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ORIGINAL ARTICLE

The impact of balance of multilingual exposure on gesture comprehension in children above preschool age

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Abstract
Previous work had shown that multilingual preschool children are better at interpreting deictic gestures than their monolingual peers. The present study examines whether this multilingual effect persists beyond preschool age and whether it extends to iconic (i.e., representing the referent) and conventional (i.e., holding an arbitrary meaning) gestures. A total of $N = 105$ children (aged 3 to 8), varying in their balance of exposure to more than one language since birth, completed a gamified gesture comprehension task. The three gesture types were presented in four communicative conditions, namely (1) alone, with (2) reinforcing or (3) supplementing speech, compared to (4) speech produced alone. Analyses revealed that children with greater balance in their multilingual exposure understood significantly more speechless iconic gestures than children with less balanced multilingual exposure. Findings align with previous work and theoretical frameworks, indicating that multilingual exposure enhances children's sensitivity to non-verbal communicative cues.

Keywords: Bilingualism; gesture comprehension; multimodal integration; non-verbal communication

Multilingualism and communicative advantage

Multilingual children, defined as individuals exposed to two or more languages (Grosjean, 1982), have been reported to present "communicative advantages" compared to their monolingual peers (Wermelinger et al., 2017, p. 2). Indeed, it has been hypothesized that, due to their exposure to more diverse and complex linguistic and communicative environments, multilinguals display a *heightened sensitivity* toward the interactional situation and their interlocutors (e.g., Ben-Zeev, 1977; Fan et al., 2015). Such sensitivity would notably enable multilinguals to interpret the speaker's intent better (Yow & Markman, 2015), to repair misunderstandings more often (Wermelinger et al., 2017), and to more efficiently manage communicative breakdowns (Genesee et al., 1996).

Researchers have primarily highlighted the role of exposure to multilingual environments on communication effectiveness (Fan et al., 2015; Yow & Markman, 2015, 2016). In their view, the socio-linguistic and socio-pragmatic experience of growing up multilingual, with exposure to more diverse communicative environments and partners, improves the enhanced communicative competence of multilinguals. The more frequent and greater need to monitor the interactional context (e.g., monitor the speaker's language to respond adequately and repair communicative failure more) would also train multilingual individuals to a larger extent, thus resulting in an increased *sensitivity* to the communicative environment (van Wonderen et al., 2023; Wermelinger et al., 2024).

The COMmunicative-Experience perspective (COME perspective; Wermelinger et al., 2024) provides a theoretical framework to shed light on why multilingual children may benefit in terms of their communicative development. Multilingual children may face more challenging communicative situations (e.g., limited vocabulary and language choice) and consequently develop a broader repertoire of communicative strategies, which they use with greater flexibility than their monolingual peers (Wermelinger et al., 2024).

Communicative gestures and their development

One important aspect of communication that may be affected in a multilingual environment is the use and understanding of non-verbal linguistic cues, such as gestures. Gestures (i.e., also called "co-speech gestures") are hand movements accompanying, emphasizing, or replacing speech (McNeill, 1992). These gestures provide communicative and cognitive benefits for both the speaker and the listener (see Clough & Duff, 2020 for a review). Because gestures often provide additional information and clarification that complements the spoken discourse, they appear crucial in multilingual settings, where linguistic expressions can be ambiguous or unfamiliar. They may help disambiguate intent, put emphasis, clarify speech, and are therefore important to be monitored efficiently.

Different types of gestures can be described based on their semantic function. Deictic gestures serve to locate, indicate, or refer to an entity in the physical or discourse space (Kita, 2003). The most common form of gesture is pointing, typically produced with the index finger, which may refer to a concrete object of location (e.g., pointing to a cup), or to an abstract element in the discourse (e.g., pointing to an absent person or prior topic). Other forms, such as hand waves, may also serve a deictic function (Arikan et al., 2025; Moreno-Núñez et al., 2020). Iconic gestures represent aspects of objects or actions through a visual resemblance in form or movement (e.g., miming drinking, or shaping the hands to

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outline a ball). In contrast to pantomimes, which typically involve enacting a complete action sequence as if manipulating an object, iconic gestures usually provide a schematic, conventionalized depiction of key features of the referent (Behne et al., 2014; Kita et al., 2017; Ortega & Özyürek, 2020). Conventional gestures convey an arbitrary, culturally specific meaning within a given community (e.g., waving the hand to signify GOODBYE; McNeill, 1992). It is important to note that these gesture types lie on a continuum rather than forming strictly discrete categories, as they may share features and are not mutually exclusive (Kendon, 2004; McNeill, 1992).

