 7 years vs. 8 years vs. 9 years vs. 10 years), the significance of the Gaze and Pointing Cuing Effects was tested with a two-tailed t-test against 0. Cohen's d values are reported as an index of effect size. These analyses aimed to assess the robustness of the cuing effects and the reliability of TooN in measuring nonverbal social cue-following.

Finally, to preliminarily assess the construct validity of TooN, we performed partial Spearman's correlation analyses between TooN performances (RT Global, Gaze Cuing Effect, and Pointing Cuing Effects) and the visual attention score from the NEPSY. These analyses were controlled for the confounding effect of Age and adjusted using Bonferroni corrections.

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Normative data calculations

To calculate normative data, we selected 10 dependent variables: five related to RTs (RT Global, RT Gaze Congruent, RT Gaze Incongruent, RT Pointing Congruent, RT Pointing Incongruent), two related to cuing effects (Gaze Cuing Effect, Pointing Cuing Effect) and three related to accuracy scores (%CR, Omissions, False Alarms). False Alarms occurred when a child pressed the button when no object appeared or within 200 ms of an object's appearance. The latter trials were considered as anticipated responses because the participant responded before having had time to process the stimulus (Ethier et al., 2015). Omissions happened when the child failed to press the button when an object appeared.

For RTs and Cuing Effects, we developed regression-based normative data following approaches similar to those previously described in the literature (Fellows & Schmitter-Edgecombe, 2019; Parmenter et al., 2010; Stricker et al., 2021; Testa et al., 2009). To normalize the data, raw test scores were converted into cumulative frequencies relative to the distribution of raw scores. These frequencies were then transformed into scaled scores with a mean of 10 and a standard deviation of 3. Then, we conducted a total of seven multiple linear regression models to estimate performance across all tests' scaled scores (RT Global, RT Gaze Congruent, RT Gaze Incongruent, RT Pointing Congruent, RT Pointing Incongruent, Gaze Cuing Effect, Pointing Cuing Effect) based on demographic characteristics (Age, Sex, and Parental Education). In the seven initial models, we included Age, Sex, Parental Education and all two-way interactions as predictors. Age and Parental Education were included as continuous variables in the analyses, while Sex was coded 0 for girls and 1 for boys. Since no interactions reached significance, they were excluded from the final models. To determine which demographic variables were necessary in each model, we used a hybrid model selection approach, combining forward and backward selection strategies. This selection process

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iteratively adds and removes predictors based on the Akaike Information Criterion (AIC), selecting the model with the lowest AIC at each step.

After fitting the models and selecting the relevant demographic variables, the assumptions of regression analysis (normality, homoscedasticity, absence of multicollinearity, and absence of outliers) were verified for each model. Normality was tested by examining Q-Q plots of the residuals. Homoscedasticity was assessed by dividing participants into tertiles based on their predicted scores and applying Levene's test to the residuals. Multicollinearity was evaluated by computing the Variance Inflation Factors (VIFs), with values below 5 indicating acceptable levels (Akinwande et al., 2015). Finally, the absence of outliers was analyzed with Cook's distances, with values greater than 1 indicating potential outliers (Cook, 1986).

Using the results from the final models, TooN first converts participants' raw scores into unadjusted scaled scores. Then, these scaled scores are adjusted to z-scores in three steps. First, the predicted score is calculated based on the participant's values for each predictor (e.g., Age, Sex, Parental Education) and the regression weights from the normative sample [$\text{Predicted value} = B_0 + B_1 X_1 + B_2 X_2 + \dots + B_k X_k$]. Second, the residuals are computed as the difference between the observed and predicted scores [$e = \text{Observed value} - \text{Predicted value}$]. Third, these residuals are standardized to obtain the z-score [$z\text{-score} = e / \text{SD}(e)$].

Due to the highly skewed and heteroscedastic distribution of accuracy scores (%CR, Omissions, and False Alarms), nonparametric analyses were conducted to determine the sociodemographic variables that were associated with these performances. We conducted a Kruskal-Wallis test to estimate the effect of Age and Parental Education. Age was categorized into five groups: 6 years, 7 years, 8 years, 9 years, and 10 years. Similarly, Parental Education levels were categorized into five groups: 1-9 years, 10-12 years, 13-15 years, 16-17 years, and 18-20 years. These categories are based on key qualifications in the French education system,

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reflecting typical educational progression (*Ministère de l'Enseignement supérieur, de la Recherche et de l'Innovation*, 2021): secondary school diploma (9 years), high school diploma (12 years), Bachelor's degree (15 years), Master's degree (17 years), and Doctorate (20 years). In addition, we applied a Mann–Whitney–Wilcoxon test to assess the effect of Sex (Girls vs. Boys) on each dependent variable. When an effect was significant, post-hoc tests with Bonferroni correction were performed. Percentiles were generated for each variable according to the significant effects.

Data availability

Data and code supporting the analyses are publicly available at <https://osf.io/68fre/>.

Results

Demographic characteristics

The final normative sample consisted of 339 typically developing children (169 girls and 170 boys) aged between 6 and 10 years old (mean Age in months = 101.2, SD = 16.7), with Parental Education levels ranging from 6 to 20 years (mean Parental Education level = 14.3, SD = 3.0). Table 1 shows the demographic characteristics of the participants.

-----Table 1 about here-----

Preliminary analyses

First, consistency estimates of RTs in each condition ranged from 0.77 to 0.86 (Global $r_{\text{Spearman-Brown corrected}} = 0.79$, 95%CI [0.75, 0.83]). These values are consensually recognized as good indicators of reliability (Parsons et al., 2019).

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Then, the analysis of variance conducted on Cuing Effects showed an effect of Cue, $F(1.334) = 53.19$, $\eta^2_p = 0.14$, $p < .001$. The Pointing Cuing Effect ($M = 93$, $SD = 88$) was larger than the Gaze Cuing Effect ($M = 50$, $SD = 90$). There was also an effect of Age, $F(4.334) = 6.75$, $\eta^2_p = 0.08$, $p < .001$: 6-, 7-, 8- and 9-year-old children had a larger cuing effect than 10-year-old children (all $ps < .05$). However, there was no significant interaction between Cue and Age, $F(4.334) = 2.25$, $p = .06$. Analyses also confirmed that Gaze and Pointing Cuing Effects were both significantly higher than 0 for all age groups (all $ts > 3.81$, all $ps < .001$, all $ds > 0.46$; except for Gaze in 10-year-olds, $t = 2.70$, $p < .01$, $d = 0.34$).

