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Language level predicts perceptual categorization of complex reversible events in children

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HIGHLIGHTS

- Mental representations of complex event types were investigated.
- An event imitation task was used in children with and without language disorders.
- Chronological age and verbal mental age both predicted performance.
- Grammatical comprehension in the clinical group did as well.
- Cognizing complex events may be linguistically conditioned.

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ABSTRACT

Language plays a well-documented role in perceptual object categorization, but little is known about its role in the categorization of complex events. We explored this here with a perspective from age or developmentally appropriate language capacities in neurotypical children between the ages of two and four years (N = 21), and from delayed language development in a clinical group of children (N = 20), whose verbal mental ages (VMA) often fell far below their chronological ages (CAs). All participants watched two demonstrations of a series of transitive events (e.g. *tiger jumps over a girl*). The toy agents were then moved out of sight, and participants had to act out the same event type, based on a different tiger and girl that were selected among two distractors. We aimed to determine how mastery of this task relates to CA in the neurotypical group, and whether task performance in the clinical group was predicted by VMA and a standardized measure of grammatical comprehension. Results from a series of logistic mixed-effect regression models showed that neurotypical children start to perform correctly on this task with a chance of around 50% during their third year of CA but reach ceiling performance only during their fourth. A similar pattern emerged for VMA in the clinical group, despite a wide range of CAs and diagnoses. In addition, grammatical comprehension predicted performance. These patterns suggest that language competence plays a role in the perceptual categorization and encoding of complex reversible events.

1. Introduction

During your morning walk you might see, in passing, a dog chasing a boy. There seems to be nothing linguistic about the cognitive process involved: there is no talking and no comprehension of speech. Yet might our perception of such events be conditioned by language competence in some way? We already know that words used to name objects have a profound impact in cognitive development on how infants and preschoolers perceptually categorize objects (Waxman and Markow, 1995; Graham et al., 2004; Schulz et al., 2008; Dewar and Xu, 2009; Westermann and Mareschal, 2014; Havy and Waxman, 2016; Ferry et al., 2010; and Novack and Waxman, 2019; Vouloumanos and Waxman, 2014

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for review). Events are, if anything, more complex than objects, insofar as the former contain the latter necessarily as parts. It is thus natural to expect similar effects for event classification as have been observed for objects.

Evidence for such a language effect is limited, though some studies have shown that early event cognition relates to language in pre-productively verbal infants. An electrophysiological study of 9-month-olds by Kaduk et al. (2016) showed that the infants' understanding of the semantic structure of complex actions was related to language measures at both 9 and 18 months of age. As the authors interpret this result, language and processing events are linked as cognitive domains, sharing a common substrate. There is also evidence that labeling actions through verbs of different types aids in perceiving the corresponding actions as a class (Pruden et al., 2013; Gleitman et al., 2005).

At the same time, there is evidence that many aspects of event cognition do *not* depend on advanced levels of linguistic development. Thus, 6-month-old infants parse discrete events in terms of causal relations (Saxe et al., 2007), they represent actions in terms of agents' goals (Woodward, 1998; evidence from infants as young as 5 months), and they parse goal-directed action events in line with meaningful constituent parts (Baldwin et al., 2001; evidence from 10- to 11-month-old infants). Infants not only have a grasp of the intentional structure of an event, but can also discriminate between events based on manner, e.g. a puppet jumping from a puppet falling (Sharon and Wynn, 1998; Pulverman et al., 2013). Event *categorization* goes beyond discrimination between types of events in requiring abstracting out an event class from perceptually different instances, and determining for a new instance whether it belongs to the class or not. Using a preferential looking paradigm, Song et al. (2016) found that 10-12-month-old infants also could categorize dynamic motion events according to the manner of motion in which a figure moved (e.g., marching, with different agents and paths of motion).