Gesture production and comprehension are both dynamic and interrelated, following a similar developmental trajectory (Dimitrova & Özçalışkan, 2022). In particular, children start to produce and understand deictic gestures toward the end of the first year of life (Behne et al., 2012). Then, iconic gesture production and comprehension emerge around the age of 2 to 3 (Namy, 2008), followed by the development of conventional, arbitrary gestures slightly after (Namy et al., 2004).

Other studies, however, have observed that conventional gesture production, often occurring as a standalone gesture without language, sometimes emerges before the age of two (E. Bates et al., 1989; Nicoladis, 2002). Besides, conventional gestures are deemed more difficult to understand because of their arbitrary meaning, and lower transparency between the sign and the referent (Hodges et al., 2018).

Multilingualism and gesture comprehension

Gesture production, in particular, has received increased attention in multilingual research over the past decades, notably for its potential to inform language processing and development (e.g., Gullberg, 2012). While bilingual children gesture more than monolinguals in narrative tasks (Nicoladis et al., 2009; Zvaigzne et al., 2019), their gesture comprehension remains largely unexplored.

In a pioneering series of studies, Yow and Markman (2011) showed that 2-, 3-, and 4-year-old bilinguals (i.e., in this case, children exposed to an additional language more than 30% of the week) better interpreted pointing gestures, enabling them to discover a hidden toy, in comparison to monolingual peers.

This finding, however, has not been shown for iconic gestures. Indeed, in a study investigating iconic gesture comprehension in a narrative, no group difference was found between 3.5-year-old monolinguals and bilinguals in their gesture recognition accuracy (Wermelinger et al., 2020). In this study, bilinguals were defined as children exposed to two languages since birth, with a 20% minimum of input of both languages. The authors presumed that the task was not challenging enough for multilinguals, who have been reported to show an advantage in more demanding communicative environments, such as situations with conflicting information (Bialystok & Martin, 2004; Yow & Markman, 2011) or where the integration of multiple cues is required.

In line with this perspective, Yow and Markman (2015) showed that 3-year-old multilinguals could better integrate verbal, non-verbal, and pragmatic cues than monolinguals when interpreting a speaker's intent. To date, no study has investigated the effects of multilingualism on the *comprehension* of conventional gestures.

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Multilingualism as a continuum

Given these findings, one could expect a difference between children of various levels of exposure to multiple languages to emerge: (1) in a task requiring the integration of both verbal and non-verbal cues (i.e., multimodal integration), and (2) in participants benefiting from varied communicative environments, such as children attending primary school, which offers more diverse and complex communicative contexts compared to the home environment (e.g., diversity of interlocutors, additional socio-pragmatic parameters required for successful communication, such as social convention, speech registers, etc.).

However, work to date has not investigated these predictions. Indeed, the inconsistent findings of the few studies investigating multilingual effects on co-speech gesture comprehension (Wermelinger et al., 2020; Yow & Markman, 2011) do not allow us to draw firm conclusions as to whether multilingual children across childhood might better understand gestures than their monolingual peers. The findings are moreover restricted to preschoolers and the assessment of only one gesture type at a time.

Furthermore, it has been suggested that the very design of studies comparing monolinguals and multilinguals based on a single criterion of multilingualism needs to be reconsidered because it does not fully capture the multidimensional nature of multilingualism or the diversity of individuals' linguistic profiles (e.g., de Bruin, 2019; Luk & Bialystok, 2013).

While it is challenging to operationalize a score comprehensively reflecting the full richness of every multilingual experience such as a "bilingualism quotient" would (Marian & Hayakawa, 2021), we propose here to place all individuals on the same scale, based on an (1) explicit and (2) hypothesis-driven criterion (as recommended by e.g., de Bruin, 2019; Surrain & Luk, 2019). This allows to capture the variability between participants that a binary comparison inevitably masks (De Houwer, 2023; Marian & Hayakawa, 2021).