After performing partial Spearman's correlation analyses to control for Age and applying the Bonferroni correction, we showed that visual attention scores correlated with Global RT ($\rho = -0.14$, $p < .05$) but not with Gaze Cuing Effect ($\rho = -0.03$, $p > .1$) or Pointing Cuing Effect ($\rho = -0.03$, $p > .1$).

Multiple linear regression analyses of RTs and cuing effects

Table 2 provides the conversion of raw scores to unadjusted scaled scores. The final multiple linear regression models and their results are presented in Table 3. The associations between the predictors included in the final models (Age, Sex, and/or Parental Education) and the primary dependent variables (RT Global, Gaze Cuing Effect, and Pointing Cuing Effect) are illustrated in Figure 3. For each RT and cuing effect model, results show no violations of assumptions.

-----Table 2 about here-----

-----Table 3 about here-----

-----Figure 3 about here-----

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In the RT models, the hybrid selection approach identified Age, Sex, and Parental Education as the best-fit predictors. The RT Global model accounted for 32% of the variance ($F(3.335) = 52.87, p < .001$), the RT Gaze Congruent for 31% ($F(3.335) = 49.68, p < .001$), the RT Gaze Incongruent for 33% ($F(3.335) = 55.23, p < .001$), the RT Pointing Congruent for 27% ($F(3.335) = 41.59, p < .001$), and the RT Pointing Incongruent for 30% ($F(3.335) = 48.69, p < .001$). Across all five models, higher Age and Parental Education were associated with smaller RTs. Also, girls ($M = 715$ ms, $SD = 224$) had longer RT Global than boys ($M = 627$ ms, $SD = 180$). Inspection of the β indices across all these models indicated that Age was the best predictor, followed by Sex and Parental Education.

In the Gaze Cuing Effect model, the hybrid selection approach identified Age and Sex as the best-fit predictors, accounting for 4% of the variance, $F(2.336) = 7.78, p < .001$. Older Age was associated with a smaller gaze cuing effect, and girls ($M = 64$ ms, $SD = 95$) exhibited a larger effect than boys ($M = 36$ ms, $SD = 83$). Inspection of the β indices indicated that Sex was a stronger predictor than Age. In the Pointing Cuing Effect model, Age was the only significant predictor, accounting for 7% of the variance, $F(1.337) = 24.68, p < .001$.

While TooN automatically calculates z-scores for each raw score after testing, normative data can also be derived manually. First, the raw test score is converted into an unadjusted scaled score using Table 2. Second, the predicted score can be computed using the regression results from Table 3. Third, residuals can be calculated [$e = \text{Observed value} - \text{Predicted value}$] and standardized [$z\text{-score} = e / SD(e)$] using the same Table 3. Detailed procedures and equations for adjusting z-scores based on Age, Sex, and/or Parental Education are provided in the Supplementary Material.

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Percentiles for accuracy scores

Results showed an effect of Age on %CR, $\chi^2 = 35.58$, $p < .001$; on Omissions, $\chi^2 = 37.32$, $p < .001$; and on False Alarms, $\chi^2 = 26.45$, $p < .001$. Indeed, 6- year-old children had smaller %CR and made more omissions than 8-, 9- and 10-year-old children (all $ps < .01$). In addition, 7- year-old children had smaller %CR than 8- and 10-year-old children (all $ps < .05$) and made more Omissions than 10-year-old children ($p < .05$). The 6- and 7-year-old children also made more False Alarms than 8- and 10-year-old children (all $ps < .05$). However, no effects of Parental Education or Sex were observed except for False Alarms, in which girls ($M = 1.3$, $SD = 2.1$) had better performances than boys ($M = 1.7$, $SD = 2.2$), $W = 12238$, $p < .05$.

As there were differences in performance between the groups of 6- and 7-year-olds versus the 8-, 9-, and 10-year-olds, we computed percentiles independently for each of these cohorts. Based on our results, we considered Sex only in relation to False Alarms (Table 4).

-----Table 4 about here-----

Discussion

The aim of this study was to collect normative data for a new computerized tool, named ToonN, designed to assess whether a child spontaneously follows nonverbal social cues. To that end, linear multiple regressions were performed for each RT and cuing effect score using age, sex, and parental education as predictors, while percentiles were provided for accuracy scores. Results revealed that: (1) the cuing effects were observed at each age, and pointing (which corresponds to the cumulative presentation of gaze, head, and pointing gestures) led to larger cuing effects than gaze alone; (2) RTs and cuing effects decreased with age; (3) girls had larger RTs and gaze (but not pointing) cuing effects than boys; (4) parental education was a significant predictor of RTs, but not of cuing effects. Results are discussed in detail below.

Nonverbal social cue-following: assessment and reliability insights

To our knowledge, our study is the first to investigate nonverbal social cue-following using Posner's paradigm with videos of real people gazing and/or pointing at everyday objects in a realistic environment. Firstly, our data show that children's cuing effects are robust, and their performance exhibits good internal consistency, indicating that TooN is reliable. Moreover, typically developing children had larger cuing effects when exposed to a combined presentation of gaze, head, and pointing gestures (i.e., pointing condition) compared with gaze alone (i.e., gaze condition). These findings suggest that natural pointing enhances cuing effects relative to natural gaze, which is in line with previous findings manipulating isolated hand gestures (Gregory et al., 2016). In our study, the combined presentation of head, gaze and arm orientation has likely contributed to this potentiation, highlighting the power of combining several nonverbal social cues in directing attention (Langton et al., 2000). Future research should explore TooN's applicability in clinical populations and assess whether gaze and pointing cuing effects may be affected differently.

To preliminary assess the validity of TooN, we investigated its relationship with visual attention abilities. As expected, results revealed that visual attention scores from the NEPSY correlated negatively with Global RTs, but not with gaze or pointing cuing effects. This supports the divergent validity of the cuing effects, with RT scores measuring visual attention, and gaze and pointing cuing effects measuring a different construct. Further research should investigate TooN's validity in relation to other cognitive domains (e.g., additional aspects of attention, inhibition, and social cognition) to refine its interpretability and clinical applicability. Moreover, to verify TooN's clinical utility, future studies should examine how performances relate to real-life social functioning, as assessed by standardized parent- and teacher-rated

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measures (e.g., SRS-2, The Social Responsiveness Scale; Constantino & Gruber, 2012) and observations during spontaneous social interactions (Tsamitrou & Plumet, 2024).