Together, this evidence suggests that several months before language is produced, infants represent events in terms of abstract concepts such as causality, path, manner, or goal. Events, however, unlike the objects they contain, also involve structural relationships between their participants, which can be crucial to categorizing them but are different from the foregoing. Thus, when categorizing a perceptual event as being one of a *dog chasing a boy*, it is the dog that plays the role of 'chaser' (Agent) and the boy the role of 'chasee' (Patient). In an event conceptualized as a *boy chasing a dog*, the abstract roles are the same, the action is, and the participants are. But the participants associate differently with the roles. Do pre-productively verbal infants represent events in terms of abstract agent and patient roles assigned to event participants? There is evidence that infants represent causal agents, even when no such agent was seen during a habituation phase (in which objects were tossed over different barriers, Saxe et al., 2005), and that they attribute volition and sentience to such agents (Saxe et al., 2007). Their representations of goals relative to sources of motions are also sensitive to whether agents are involved or not (Lakusta and Carey, 2015). Yet for all that, it remains unclear, as reviewed in Wagner and Lakusta (2009), whether infants truly represent abstract agent and patient categories of the kind that have entered linguistic theories of event structures in language, such as Dowty (1991).

Crucially, for an event like *dog chases boy*, the agent role has to be represented *together* with the patient role, in the same representation, in order to obtain a representation appropriately distinct from *boy chases dog*. While very few studies have investigated this aspect of the reversibility of complex events, a recent study (Shukla and DeVilliers, 2021) shows with a non-verbal anticipatory eye-tracking paradigm that 12-24-months-old infants could not generalize across perceptually different instances of a general event concept such as *dog pushes car*, while they could do so for simpler events involving single participants without the option of reversibility, such as *dog jumping*. In an additional adult group that verbally shadowed complex language while generalizing across events in the same nonverbal task as was given to the infants, an impact of the verbal shadowing was seen on the formation of two-place, asymmetric and reversible events, but not irreversible one-place events. Online access to linguistic representations in adults, and more fully developed language levels in toddlers, may thus be necessary to conceptually classify certain types of events as belonging to a general type.

Motivated by these findings we here aimed to further pursue the hypothesis that language maturity may be a critical factor in representing and categorizing complex reversible events. In terms of the mental representations involved, it is clear that the structure of a clause with a transitive verb would exactly provide the structural elements needed to represent such events. Through its lexical-conceptual ingredients, it provides concepts for who is involved in the event and what the action is. Its grammatical structure specifies which participant plays which abstract event role ('agent-of' and 'patient-of'). As long as the values taken by these abstract role variables are independent of these role variables themselves, such representations ipso facto allow for reversibility: the values can be switched while the variables and structure stay the same. A simple hypothesis could thus be that mental representations of reversible events have to be isomorphic to exactly a structure of this type. There already is some psycholinguistic evidence, from both neurotypical (Belacchi and Cubelli, 2012) and language-impaired children (Artuso et al., 2021) that linguistic representations (e.g. gender morphology) are implicitly accessed even in tasks that impose no overt linguistic demands (such as a purely semantic task of classifying animals by their biological gender (male or female).

For the case of conceptual representations of events, Wagner and Lakusta (2009) specifically pursued the hypothesis of an isomorphism between the mental representations involved in pre-productively verbal infants and linguistic representations of such events (see also Papafragou and Grigoroglou, 2019). To the extent that such an isomorphism obtains, language acquisition can be thought of as a mapping procedure, in which pre-existing cognitive structures become the meanings of linguistic representations, once these are learned (Wagner and Lakusta, 2009, p.183). To the extent that it did not obtain, on the other hand, language development itself would provide concepts and contents that did not pre-exist the linguistic forms in which we see them encoded in language. While this second option would, to the same extent, limit the scope of 'pre-linguistic thought' in relation to thought mediated by language, there is a conceptual problem with interpreting even an isomorphism as evidence for event structures present in pre-linguistic thought or as pre-dating language. This is because, if the structures in the posited forms of pre-linguistic thought and in language are indeed isomorphic, then the one cannot be more or less 'linguistic' than the other – they are isomorphic. If 'linguistic' is a label we give to the one, it would have to fit the other, and the fact that the infants in question do not yet *talk* does not affect the structure of the representations. Isomorphism, therefore, motivates to *eradicate* a distinction between thought and language rather than reinforcing this dualism or some priority of one over the other. Since it is a basic insight of modern linguistics that language is not the same as speech, there is no conceptual problem in assuming that a brain can produce linguistic representations even when they are not yet mapped onto the motor channel of speech (see Hinzen and Mattos, 2021, for further discussion).