The present study

Building on previous findings showing that children with more exposure to a second language develop enhanced abilities in interpreting non-verbal communicative cues such as pointing gestures (Fan et al., 2015; Yow & Markman, 2015, 2016), the present study examined whether this effect extends to different types of co-speech gestures beyond the early (preschool) ages. While some studies suggest bilingualism may enhance gesture comprehension, findings remain mixed, and existing work has focused primarily on preschoolers using limited gesture types and categorical operationalization of multilingualism. To address these gaps, this study included children beyond preschool age and used a continuous measure of multilingual exposure: the ***balance of multilingual exposure (BME)*** *score*, estimating how evenly participants were exposed to the testing language and another language since birth (the more balanced a child's exposure to multiple languages since birth, the higher the BME *score*; see Methods and Appendix 4 for details). Children with more balanced exposure to multiple languages may encounter a wider range of communicative situations and partners, requiring them to monitor the paralinguistic context and non-verbal cues more accurately than children with lower *balance of multilingual exposure*, including monolinguals (van Wonderen et al., 2023; Wermelinger et al., 2024).

This study investigated whether *balance of multilingual exposure* impacted the understanding of three different types of gestures in children above 3 years: deictic (i.e., POINTING to a cat to indicate "cat"), iconic (e.g., gesturing DRIVE, by miming holding and turning a steering wheel), and conventional gestures (e.g., gesturing LISTEN, by cupping a hand behind the ear). While gestures emerge early in development, the mastery of their comprehension is a long-term process that lasts beyond pre-school age, as demonstrated by the pivotal effect of age on gesture comprehension (Perrault et al., 2019) and the absence of a ceiling effect in previous studies with children both below 4 years (Dimitrova et al., 2017; Wermelinger et al., 2017) and, crucially, above (Perrault et al., 2019).

Different communicative conditions were tested: gestures were presented (1) alone (e.g., gesturing SLEEP by placing hands together and tilting them under the cheek), (2) with a label that reinforced the gestures (e.g., gesturing SLEEP and saying "sleeping"), and (3) with speech transmitting additional semantic information not conveyed by the gesture (i.e., gesturing SLEEP and saying "baby"). Children naturally develop and produce these three conditions gradually in their development, and the two latter conditions have been shown to significantly predict children's lexical and morphosyntactic development, respectively (see Capone & McGregor, 2004, for a review). Finally, a fourth condition corresponded to (4) speech produced alone, as a baseline.

This approach offers a more nuanced understanding of gesture comprehension in children and reflects different conditions in which these cues occur in real-life narrative and conversational situations. Furthermore, it allowed us to test whether a multilingual exposure difference would be visible in a more challenging task with a condition requiring multimodal integration, as previously hypothesized (Wermelinger et al., 2020; Yow & Markman, 2015).

Research question and hypotheses

The current study asked: *"Does balance of multilingual exposure impact the comprehension of deictic, iconic and conventional gestures, presented alone, with reinforcing or supplementing speech in children above preschool age?"*

We predicted that children with greater balance in multilingual exposure would perform better in gesture comprehension than children with less balanced multilingual exposure. Within an exploratory approach, different predictions about performance in the different gesture types could be made: first, this effect could extend more strongly to conventional gestures, which hold an arbitrary and cultural component. Understanding which gesture is most appropriately used in a given community (e.g., to greet someone adequately) is just as important as using the adequate language or speech register. Arbitrary and cultural components are crucial socio-pragmatic parameters to consider and monitor for effective communication. Conventional gestures require understanding social norms for their interpretation, because they are embedded within specific cultural contexts. Children with more balanced multilingual exposure often navigate multiple cultural frameworks, and through this experience, they may become more adept at

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monitoring, recognizing, and adapting to these socio-pragmatic nuances. In doing so, they would hone their ability to decode culturally specific gestures effectively.

Alternatively, the heightened sensitivity to the communicative context shown in bilinguals could translate into a better comprehension of iconic gestures, because they directly represent the action they refer to, requiring close attention to the interactional situation. According to previous research and current theoretical considerations (Wermelinger et al., 2024; Yow & Markman, 2016), this skill has been more extensively trained in children with more balanced multilingual exposure than in children with lower balance in multilingual exposure, due to their greater experience with diverse communicative contexts.