TooN's normative data

Based on the analyses described in this study, we developed an outcome interface in TooN, allowing for the comparison of a child's performance to that of our normative sample to determine if the child's scores deviate from the norm (Amieva et al., 2011). To identify the level of impairment of a given child, TooN automatically calculates adjusted z-scores for each RT and cuing effect condition, taking into account age, sex and/or parental education. These variables were adjusted using linear regression analyses, as this method offers more reliable results than the traditional method. In the traditional approach, z-scores are calculated by subtracting the mean of a comparison group of a similar age and sex from the individual's raw score and dividing by the group's standard deviation. However, this method can introduce inconsistencies because it relies on arbitrary categories such as age and education groups. An individual's relative standing may vary significantly when they move from one group to another (Crawford & Howell, 1998). In contrast, multiple linear regression provides a more accurate estimate of a participant's expected result by considering their unique characteristics (e.g., age, sex, parental education) without grouping them into arbitrary categories. This approach reduces demographic biases often encountered when using raw scores in clinical tests (Van Der Elst et al., 2006).

In addition to RTs and cuing effects, TooN provides accuracy scores (%CRs, false alarms and omissions), which can also serve as normative measures for evaluating a child's cognitive functioning. However, given their skewed and heteroscedastic distribution, we provided normative data based on percentiles rather than z-scores.

In clinical practice, z-scores below -1.65 or above +1.65 (which correspond to percentiles 5 and 95, respectively) are commonly used as thresholds to determine deviation

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from the norm (Colombo et al., 2016). Using our normative data, clinicians could use these thresholds to identify abnormal RTs or accuracy scores. However, to interpret cuing effects, we propose an alternative approach that enables clinicians to place the child's performance on a continuum, providing several interpretations (identical for both the Gaze and Pointing conditions). After each test, TooN provides these interpretations alongside the raw and standardized scores obtained by the patient. These interpretations are informed by the consensus guidelines from Guilmette et al. (2020) for labeling performance on clinical tests. As detailed in Table 5, they help clinicians assess whether a patient follows nonverbal social cues. Clinical applications of these interpretations are described in the Supplementary Material.

-----Table 5 about here-----

Effects of sociodemographic characteristics

Age was a significant predictor of RTs and of gaze and pointing cuing effects. Although the effect was small, particularly for the gaze cuing effect, it confirmed that cuing effects decreased with age, as reported by previous studies (Gregory et al., 2016; Kuhn et al., 2011; Neath et al., 2013; Ristic et al., 2002). Neath et al. (2013) showed that the gaze cuing effect decreased until 12-13 years of age, which is when adult performance was reached. In our study, the gaze cuing effect in 10-year-old children is already relatively small. This decrease with age has been associated with the development of inhibition abilities, as a consequence of the maturation of the prefrontal cortex (Kramer et al., 2005; Moriguchi & Hiraki, 2013).

Our analyses also showed that sex was a significant predictor of RTs and the gaze cuing effect, but not the pointing cuing effect. Although the effect was small, girls showed a larger gaze cuing effect than boys. This finding aligns with previous studies in adults, showing that women are generally more sensitive to gaze direction than men (Alwall et al., 2010; Bayliss et al., 2005; Deaner et al., 2006; McCrackin & Itier, 2019). This difference is often attributed to

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women's stronger social skills, including greater empathy, facial emotion recognition, and understanding of mental states (e.g., Bosacki, 2000; Derntl et al., 2010; Suzuki et al., 2006). However, given that boys had faster RTs than girls in both congruent and incongruent trials, the smaller gaze cuing effect in boys may be the result of using a performance-oriented approach. Moreover, our results showed no sex differences in the pointing cuing effect. This strengthens the view that this condition triggers strong attentional orientation, which may be less influenced by individual strategy differences related to gaze.

While parental education was a significant predictor of RTs, this was not the case for gaze and pointing cuing effects. To our knowledge, our study is the first to examine the link between education and social cuing effects. The lack of significant findings converges toward the view that social cuing effects rely on innate mechanisms that are unaffected by learning processes (Baron-Cohen, 1995; Perrett & Emery, 1994).

Limitations

Our study has several limitations. First, although we ensured participants had no known history of brain injuries, neurological or psychiatric conditions, or neurodevelopmental disorders (e.g., ADHD, ASD, or language disorders), we probably included children with undiagnosed disorders. Due to logistical and time constraints, we were unable to formally verify the absence of such disorders in each child using diagnostic tools (e.g., the Schedule for Affective Disorders and Schizophrenia for School-Age Children-Present and Lifetime Version; K-SADS-PL; Kaufman et al., 1997). However, testing a group of "perfect" children can also be a limitation, as it may lead to the over-diagnosis of cognitive impairments in children assessed later.

Second, our sample included a substantial number of both girls and boys, as well as a wide range of ages and education levels. However, there was an underrepresentation of children with low levels of parental education (less than 9 years) relative to the demographic profile of

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individuals aged 35-44 residing in France (*Institut National de la Statistique et des Sciences Economiques*, 2020).

Third, as social attention varies by cultural context (Marchesi et al., 2023; Zhang et al., 2020, 2021), the provided norms may not be suitable for all cultures. In particular, caution is advised when interpreting the results of TooN in non-Western populations (see for example Astor & Gredebäck, 2022). Beyond cultural differences, characteristics of the model such as age, gender, ethnicity, expressiveness and social familiarity may also influence children's responses. Future research is needed to determine how these factors impact their ability to follow nonverbal social cues.

Finally, TooN only tests the ability to follow nonverbal social cues, but not other non-social symbols such as a central arrow. This limits its capacity to identify specific difficulties in the social domain. However, arrows trigger cuing effects very similar to gaze, and the existence of divergent mechanisms subtending these two types of cues is debated (for a meta-analysis, see Chacón-Candia et al., 2023). Moreover, extending the test duration would pose practical challenges, and neuropsychological tests are rarely designed to be used on their own. A comprehensive understanding of a patient's cognitive functioning requires assessing multiple domains. TooN is designed to be part of a broader neuropsychological assessment. For example, if a patient does not follow gaze and/or pointing cues, clinicians must interpret this in conjunction with performance on other cognitive tests to determine whether the difficulty is social in nature or if it stems from an underlying executive and/or attention impairment. Furthermore, it is important to note that even if the deficit in social cue-following is not purely social, such deficits must be considered in neuropsychological care, as they could lead to impairments in the social domain.