In line with this conceptual point is the fact that there is also no empirical sense in which even infants that do not yet produce words have pre-linguistic minds. Language structures social and communicative interaction in infants from birth (Dominguez et al., 2016; Vouloumanos and Werker, 2007). As noted, it plays a crucial role in perceptual categorization and learning during the first year, including an effect of parts of speech distinctions (noun versus verb versus adjective) on the categorization of objects, actions, and properties, respectively, during the second year of life (Novack and Waxman, 2019). Linguistic communication is understood by infants as referential from 6 months (Marno et al., 2015), and word meaning is significantly comprehended from 4 months (Bergelson and Aslin, 2017). At a brain level, a neural infrastructure of language corresponding to adult patterns is remarkably in place from birth, whether in terms of functional activations in response to linguistic stimuli (Dehaene-Lambertz et al., 2006), the neuroanatomy of language regions (Dubois et al., 2010), or functional connectivity revealing a language network active in the resting state (Cusack et al., 2018). For encountering more ruly 'language-less' minds, therefore, we have to look elsewhere.

This motivated the perspective taken in the present paper. The search of 'thought independent of language' can only partially be accomplished by looking at early stages of language development, for the reasons just given, and the same applies to adults whose language faculty becomes inaccessible in verbal shadowing tasks. As argued in Hinzen et al. (2019), however, a potentially more powerful source of insight comes from school-age children with neurodevelopmental disorders, who do not develop language in either production or comprehension at all. This includes 30% of people on the autism spectrum (Norrelgen et al., 2015; Slusna et al., 2021) – a population that, while neglected in research terms (Jack and Pelphrey, 2017), is of considerable importance for raising fundamental questions about the neural basis of language and cognitive functioning under conditions of language absence (Hinzen et al., 2019). Such children are unlikely to develop language later (Slusna et al., 2021) and provide us with an alternative and arguably closer approximation of a 'language-less' mind than either neurotypical infants or verbally shadowing adults could do. Absence or regression of language development is by no means confined to non- or minimally verbal autism, moreover, but found in various instantiations and degrees across numerous neurogenetic conditions including Phelan-McDermid, Angelman, Coffin-Siris, Landau-Kleffner, Rett, and Cri du Chat syndromes (Hinzen et al., 2019).

This led to our principal aim here, which was to explore the language dependence of conceptual representations of complex reversible events in children with language delays due to a variety of neurodevelopmental conditions, including severe cases of absence of functional language development. We explicitly aimed for recruiting across the diversity of the real-life spectrum of language-impaired groups, in order to determine whether a relation between language and our experimental task could be attested that cuts across diagnostic differences and differences in neural substrates. Indeed, evidence for widespread non-verbal cognitive impairment in language disorders (such as specific language impairment/developmental language disorder, SLI/DLD), and patterns of language impairments in groups with 'cognitive' (but not 'language-specific') disorders, have long questioned the utility of dividing language disorders into those that are specific and those that are not (for discussion, see Leonard et al., 2007; Tomblin et al., 2004; Bishop et al., 2017; Leonard, 2020). In addition, restricting our recruitment to a diagnosis of SLI/DLD would have excluded a range of severity of language dysfunction from our sample that we considered critical to include: in such children, the canonical indicators of SLI/DLD (e.g. difficulties in distinguishing phonemes, inflectional morphology, or production of syntactically complex sentences) are hard or impossible to differentially assess, since there is not enough language to start with.