With respect to the communicative conditions, previous work in preschoolers has shown that bilingual participants better integrate multiple verbal and contextual cues to infer a speaker's intent (Yow & Markman, 2015). Based on this finding, we predicted the difference in gesture comprehension performance between children with greater balance of multilingual exposure, as compared to children with lower balance of multilingual exposure, to be particularly noticeable in the condition requiring multimodal integration (i.e., *supplementary speech-gesture combination [SUPP]*, see Methods section). This condition has indeed been shown to be the most difficult in previous work in preschoolers (Dimitrova et al., 2017) as it requires to combine and integrate both verbal and gestural streams of information.

Methods

Participants

A total of $N = 200$ children aged 2;10 to 11;10 years with no reported or suspected cognitive, linguistic, neurological impairment or neurodevelopmental condition participated in this study. Participants were recruited via flyers, newsletters, and the project's website on the different sites in which this international project took place (Switzerland: 36.0 %, Germany: 30.0%, France: 14.0%, UK: 11.5%, Canada: 2.0%, USA: 6.5%). The sample constitutes a WEIRD sample (Western, Educated, Industrialized, Rich and Democratic; Henrich et al., 2010) with predominantly White children.

Because this study aimed to inform about multilingual effects beyond early childhood, the initial sample comprised participants spanning a wide age range, from preschool to the end of primary school (i.e., $N = 200$ children between 3 and 11 years). However, data inspection showed that performance in older participants (96 months and above) started plateauing at high accuracy, suggesting that participants tended to perform at ceiling and that the task showed little sensitivity above this age (see Appendix 1). Therefore, subsequent analyses were only conducted on the younger participants (i.e., $N = 105$ children aged below 96 months; see Table 1 for the participants' characteristics), and data for the older participants ($N = 95$) were not further examined.

Before assessment, caregivers filled in the "Quantifying the Bilingual Experience" questionnaire (Q-BEx; De Cat et al., 2022), an extensive parental questionnaire precisely capturing key variables of the linguistic environment of the child since birth in the different language(s), such as their current and cumulative exposure and use of the language(s), the richness of their experience and estimated proficiency, among others (see Appendix 2 for the description of the participants' linguistic background and Appendix 3 for the visualization of the languages they were exposed to, in addition to the testing language). Participants were tested in their most proficient language, as estimated by their caregivers, when this language corresponded to a language of the task, namely English, French, German, or Italian ($N = 92$). When a task version was not available in the child's most proficient language, they were tested in the societal language of the country or region where testing occurred ($N = 13$).

Consistent with the hypothesis that children with more exposure to multilingual environments develop increased sensitivity to the communicative context and better interpret gestures, a *BME* was operationalized as follows: the absolute difference between the percentage of cumulative exposure to the language of testing and the second language was calculated, then subtracted from 100 *(Formula: 100 - |Exposure to L1 - Exposure to L2|)*. This yielded a score between 0 and 100, translating the participants' balance in their multilingual exposure (with a higher score reflecting a greater balance of exposure to multiple languages since birth). Specifically, a score of 100 reflected a balanced exposure between two languages, in the sense that participants had been equally exposed on average to two languages since birth (e.g., lifetime exposure to the testing language 50% of the time, 50% to an additional language, *score = 100 - (50 - 50) = 100*). In contrast, a participant who had been mainly exposed to a single language would present a low *BME score* with a score approaching 0 (e.g., a strict monolingual with exposure to a language at 100% and 0% to an additional language would have a BME *score = 100 - (100 - 0) = 0*). In the case of participants being exposed to three languages, the maximum rate of exposure between the second and the third language was selected. For instance, a participant with an exposure of 50% to the L1, 30% to the L2, and 20% to the L3 would obtain a *BME score = 100 - (|50 – 30|) = 80* (see Appendix 4 for additional examples).

To index the participant's socioeconomic status, the highest value of the caregivers' educational levels was used (i.e., 5-point Likert scale from (1) "elementary school" to (5) "university degree"), since this factor is strongly linked to children's academic achievement (Sirin, 2005) and cognitive development (Rindermann & Ceci, 2018).

Measures

Participants were tested individually by a trained experimenter in a quiet room. Measures included the gesture comprehension task, the *Raven's Progressive Matrices* (Raven's 2, Raven et al., 2018), and the *Peabody Picture Vocabulary Test* (PPVT-4, Dunn & Dunn, 2007).