Conclusions and clinical implications

We developed TooN, a tool designed to assess nonverbal social cue-following, and collected normative data from a sample of 339 typically developing children aged 6 to 10 years old. TooN aims to help clinicians refine cognitive profiles and adapt intervention strategies. For children with difficulties in social cue-following, clinicians might recommend interventions targeting joint attention mechanisms. Several such interventions have been developed, some based on structured reinforcement, prompting, and modeling (Applied Behavior Analysis – ABA; Martins & Harris, 2006; Taylor & Hoch, 2008), while others emphasize natural settings and interactive play (Naturalistic Developmental Behavioral Interventions – NDBIs; Schreibman et al., 2015). Although these interventions have mainly been studied in preschoolers, research suggests that they may also benefit school-age children (Basso et al., 2021). Moreover, recent technology-mediated interventions, such as augmented reality and social robots, provide new and engaging ways to enhance joint attention (Pérez-Fuster et al., 2022; Sani-Bozkurt & Bozkus-Genc, 2023). Conversely, if a child spontaneously follows nonverbal social cues, clinicians can consider this strength during interventions to better direct the child’s attention and work on improving their attentional or executive functions. Overall, TooN is a neuropsychological tool that assesses nonverbal social cue-following in typically developing children. Its validity now needs to be tested in clinical populations to confirm its broader applicability.

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Acknowledgments

We would like to thank the Hauts-de-Seine Departmental Education Services for allowing us to conduct this study in their schools, as well as all children, parents, teachers, and principals of the participating schools. We would also like to thank Yoann Yilmaz, Laetitia Yeranian, Maud Gaucher and Vanessa Barbier, master's students in Neuropsychology, for their participation in testing the tool. Finally, we would like to thank Fabien Cerrotti, Corentin Gosling and Romain Di Stasi for their help and advice on the statistical analyses.

Disclosure statement

The authors report there are no competing interests to declare.

Data availability statement

Data and code supporting the analyses are publicly available at <https://osf.io/68fre/>.

Funding details

This study was supported by Paris Lumières University (project “TooN-2019.22”).

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Tables

A new psychometric tool for evaluating nonverbal social cue-following: regression-based normative data for children 6 to 10 years old

Table 1. Demographics of participants in the normative sample (N = 339).

Table 2. Conversion of raw scores to unadjusted scaled scores.

Table 3. Final multiple linear regression models after hybrid selection process.

Table 4. Percentiles for accuracy scores.

Table 5. Interpretations provided by Toon based on the scores obtained.

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Table 1. Demographics of participants in the normative sample (N = 339).

Characteristics	N	%	Mean (SD)
Age			
6 years	67	19.8	78.3 (3.2) months
7 years	69	20.3	89.8 (3.8) months
8 years	76	22.4	101.7 (3.3) months
9 years	64	18.9	113.5 (3.0) months
10 years	63	18.6	125.3 (3.7) months
Parental Education			
1-9 years (Primary and secondary school)	33	9.7	8.5 (0.7) years
10-12 years (High school)	67	19.8	11.4 (0.7) years
13-15 years (Bachelor's degree)	88	26.0	14.0 (0.8) years
16-17 years (Master's degree)	121	35.7	16.7 (0.5) years
18-20 years (Doctorate)	30	8.8	18.4 (0.9) years
Sex			
Girls	169	49.9	
Boys	170	50.1	

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Table 2. Conversion of raw scores to unadjusted scaled scores.

SS	Raw scores (in ms)						
	RT Global	RT Gaze Congruent	RT Gaze Incongruent	RT Pointing Congruent	RT Pointing Incongrue nt	Gaze Cuing Effect*	Pointing Cuing Effect*
2	≤ 361	≤ 360	≤ 362	≤ 348	≤ 366		
3	362-373	361-375	363-392	349-369	367-379		
4	374-406	376-407	393-418	370-378	380-417		
5	407-437	408-428	419-458	379-397	418-437		
6	438-466	429-462	459-485	398-431	438-469		1-7
7	467-494	463-492	486-524	432-451	470-500		8-24
8	495-537	493-547	525-575	452-493	501-557	1-8	25-39
9	538-585	548-587	576-624	494-540	558-619	9-29	40-61
10	586-640	588-641	625-697	541-581	620-693	30-52	62-89
11	641-743	642-750	698-818	582-678	694-788	53-86	90-121
12	744-831	751-843	819-907	679-768	789-895	87-110	122-153
13	832-927	844-959	908-1031	769-848	896-994	111-140	154-192
14	928-1066	960-1074	1032-1153	849-978	995-1104	141-186	193-237
15	1067-1151	1075-1123	1154-1220	979-1071	1105-1229	187-230	238-277
16	1152-1173	1124-1202	1221-1307	1072-1099	1230-1287	231-289	278-323
17	1174-1245	1203-1299	1308-1366	1100-1148	1288-1371	290-304	324-384
18	1246-1269	1300-1334	1367-1412	1149-1215	1372-1448	305-354	385-426
19	≥ 1270	≥ 1335	≥ 1413	≥ 1216	≥ 1449	≥ 355	≥ 427

Note: SS = Scaled Score; *Negative values for Gaze and Pointing Cuing Effects are not provided because TooN does not calculate a z-score in such cases. Instead, these results are classified as “non-responders”, as there is no observable difference between congruent and incongruent trials.

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Table 3. Final multiple linear regression models after hybrid selection process.