Our principal research question, then, was whether, despite a large variety of diagnoses and underlying neurobiological substrates in this clinical group, a relation between event cognition and language competence could be attested. We explored this with a simple experiment in which participants had to form general reversible event concepts of novel events involving toy agents (e.g. *tiger jumps over girl*), as revealed through their capacity to imitate the event just witnessed by acting it out with different participants of the same types (in the foregoing example, a different tiger and girl) and playing the same roles (agent and patient, respectively). de Villiers (2014) (see also de Villiers et al., 2011) reported for an analogous perceptual task that only a group of four-year-old neurotypical children performed well on this task. Apart from investigating this paradigm in a clinical group with language dysfunction, we aimed to corroborate this previous finding in a group of neurotypical children between the ages of two and four years of chronological age (CA). Following De Villiers' lead, our basic prediction was that neither neurotypical children with CAs below four years nor children with language disorders and verbal mental ages (VMAs) below four years would be likely to succeed on our task. At a more explorative level, we also asked whether the online provision of a linguistic description of the events in question would aid in task performance on this perceptual task or not.

2. Methods

Sample. 21 neurotypical 2-4-year-old children without any reported developmental delays or disorders were recruited, along with 20 children with special needs attending a special education school specifically dedicated to children with neurodevelopmental disorders affecting language. The schools from which both groups were respectively recruited were close to each other, sharing the same neighbourhood and socio-economic environment. In the neurotypical group, absence of any indication of developmental delays or problems, and of associated interventions, was assessed based on information obtained from parents and teachers of their school. In the clinical group, children with motor or psychological (e.g. attentional) disabilities making them unable to perform the required actions were excluded. The neurotypical group had a mean CA of 3 years and 9 months (SD 12.97, range 27–65 months). The clinical group (N = 20) is summarized individually in Table 1, reflecting a diverse sample with language capacities forming a wide spectrum, from virtually no functional language in either production or comprehension to language abilities at nearly normal levels, across a wide range CAs exceeding their verbal mental age (VMA) in all cases. The study was approved by the responsible ethical review of the Fundación Querer (study nº 01/2019) and an informed written consent form was signed by all parents of participating children. Table 1 presents the demographics, diagnoses, and results from the standardized test profiles: VMA as computed from the Peabody Picture Vocabulary Test (PPVT, Dunn, 2007), and CEG: Test de Comprensión de Estructuras Gramaticales [Test of grammatical comprehension] (Calet et al., 2010).

Standardized measures: All children in the clinical group were evaluated with the Peabody Picture Vocabulary Test, IV (Dunn, 2007),

Table 1. Demographics of the clinical group.

Subjects	CA (y/m)	Diagnosis	VMA (y/m)	CEG
1	8; 5	Coffin-Siris	3; 2	31
2	5; 8	Fragile-X	3; 5	19–34
3	4; 9	SLD	3; 9	32
4	11; 4	Landau-Kleffner	4; 11	35–52
5	15; 3	ID	7; 7	43–62
6	13; 4	ASD	6; 10	39–48
7	9; 1	ID	6; 10	44
8	8; 2	ADD + SLD	6; 6	56
9	3; 6	ASD	2; 10	NA
10	5; 8	SLD	4; 2	35
11	6	ASD	4; 1	37
12	6; 7	SLD	5; 6	39
13	5; 11	ID	4; 8	32
14	10; 2	ASD	6; 6	30
15	9; 3	RGD	8; 1	61
16	13; 1	ID	6; 9	68
17	7; 8	RGD	4; 5	37
18	6; 2	RGD	4; 5	35
19	3; 4	DLD	3; 5	NA

Abbreviations: ADD: Attention deficit disorder; ASD: Autism Spectrum Disorders; CA: Chronological Age; CEG: Test de Comprensión de Estructuras Gramaticales (Calet et al., 2010); DLD: Developmental Language Disorder; ID: Intellectual disability; SLD: Specific Learning Disability; RGD: rare genetic disorder; VMA: Verbal Mental Age, a standardized variable computed from the Peabody (PPVT, Dunn, 2007); NA: test data not obtainable due to insufficient CA.

from which a standardized measure of VMA can be directly computed. In children with intellectual disabilities, VMA scores are more informative than CA-adjusted verbal IQ scores, which can also be obtained from the Peabody test, because bottom-level verbal IQ punctuations (as were found in about half of our sample) often conceal considerable variability in raw receptive vocabulary scores. They are also increasingly disadvantageous as children get older, insofar as these IQ scores state how far children are below average relative to their age, and disabled children likely acquire new words at different rates. For these reasons, VMA scores were used here. Wherever possible given the age of the child, the CEG (Test de comprensión de estructuras gramaticales) was also administered, Calet et al., 2010).