Gesture comprehension task

This task was inspired by Dimitrova and colleagues (2017) and was embedded in a so-called *serious game* (i.e., a game-like activity) on a tablet (iPad), explicitly developed for the purpose of the study. The task was introduced and entirely

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explained by a 3D human-like character, Gabi, with a natural voice, who was watching TV and asking for help to understand the videos better. All pre-recorded instructions and stimuli were translated, adapted, and recorded by native speakers in four languages (i.e., English, German, French, and Italian), ensuring consistent quantity and quality of instructions between participants and across language versions.

NATURE OF THE STIMULI. The task consisted of 48 pre-recorded short video sequences of a gesture preceded by two warm-up trials (i.e., 4 items*3 gesture types*4 communicative conditions, resulting in 48 stimuli). Participants watched one gesture at a time and were asked to select, out of three options, the picture corresponding to the gesture displayed. Gestures could be of three types: 1/3 of the stimuli were deictic, 1/3 iconic, and 1/3 conventional. Each gesture item appeared in four different communicative conditions: (1) *gesture-only* condition (GO), where a speechless actor performed the target gesture; (2) *reinforcing speech-gesture combination* (REINF), where the actor performed the target gesture accompanied by naming the corresponding label; (3) SUPP, where the actor performed the target gesture and enunciated supplemental verbal information necessary to select the correct picture; and (4) *speech-only* condition (*SO*) as a control, where the actor named the label of the gesture without gesturing.

As in the original task (Dimitrova et al., 2017), stimuli were pseudo-randomized: for each item, the *gesture-only* and *SUPP* conditions always appeared before the *SO* and *reinforcing speech-gesture combination* conditions for this item, to avoid directly providing the participant with the label.

All labels were selected from the Mac-Arthur Bates Communicative Development Inventory of the respective languages (i.e., English: Fenson et al., 2007; French: Kern et al., 2010; German: Szagun et al., 2009; Italian: Rinaldi et al., 2019), ensuring limited lexical complexity as these words are considered acquired at 36 months. The conventional gestures were selected for their universality and minimal variations across the four testing languages and Western countries where testing took place. The nature of the congruent speech proposed with the gesture (i.e., in the reinforcing speech and gesture condition) was chosen to reflect how they are most naturally encountered (McNeill, 1992): because deictic gestures rarely represent verbs, and conventional gestures rarely nouns, a noun accompanied deictic gestures in the *reinforcing speech and gesture condition* (e.g., POINTING + "hat"), and a verb accompanied conventional ones (e.g., LISTEN + "listening"). For iconic gestures, verbs were selected, but iconic gestures representing nouns are also common (see the Limitation section for a discussion of this choice). The stroke (i.e., most expressive and meaningful phase of a gesture (McNeill, 1992), like the thumb and index pinching the nose to convey DISGUSTING) was not depicted in the picture options for conventional gestures, in order to have the participant access the meaning of the gesture, rather than operating a mere gesture-to-picture matching. Figure 1 describes a stimulus for an item of the iconic type, and video examples are accessible in Appendix 5. The complete item list is available in Appendix 6.

NATURE OF THE RESPONSE CHOICES. For each stimulus, three pictures were proposed in random order: (1) the correct response, (2) a visual distractor (i.e., for deictic gesture: a picture close to the target; for the other gesture types: a picture