Variables	B	SE (B)	β	T	RMSE	R ²
RT Global					2.466	0.321***
(Constant)	21.820	1.046		20.867***		
Age	-0.091	0.008	-0.509	-11.297***		
Sex	-1.060	0.271	-0.177	-3.906***		
Parental Education	-0.142	0.045	-0.141	-3.122**		
RT Gaze Congruent					2.491	0.308***
(Constant)	21.723	1.056		20.573***		
Age	-0.090	0.008	-0.504	-11.075***		
Sex	-0.905	0.274	-0.151	-3.302**		
Parental Education	-0.147	0.046	-0.146	-3.202**		
RT Gaze Incongruent					2.449	0.331***
(Constant)	21.868	1.038		21.062***		
Age	-0.092	0.008	-0.511	-11.427***		
Sex	-1.178	0.269	-0.197	-4.373***		
Parental Education	-0.138	0.045	-0.138	-3.063**		
RT Pointing Congruent					2.555	0.271***
(Constant)	20.758	1.083		19.159***		
Age	-0.083	0.008	-0.461	-9.881***		
Sex	-1.079	0.281	-0.180	-3.839***		
Parental Education	-0.127	0.047	-0.127	-2.706**		
RT Pointing Incongruent					2.498	0.304***
(Constant)	21.483	1.059		20.283***		
Age	-0.089	0.008	-0.494	-10.840***		
Sex	-1.034	0.275	-0.173	-3.761***		
Parental Education	-0.137	0.046	-0.137	-2.983**		
Gaze Cuing Effect					2.927	0.044***
(Constant)	12.755	0.991		12.866***		
Age	-0.022	0.010	-0.122	-2.294*		
Sex	-1.007	0.319	-0.168	-3.152**		
Pointing Cuing Effect					2.890	0.068***
(Constant)	14.773	0.968		15.260***		
Age	-0.047	0.009	-0.261	-4.968***		

Note: RMSE = Root Mean Square Error; ***p < .001; **p < .01; *p < .05.

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Table 4. Percentiles for accuracy scores.

Measure	Percentiles								
	1 st	2 nd	5 th	10 th	15 th	25 th	50 th	75 th	95 th
%CR									
6-7 years	89.5	90.0	92.5	94.2	95.0	96.7	98.3	99.2	100
8-10 years	92.5	93.4	96.7	97.5	98.3	98.3	99.2	100	100
Omissions									
6-7 years	8	4	2	2	1	1	0	0	0
8-10 years	3	2	1	1	0	0	0	0	0
False Alarms									
6-7 years									
Girls	9	9	7	5	4	3	1	0	0
Boys	11	10	7	6	6	3	1	1	0
8-10 years									
Girls	9	8	3	2	2	1	0	0	0
Boy	6	5	4	3	3	2	1	0	0
s									

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Table 5. Interpretations provided by TooN based on the scores obtained.

Score	TooN interpretation
Raw score ≤ 0 ms*	Non-responder
z-score < -1.341	Very low responder
$-1.341 \leq$ z-score < -0.674	Low responder
$-0.674 \leq$ z-score $< +0.674$	Responder
z-score $\geq +0.674$	High responder

Note: *If the cuing effect is 0 ms or less, TooN does not calculate a z-score and categorizes the result as “non-responder”, as there is no advantage observed in congruent trials compared with incongruent trials.

Figures

A new psychometric tool for evaluating nonverbal social cue-following: regression-based normative data for children 6 to 10 years old

Figure 1. Illustration of four trials.

Figure 2. Time course of an experimental trial in the Gaze and Pointing conditions.

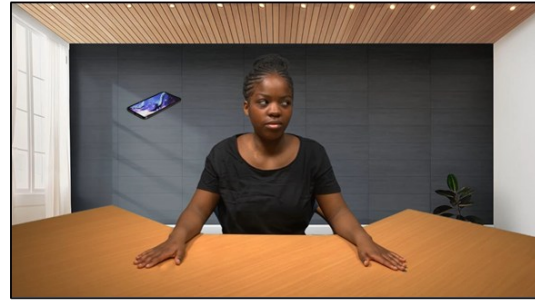
Figure 3. Illustration of the relationships between predictors included in the final models and the dependent variables (RT Global, Gaze Cuing Effect, and Pointing Cuing Effect).

NORMS FOR A NONVERBAL SOCIAL CUE-FOLLOWING TEST

(A) Gaze condition



Congruent trial

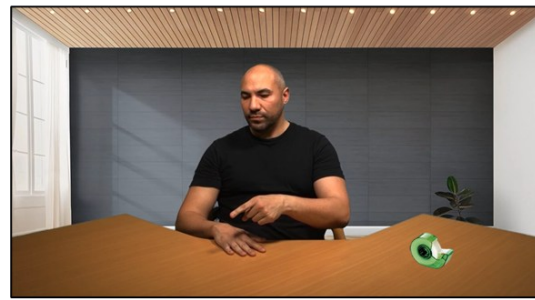


Incongruent trial

(B) Pointing condition



Congruent trial

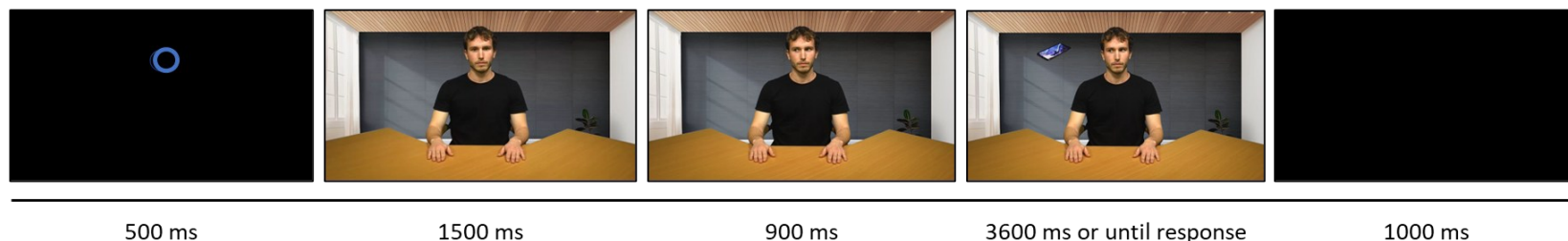


Incongruent trial

Figure 1. Illustration of four trials. **(A) Gaze condition.** The model deviates their gaze to the right or the left and the object appears on the side indicated by the model (**Congruent trial**) or on the opposite side (**Incongruent trial**). **(B) Pointing condition.** The model orients their gaze, head, and finger to the right or the left and the object appears on the side indicated by the model (**Congruent trial**) or on the opposite side (**Incongruent trial**).