Experimental procedure: The experimental procedure was the same for both groups. One of the children's teachers (henceforth, the experimenter) sat down with them at a table in the setting of their daily school environment (see Figure 1). The experimenter ensured that the child was attentive and took two toy figures (e.g. a Lego girl and a tiger) and said 'Look!', after which she performed an action under the attention of the child, e.g. the tiger jumping over the girl. Immediately afterwards, the same action was repeated with the same participants. Following this, the two objects were moved out of sight and a tray was brought with two new instances of the previous participant categories (another tiger and girl), together with two distractors (e.g. a boy and an elephant). The experimenter made eye contact with the child, offered the tray, and said: 'Now you do the same!'. There were two conditions. In one, an explicit verbal description of the event type was provided as and when it was initially performed ('Look, this is a tiger, and this is a girl. The tiger is jumping over the girl!'), each of the two times that it was performed. In the other, there was no such verbalization of the event. There was a total of ten trials in each condition, with no events repeated. The intention was to select novel events, where the interaction of the event participants was not predictable on independent grounds (e.g. a tiger jumping over a girl, not a father carrying a child). The total list of trials is provided in Supplementary Materials A. The same children participated in both conditions, first in the 'with language' condition, then between one and two months later, in the 'no language' condition. Position of target objects in the tray was counterbalanced across trials.

Rating: Responses were rated on a binary basis as either correct or incorrect. Children were allowed to self-correct once, but wrong initial answers were still rated as errors. Accepted errors were wrong action (e.g. jumping versus pushing), wrong participants (i.e. choice of distractors), and wrong direction of the action (e.g. who pushes whom). Non-accepted error patterns, leading to exclusion from the study in one case, were when a child did not perform any action, nor chose any objects from the tray. In four additional cases with very low punctuations, where erroneous objects or actions were chosen, a simplified test was run to control for whether these children were able to imitate at all. In this case, the requirement of categorization (choice of novel participants) was removed, keeping the rest of the above experiment identical. Verbal descriptions were provided, of the form 'Look, this tiger jumps over this baby.' There were two items. All four children performed satisfactorily in this task.

Analysis: In order to analyze the probability of producing a correct response, a series of logistic mixed-effect regression models were fit in R (version 4.1.1; R Core Team, 2021) using the package lme4 (version 1.1–27.1; Bates et al., 2015). Correct responses were coded as 1 and incorrect responses as 0. When possible, models included random intercepts for Participant and Item, as well as a random slope for Condition by Participant and Item. When the models failed to converge, the random slope for Condition by Item was dropped first, followed by the random slope for Condition by Participant. Condition was dummy coded as a factor with two levels: 'Language' and 'No language', with 'Language' being represented by the intercept. For the control group, the only predictor of interest other than experimental condition was the participants' CA in months. For the clinical group, there were two predictors derived from test-based scores: VMA and CEG.

3. Results

Complete tables for all regressions are included in the appendix, numbers reported in the text have been rounded to three decimal places. As all models are logistic regression models with estimates in log-odds, positive estimates mean that an increase in the independent variable is associated with an increase in the probability of a correct response. No interactions were tested as the research questions were focused on additive effects, and we had no hypotheses regarding potential interactions.

Neurotypical group. Results from the modelling of correct responses in the control group indicated that *Age* was a significant predictor of correct responses ($\widehat{\beta}$ =0.203, SE = 0.039, $p < 0.001$), with older children being more accurate. The predicted values for the effect of age from this model are presented in Figure 2. *Condition* did not have a significant effect of the probability of being correct ($\widehat{\beta}$ =-0.025, SE = 0.484, p = 0.958). The predicted values for the effect of condition are presented in Figure 2.