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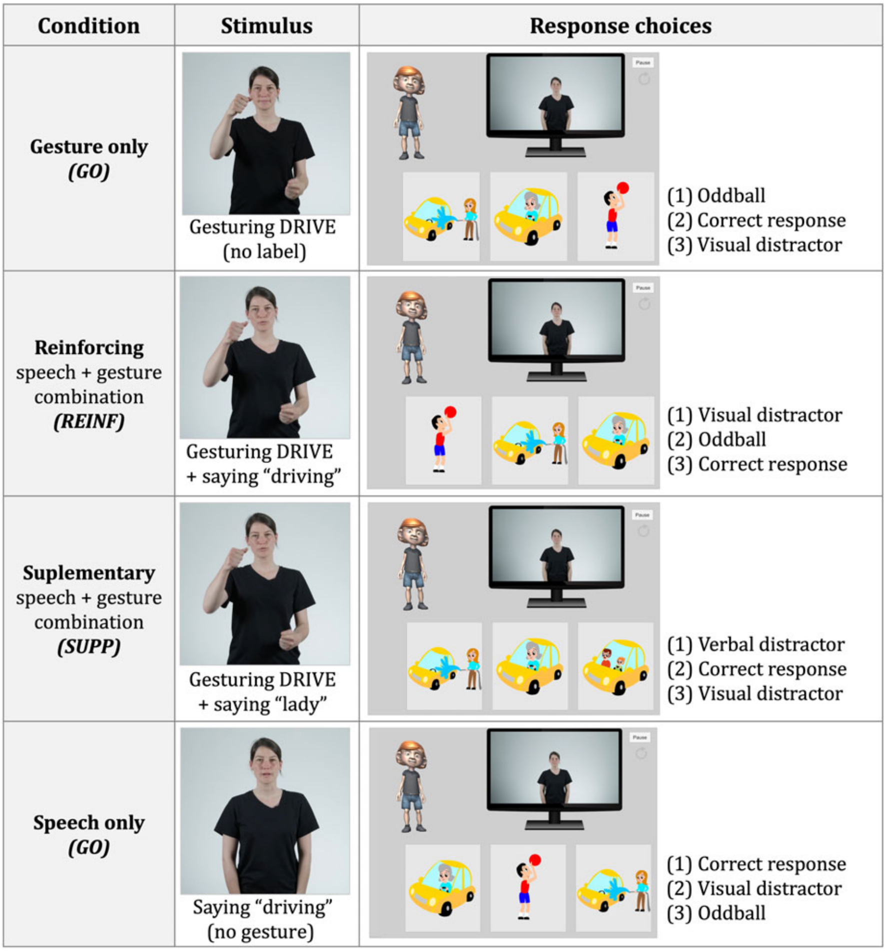

Figure 1. *Example for the item DRIVE in the four conditions.* The "stimulus" column depicts the video presented to the participant, which was followed by the screen displaying the 3 response options (right column). Numbers refer to pictures from left to right.

corresponding to another gesture made in the same area), (3) a third response choice corresponding to both an oddball in the *gesture-only, SO* and *reinforcing speech and gesture* conditions, and to a verbal distractor in the case of the *supplementary speech and gesture* condition, as it matched the stimulus' verbal part. Thus, responding accurately to the *SUPP* required processing both the verbal and the gestural parts of the item. The task was designed such that the correct picture of one item was an incorrect response for another item to avoid repeating the same picture as the correct option across trials (see 5 for further details on response options).

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Scoring. Each correct picture selection was awarded 1 point, while each incorrect response received 0 points, yielding a maximum score of 48.

Raven's progressive matrices 2nd edition (Raven's-2)

The short version of the digitalized Raven's-2 (Raven et al., 2018) was proposed to estimate non-verbal reasoning abilities. Among five choices, participants selected the missing piece of various puzzles of increasing complexity. Standardized IQ scores were selected for the analyses.

Peabody Picture Vocabulary Test (PPVT-4)

The participants' receptive vocabulary breadth was measured using the PPVT-4 (Dunn & Dunn, 2007) and respective adaptations in the languages of the test (French: Dunn et al., 1993, Italian: Stella et al., 2000; German: Lenhard et al., 2015). Participants listened to pre-recorded words of increasing difficulty and selected the corresponding picture among four choices. Z-scores were used to enable comparison across language versions.

Statistical analysis

To determine whether greater balance of multilingual exposure differently impacted the participants' gesture comprehension while accounting for differences in their demographic information (age, sex assigned at birth, socioeconomic status) and verbal and non-verbal abilities, binomial generalized linear mixed effects models were fitted in R and R Studio Version 2023.12.0+369 (R Core Team, 2020) using *lme4* package (D. Bates et al., 2015).