NORMS FOR A NONVERBAL SOCIAL CUE-FOLLOWING TEST

(A) Gaze condition



(B) Pointing condition

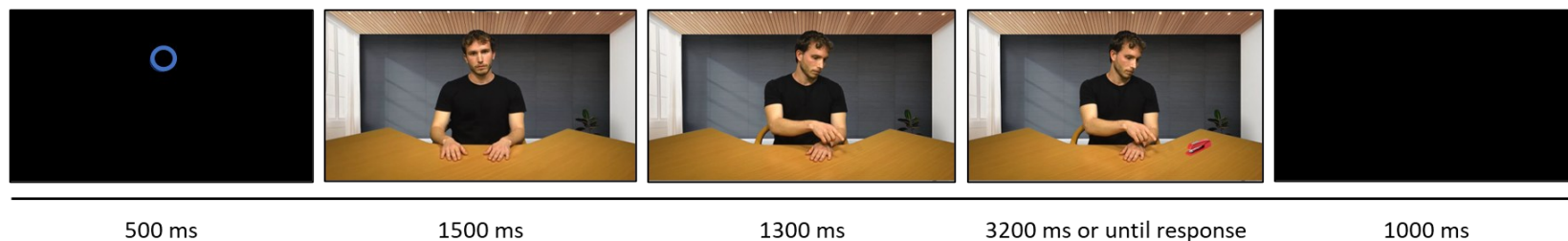


Figure 2. Time course of an experimental trial in the Gaze and Pointing conditions. All trials started with a blue fixation circle that appeared for 500 ms at the level of the head of the model, which appeared after. Participants were asked to maintain their attention on the fixation circle and then on the model's head until the object appeared, at which time they were free to initiate eye movements. All videos lasted 6 seconds. **(A) Gaze condition.** The model initiated the gaze movement 1500 ms after video onset. Then, the object appeared 900 ms after the initiation of the gaze movement and the child participant had 3600 ms to press the button. When they responded, or at the end of the 3600 ms, the video ended, and a black screen appeared (for 1000 ms) before a new trial started. **(B) Pointing condition.** The model initiated the pointing, head or gaze movement 1500 ms after video onset. Then, the object appeared 1300 ms after the initiation of the movement and the child had 3200 seconds to press the button. When the participant responded, or at the end of the 3200 ms, the video ended, and a black screen appeared (for 1000 ms), before a new trial started.

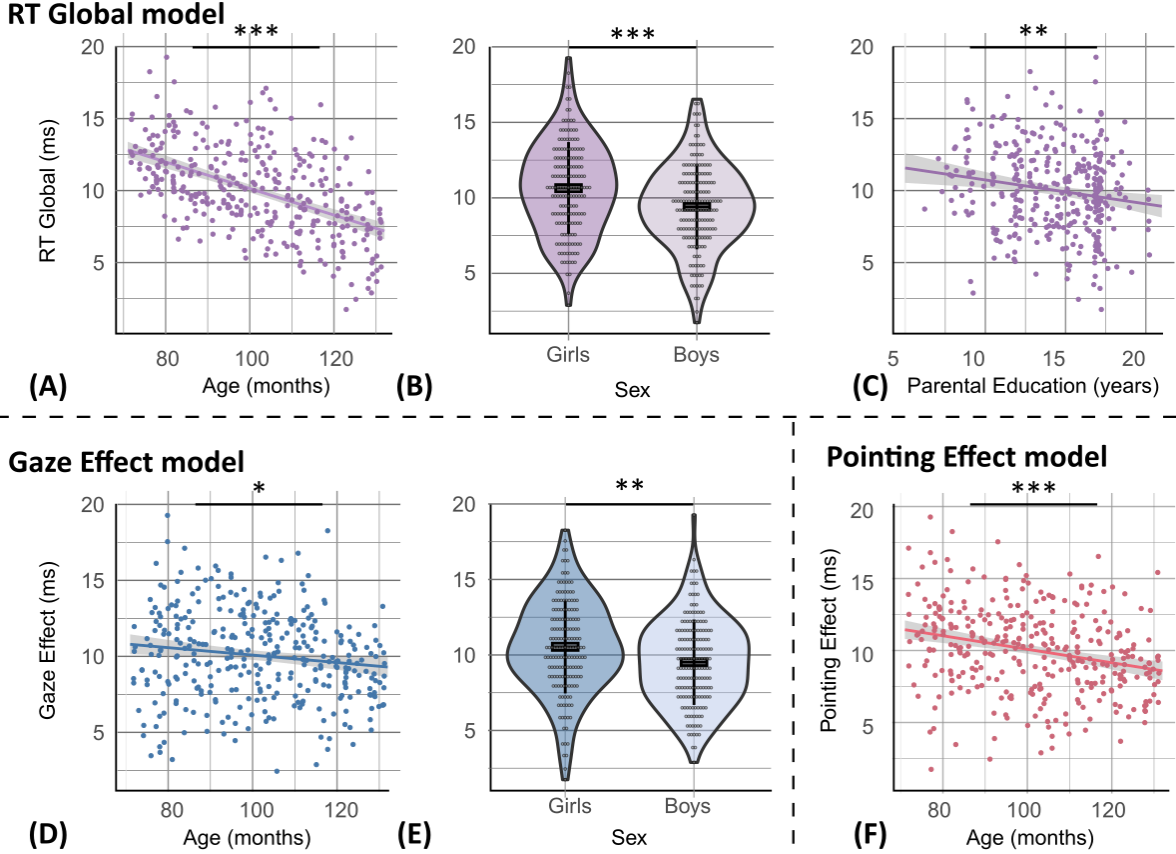


Figure 3. Illustration of the relationships between predictors included in the final models and the dependent variables (RT Global, Gaze Cuing Effect, and Pointing Cuing Effect). For the RT Global model, predictors were Age (A), Sex (B), and Parental Education (C). For the Gaze Effect model, predictors were Age (D) and Sex (E). For the Pointing Effect model, Age (F) was the only predictor. The dependent variables are represented as scaled scores. P-values are derived from the final models to indicate the statistical significance of each predictor’s effect.

Supplementary Material

A new psychometric tool for evaluating nonverbal social cue-following: regression-based normative data for children 6 to 10 years old

Supplementary Material 1. More details regarding materials and procedures.

Supplementary Material 2. Equations to calculate z-scores adjusted for Age, Sex, and/or Parental Education.

Supplementary Material 3. Clinical examples for interpretive guidance.

NORMS FOR A NONVERBAL SOCIAL CUE-FOLLOWING TEST

Supplementary Material 1. More details regarding materials and procedures.

Materials

The Tool for evaluating nonverbal social cue-following in Neuropsychological disorders (TooN) was developed in Python language by Jawel Mersali, an independent computer engineer. It is based on Posner's paradigm but uses videos of real people sitting at a desk and gazing and/or pointing at everyday objects in a realistic environment.