Clinical Group. The independent variables of interest for predicting the performance of the clinical group were *Condition*, *VMA*, and *CEG*. *VMA* and *CEG* were first added to the baseline model including *Condition*. As both variables are related to language proficiency and were highly correlated (r = 0.71), we first added them to the baseline model separately and then fit a full model with both predictors. The highest variance inflation factor was 1.474, below the most common thresholds for problems with collinearity. There were suppression effects, however, which we outline below.

When *VMA* was added to the baseline model with only *Condition*, it was a significant predictor ($\widehat{\beta}$ =0.140, SE = 0.040, p < 0.001), with

Figure 1. Experimental setup.

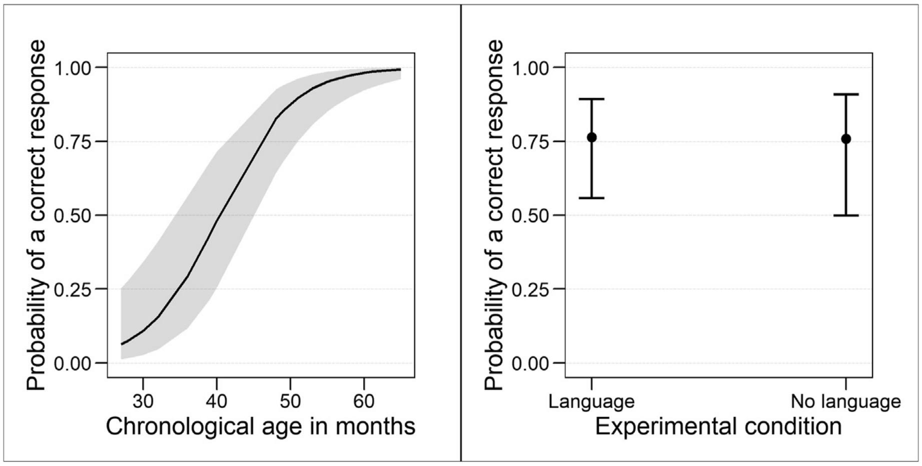

Figure 2. Probability of correct responses based on chronological age and condition in the neurotypical group. On both graphs, the y-axes are back-transformed from the log-odds scale to the probability scale, and represent the probability of a correct response on an average item by an average participant. The shaded grey area (left) and whiskers (right) correspond to 95% confidence intervals.

higher *VMA* being associated with a higher probability of a correct response. When *CEG* was included in the model with only *Condition*, it was a significant predictor ($\widehat{\beta}$ =0.311, SE = 0.092, p < 0.001), with higher scores on *CEG* being associated with a higher probability of a correct response. *VMA* and *CEG* were highly correlated, which was expected as these were two measures tapping into underlying language abilities. When both of these variables were added to the same model with Condition, suppression effects were observed, with the estimates being reduced while the standard errors remaining the same. As a result, neither *VMA* nor *CEG* were statistically significant effects after taking into account the variance explained by the other. The predicted values for *CEG* and *VMA* from the models containing *Condition* and the predictor in question are plotted below in Figure 3.

4. Discussion

According to our results, neurotypical children succeed on our task with a chance of about 50% around the age of three and a half years of CA (40 months), although 95% confidence intervals for children at 35 months and 45 months also included the 50% mark. Neurotypical children reached probabilities of a correct response over 80% only after the age of four years (Figure 2). This was so even when verbal descriptions of the events were provided, indicating a substantial difficulty of our task during this period of development. In turn, Figure 3 shows that children in the clinical group with VMAs below their CAs, reach 50% chance levels towards the end of their third year of VMA, while equally reaching 80% chance levels only after reaching four years. VMA, as measured from receptive vocabulary scores, is a very coarse-grained measure of language maturity, but our much more fine-grained measure of grammatical comprehension, the CEG, was equally predictive for our task. The finding that, on all of our measures, language maturity predicts task performance, whether or not language descriptions are provided, robustly supports our basic hypothesis of a relation between language capacity and the cognizing of complex reversible events. It is also consistent with a previously reported threshold of four years of CA for neurotypical children reported in de Villiers (2014).

Nothing in our results entails relations to language for events of simpler types, such as two-place non-reversible events (e.g. *thief stealing handbag*) or one-place events (e.g. *lady smiling*), which is an important issue for future inquiries. We also cannot address the question of underlying causality or mechanisms. Following Wagner and Lakusta (2009), the simplest hypothesis might indeed be that mental representations involved in conceptualizing complex reversible events are isomorphic to the hierarchical configuration of clauses seen in verbal descriptions of them, such as *[boy [chases [girl]]]*. In these, thematic roles of agent and patient are assigned depending on the structural positions in

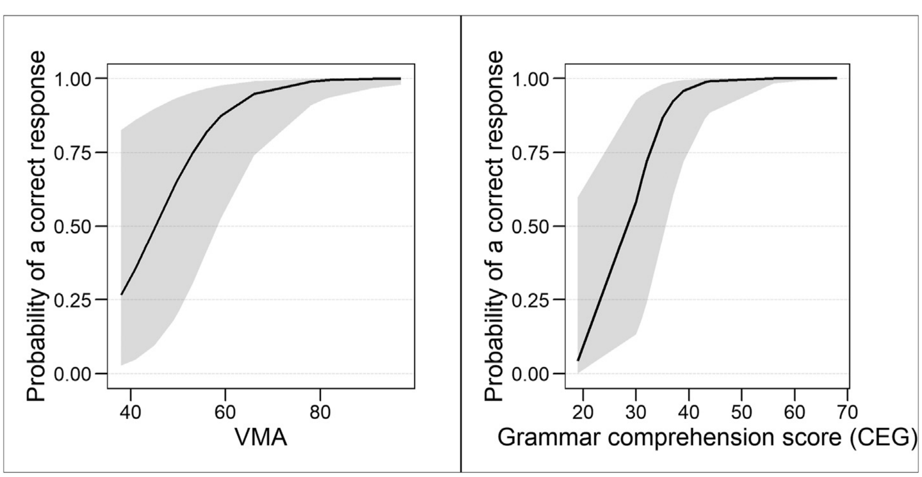

Figure 3. Probability of correct responses based on VMA and grammar comprehension (CEG) in the clinical group. On both graphs, the y-axes are back-transformed from the log-odds scale to the probability scale, and represent the probability of a correct response on an average item by an average participant. The left plot is the predicted effect of VMA from the VMA model reported in the appendix. The right plot is the predicted effect of CEG from the CEG model reported in the appendix.

which the nouns *boy* and *girl* find themselves, and hence can be re-assigned when the same nouns switch positions. While our data cannot support this specific hypothesis about the representations involved, it is intriguing that four years is also the age of maturation at which neurotypical children start to succeed on explicit theory of mind tasks: performance on such tasks has long been noted to relate to the maturation of the comprehension of clausal embedding (Durrleman and Franck, 2015; Durrleman et al., 2018; de Villiers and Pyers, 2002). It is also possible that multiple neurocognitive mechanisms enter into our task, from language to working memory, attention, and perception. Our results show that, nonetheless, a predictive relation between language maturity and task performance emerges robustly against wide cognitive variation in such other cognitive factors, of the kind that would characterize any such mixed clinical group of the kind we aimed to recruit.

It is certainly possible that this mixed nature of the participant pool in terms of their specific diagnoses contains patterns that influence their performance on this task, but the low number of participants does not allow these differences to be modelled explicitly. Nonetheless, the random effects related to participant and item showed a relatively normal distribution around the mean, meaning while there was variation in participants and item, the model was able to take this variation into account, and the assumptions were not violated. Furthermore, the random effects for participant, presented colour-coded according to diagnosis in Appendix D, generally show a lack of patterning with respect to specific diagnoses. Due to the size and nature of the present sample, it is impossible to exclude that there is an effect of diagnosis in the performance of this task. However, the lack of systematicity with respect to the random effects leads us to argue that the generalizability of our effect across many diagnoses is a valid one. Given the considerable variability of individual performance within the same diagnoses, further research on the effect of diagnosis on this task would likely require a large sample size.