Videos

Thirteen (13) models aged 21 to 45 years old ($M = 35.2$, $SD = 9.8$, 7 women) were filmed individually in a recording studio. Models wore a black T-shirt and those with long hair wore it tied. Each video was filmed with the same lighting conditions against a green background. Lighting was achieved with a spotlight spreading a homogeneous light. In each video, models were sitting at a desk, facing the camera. The shot was steady and wide, in order to include the edges of the desk, as well as the model's face and chest.

For each model, five videos were shot: one video in which the model looked straight ahead with their hands on the desk; two videos in which the model looked straight ahead with their hands on the desk and gaze turned to the side without moving the body (right side in one video, left in the other); and two videos in which the model looked straight ahead with their hands on the desk and then pointed a finger to one side of the desk, also turning their face and gaze to the right side of the desk in one video, and to the left on the other. We thus made five videos for each model: Neutral, Gaze Right, Gaze Left, Pointing Right and Pointing Left. The Neutral video was only used to pre-test the stimuli.

In each video, the model displays a neutral facial expression. Videos were cut in order that 1.5 seconds precede the movement's onset (of gazing or pointing), and 4.5 seconds follow the movement's onset. A background presenting a room with a window, a dark background, white walls, wooden ceiling, and a plant was inlaid in every video to replace the green background.

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The videos were pre-tested on 22 participants aged 20 to 49 years old ($M = 24.9$, $SD = 7.6$, 14 women). After viewing each video containing no movements or objects, participants scored how “sympathetic” the model seemed, on a 7-point Likert scale. Then, after viewing each video that showed the completion of a movement, they assessed to what extent the model’s movement looked natural (also 1 to 7). We then selected eight models aged 21 to 45 years old ($M = 31.7$, $SD = 9.2$, 4 women) who exceeded a score of 3.5 in Sympathy and 3.3 in Natural aspect of the movement (for both the gaze and pointing gesture). A bilateral t-test showed that, on average, pointing gestures ($M = 3.7$, $SD = 0.4$) were rated as slightly less natural than gaze movement ($M = 4.0$, $SD = 0.3$), $t(21) = 2.45$, $p < .05$, $d = 0.41$. An additional model (a woman) was selected for demonstration trials.

Objects

A total of 15 freely available pictures of common objects used in daily life were chosen from the internet. They included a stapler, a notebook, a pair of scissors, keys, glasses, a cup, a toy, a watch, a wallet, a mobile phone, a computer mouse, a pen, a teacup, a pencil case, and scotch tape. We used Photoshop to create images with each of the objects on a transparent background so that they could be superimposed onto the desk. Objects were centered in a picture with a length of 170 pixels and a width of 128 pixels. In the Gaze condition, the object appeared next to the model’s head, so that the gaze faced the side on which the object appeared in congruent trials. In the Pointing condition, the object appeared on the desk, so that the pointing gesture indicated the side on which the object appeared. Using the Mirror tool, we created two layouts for each object, one adapted to the right side and the other to the left side.

Objects were pre-tested on the same 22 participants who tested the videos. At each trial, a shot of the desk, taken in the same conditions and inlaid with the same background as all other videos (but with an empty chair behind the desk) was presented for 1.5 seconds. Then, one of the 15 objects appeared either on the left (for half of the objects) or on the right, for 2 seconds. This presentation was randomly chosen by the simulation program and changed for each participant. For every object, the participant had to indicate which object they saw (by tapping the name of the object on the keyboard), and judge to what extent the object is useful in everyday life (on a 3-point Likert Scale). We selected eight objects

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that were unanimously recognized and that exceeded 1.5 points in usefulness. These were the stapler, the notebook, the pair of scissors, the glasses, the watch, the mobile phone, the pen, and the scotch tape.

Procedure

Each child was seated individually in a quiet room of their school to avoid auditory and/or visual distractions. TooN was administered on different portable computers with screen size ranging from 12'' to 15.6'' and resolution between 1366x768 and 1920x1080. In each test, the computer was centered relative to the median of the participant's body and the distance between the child and the screen was measured for each computer so that the objects appeared at approximately the same visual angle in the periphery.

TooN presents two sequences of 60 trials, in an order randomly chosen by the program. Each sequence lasts approximately 5 min. Each trial started with a blue fixation circle presented for 500 milliseconds (ms). The circle covered 7.8% of the screen width in pixels and appeared at 50% of the screen in width and 23% in height, approximately at the level of the model's head that appeared afterwards. Then, a video appeared in one of the four conditions (Gaze Right, Gaze Left, Pointing Right, Pointing Left). Afterwards, an object appeared on the target side (of the gaze or pointing finger, i.e., congruent trials) or on the opposite side (i.e., incongruent trials). Thus, four conditions were tested: Gaze Congruent, Gaze Incongruent, Pointing Congruent, Pointing Incongruent (see Figure 1 for an illustration of the four conditions and Figure 2 for an illustration of the time course of an experimental trial in the Gaze and Pointing conditions). The object appeared 2.4 seconds after the video's onset in the Gaze condition and 2.8 seconds after the video's onset in the Pointing condition.

In the Gaze condition, the object appeared on the gazed spot or on the opposite side (i.e., next to the model's face at 23% of the screen in height), at around 12° of visual angle on the x-axis. In the Pointing condition, objects appeared on the pointed spot or on the opposite side (i.e., on the desk at 76% of the screen in height), at 12° of visual angle on the x-axis. The objects appearing next to the model's head were reduced in size by 15% to look more natural.

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In each sequence, there were 48 trials with objects and 12 without objects. Among the 48 trials with objects, 32 were congruent and 16 were incongruent (with half of the trials pointing/gazing to the right and half to the left). Thus, there were 16 congruent trials and eight incongruent trials for each cuing condition (Gaze and Pointing). The eight models and the eight objects were seen twice in each congruent condition (once on the left and once on the right) and once in each incongruent condition (half of the objects and models on the left and half on the right). An additional 12 trials without objects were added (i.e., catch trials) to make sure participants waited for the object to appear to press the button. For the catch trials, each model was presented again one or two times, in a randomly picked condition, so that every four conditions (2 Cues (Gaze / Pointing) x 2 Fields (Left / Right)) were seen three times. The distribution of the trials was based on an algorithm close to the Fisher–Yates, to ensure there would not be more than two catch trials in a row, and that the models were uniformly distributed.

The children's task was to press the space bar as fast as possible as soon as an object appeared, or, if none appeared, to not answer. They pressed the space bar with their dominant hand. Once the answer was given or after the video's offset, the next trial began. The order of appearance of the trials in each sequence was random and changed for each participant.