This result has practical significance at the level of the methods of special education in classrooms with a mix of disorders, which will often be the norm. Specifically, it draws attention to the significance of language level even in the context of apparently nonverbal semantic and visually based tasks, and to language comprehension levels in particular (given the role of the CEG in our results). Artuso et al. (2021) recently already found evidence from children with DLD that linguistic representations are accessed in an implicit manner even in purely semantic object classification tasks that make no requirements on the explicit use of language. In a similar way, teachers in special education settings may benefit from more insights into which apparently nonlinguistic tasks involve and may require mental access to linguistic resources – particularly in children who do not speak (Hinzen et al., 2019). At a broader foundational level, our result reinforces the insight that, in development, language is more than speech and communication, but a 'cognitive' variable and resource as well, which plays a fundamental role in perceptual categorization and learning (Novack and Waxman, 2019).

A particular cognitive variable of interest for future studies may be working memory, which enters into our task, though events had to be repeated immediately following their presentation. Rather than viewing it as a potentially confounding variable, however, working memory deficits may themselves relate to language, as opposed to being an independent cognitive dimension. In particular, we can only remember correctly what we represent correctly in the first place. Independent evidence for this connection comes from a number of sources, including pervasive memory deficits in post-stroke acquired aphasia, where the severity of aphasia relates to both verbal and spatial memory deficits (Potagas et al., 2011); children with Specific Language Impairment/Developmental Language Disorder, who typically exhibit poor digit span and show impairment on nonword repetition (Baddeley et al., 1998; Gathercole and Baddeley, 1990); the possibility of enhancing structural language complexity through working memory training in such children (Delage et al., 2021); and the fact that memory recall scores in a picture memory task improve in 5-6-year-old children who spontaneously verbalize the information to be recalled (Elliott et al., 2021).

It is worth investigating further why children in neither group benefited from a verbal description of the event to be enacted. This was unexpected in light of previous findings arguing for the benefit of verbal description in three- and four-year-old neurotypical children (de Villiers, 2014). We also know, from both neurotypical children and those with developmental disorders, that selective language measures and language training can improve performance in nonverbal cognitive tasks such as theory of mind (for ASD and SLI, see Farrar et al., 2017; Lind and Bowler, 2009; for young neurotypical children, see deVilliers and Pyers, 2002; but also Forgeot d'Arc and Ramus, 2011; Dungan and Saxe, 2011). None of these results entail or predict, however, that in language-impaired children, the online provision of language during non-verbal cognitive tasks will actually aid performance. Our task involved a perception-action circuit, and verbal descriptions provide an additional dimension of information, which, in the context of the task, requires processes of multi-modal integration that may be cognitively taxing for language-impaired children. Our language measures measure language maturity or competence, and this is not the same as assessing the utility of language in a specific context of use and within a particular perceptual task. When children of different types benefit from verbal descriptions in such contexts, and when they do not, is an important issue for further research, and of clinical and pedagogical importance.

Finally, a further consideration is that children saw the same items in both conditions. This removes any uncertainty about whether variation in stimulus items influenced results, but it is conceivable that participants remembered some of the events they saw (or their own choices) in the initial 'with-language' condition, despite the one-to-two months delay between the two testing sessions (anecdotally, experimenters certainly did not remember the stimulus items). But as no relevant feedback was given for choices made by participants during the first session, children had no indication of which of their earlier choices was right, which could otherwise have led them to repeat them; and it seems unlikely that over such a delay period, a practice effect in this task could ensue.

In sum, this study has provided confirmatory evidence that language maturity relates to our capacity to perceptually categorize complex reversible events, regardless of whether these events are verbally described during the task or not. This result adds to previous insights on the significance of language in cognitive development and the perceptual categorization of objects, and it has pedagogical significance for teachers who need to determine what information children with language impairments can extract from visually presented information. The study motivates further studies about the exact cognitive mechanisms and neural networks involved, and specifically, whether mental representations of such events take the form of clausal configurations.

Declarations

Author contribution statement

Wolfram Hinzen: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Elisa Peinado: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Scott James Perry: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Kristen Schroeder: Analyzed and interpreted the data.

Mariana Lombardo: Performed the experiments; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data associated with this study has been deposited at: https://figshare.com/s/c54f8ea1dac98faa4a5a.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2022.e09933.

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