In addition to TooN, children completed the French Version of the Self-Report Strengths and Difficulties Questionnaire (SDQ; Capron et al., 2007; Goodman et al., 1998, 2003) and the visual attention test of the NEPSY-I (Korkman, 1998). These tests were administered between the two sequences to control time (~10 minutes) and to provide an activity similar to that presented during neuropsychological testing.

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Supplementary Material 2. Equations to calculate z-scores adjusted for Age, Sex and/or Parental Education.

Z-scores adjusted for Age, Sex, and/or Parental Education level can be calculated using the formulas provided below. According to the results from the regression analyses, RT z-scores (RT Global, RT Gaze Congruent, RT Gaze Incongruent, RT Pointing Congruent, RT Pointing Incongruent) are adjusted for Age, Sex, and Parental Education; the Gaze Cuing Effect z-score is adjusted for Age and Sex; and the Pointing Cuing Effect z-score is adjusted for Age only. A raw score for the Gaze or Pointing Cuing Effect of 0 ms or less corresponds to a lack of advantage on congruent over incongruent trials. In this case, the z-score is not calculated, and the participant is categorized as a “non-responder”.

Scaled score: Use Table 2 to determine the scaled score corresponding to the raw score.

Age: Indicate the age in months.

Sex: Assign a value of 0 for girls and 1 for boys.

Parental education level: This is calculated as the average number of years of education completed by both parents. It is coded from 1 (the first year of elementary education in France) to 20 (doctorate level). If only one parent reports their level of education, that value is used.

Here’s a guideline for calculating years of education:

- Secondary School = 9 years
- High School Diploma = 12 years
- Bachelor’s Degree = 15 years
- Master’s Degree = 17 years
- Doctorate = 20 years

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Equations for fully adjusted z-scores:

$$\text{RT Global z-score} = (\text{RT Global Scaled Score} - (21.820 + (-0.091 \times \text{Age}) + (-1.060 \times \text{Sex}) + (-0.142 \times \text{Parental Education}))) / (2.466 \times -1)$$

$$\text{RT Gaze Congruent z-score} = (\text{RT Gaze Congruent Scaled Score} - (21.723 + (-0.090 \times \text{Age}) + (-0.905 \times \text{Sex}) + (-0.147 \times \text{Parental Education}))) / (2.491 \times -1)$$

$$\text{RT Gaze Incongruent z-score} = (\text{RT Gaze Incongruent Scaled Score} - (21.868 + (-0.092 \times \text{Age}) + (-1.178 \times \text{Sex}) + (-0.138 \times \text{Parental Education}))) / (2.449 \times -1)$$

$$\text{RT Pointing Congruent z-score} = (\text{RT Pointing Congruent Scaled Score} - (20.758 + (-0.083 \times \text{Age}) + (-1.079 \times \text{Sex}) + (-0.127 \times \text{Parental Education}))) / (2.555 \times -1)$$

$$\text{RT Pointing Incongruent z-score} = (\text{RT Pointing Incongruent Scaled Score} - (21.483 + (-0.089 \times \text{Age}) + (-1.034 \times \text{Sex}) + (-0.137 \times \text{Parental Education}))) / (2.498 \times -1)$$

$$\text{Gaze Cuing Effect z-score} = (\text{Gaze Cuing Effect Scaled Score} - (12.755 + (-0.022 \times \text{Age}) + (-1.007 \times \text{Sex}))) / 2.927$$

$$\text{Pointing Cuing Effect z-score} = (\text{Pointing Cuing Effect Scaled Score} - (14.773 + (-0.047 \times \text{Age}))) / 2.890$$

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Supplementary Material 3. Clinical examples for interpretive guidance.

In clinical practice, z-scores below -1.65 or above +1.65 (which correspond to percentiles 5 and 95, respectively) are commonly used as thresholds to determine deviation from the norm (Colombo et al., 2016). Using our normative data, clinicians could use these thresholds to identify abnormal RTs or accuracy scores. However, for interpreting cuing effects, we propose an alternative approach that enables clinicians to place the child's performance on a continuum, providing several interpretations (identical for both the Gaze and Pointing conditions). After each test, TooN provides these interpretations along with the raw and standardized scores obtained by the patient. A cuing effect at or below 0 ms indicates no difference between congruent and incongruent trials, suggesting that the child may not have effectively processed social cues. In this case, TooN does not provide the z-score but indicates "non-responder". When the z-score is strictly below -1.341 (< 9th percentile), TooN classifies the child as a "very low responder". When the z-score is between -1.341 and -0.674 (9th–24th percentile), TooN indicates "low responder". When the z-score is between -0.674 and +0.674 (25th–74th percentile), the participant is considered to be a "responder", which means that the child follows social cues similarly to their reference group. Finally, a z-score of +0.674 or above (\geq 75th percentile) indicates that the child is a "high responder".

To illustrate these interpretations, consider the example of a 94-month-old girl. Her parents' average education level is 16 years, with her mother holding a master's degree (17 years of education) and her father holding a bachelor's degree (15 years of education). After completing TooN, she achieved a Gaze Cuing Effect of 80 ms and a Pointing Cuing Effect of 100 ms. Using Table 2, we converted these raw scores into unadjusted scaled scores (Gaze Cuing Effect = 11/19, Pointing Cuing Effect = 11/19). After applying regression-based normative data (see Table 3 and Supplemental Text 2), she is identified as a responder to both Gaze (z-score = 0.11) and Pointing (z-score = 0.22). If this girl experiences attentional and executive function deficits, incorporating social cues into clinical interventions or daily interactions may provide compensatory support for these challenges. Let us consider another girl aged 105 months whose parents have an average education level of 12 years. After completing TooN, she achieved a Gaze Cuing Effect of -10 ms, and a Pointing Cuing Effect of -20 ms. As her cuing effects

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are lower than 0, z-scores are not calculated, and she is identified as a non-responder. The clinician must determine whether the difficulties are specific to the social sphere or if they are the result of attentional or executive deficits. Indeed, it is crucial to interpret the cuing effects while considering RT and accuracy scores. For example, if the girl made 3 omissions (percentile < 5) or had a Global RT of 1080 milliseconds (z-score = -1,80), the clinician could investigate potential attention difficulties. Similarly, if she made 8 false alarms (percentile < 5), exploration of inhibition difficulties might be warranted.