The testing language variable (English, French, German, and Italian) was sum-coded, while sliding contrasts were used for gesture type (deictic, iconic, conventional). For the communicative conditions (SO, GO, REINF, and SUPP), customized contrasts were created: (a) the first contrast compared SO to all other conditions, to compare performance when a gesture is present, to when it is absent; (b) the second compared the GO to the SUPP communicative condition to examine multimodal integration, i.e., compare the performance when a supplementary verbal information is provided to when the gesture is presented alone; and (c) the third contrast compared REINF to SUPP, to index the change in the label nature (i.e., reinforcing versus supplementing speech). All models included random effects for participants and items; the (scaled) *BME score*, *gesture types*, *conditions,* and their interaction were added as fixed effects. To account for developmental changes in the comprehension of specific gesture types, the model included the main effect of *age* and *gesture types,* as well as their interaction. In addition, *sex assigned at birth*, *vocabulary breadth*, *non-verbal IQ*, *parental educational level,* and *testing language* were entered as covariates. Given GLMER's robustness against missingness, missing data were not imputed (Vasishth et al., 2022). All covariates were scaled, and no multicollinearity issues were detected (i.e., Variance Inflation Factor for each variable was below 5). Full details on statistical analysis and data are available at https://osf.io/cusfk/.

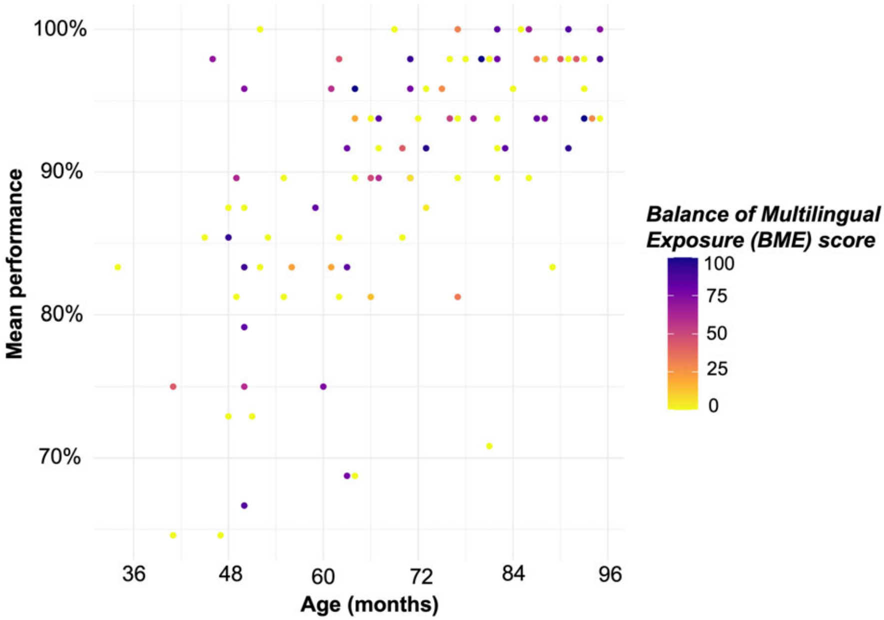

Figure 2. Observed gesture comprehension accuracy as a function of age and balance of multilingual exposure score. A higher *balance of multilingual exposure score* (i.e., darker dot) reflects a greater balance in exposure to several languages since birth, while a lower score (i.e., lighter dot) reflects a greater imbalance (e.g., greater exposure to one language as compared to another).

Results

Participants performed relatively well on the task (Figure 2).

The results of the statistical model showed a significant effect of gesture type: irrespective of the condition, conventional gestures exhibited lower performance than iconic gestures ($\beta = -0.92$, SE = 0.23, $z = -4.02$, $p < .001$) for all participants (Table 2). However, this effect cannot be interpreted as such because it further interacted with both *multilingual exposure score* and *condition*: precisely, the 2-way interaction between *conventional* gesture relative to *iconic* gesture and the *gesture-only condition* relative to *supplementary speech-and-gesture condition* was significant ($\beta = 0.84$, SE = 0.35, $z = 2.43$, $p = .02$). It furthermore interacted significantly with the *BME score*, resulting in a significant 3-way interaction between balance of multilingual exposure, gesture type (conventional—iconic), and condition (*gesture-only—supplementary speech-and-gesture condition*) ($\beta = 0.57$, SE = 0.27, $z = 2.11$, $p = .03$). Additionally, the 3-way interaction between balance of multilingual exposure, gesture type (deictic—iconic) and condition (*gesture-only – supplementary speech-and-gesture condition*) also yielded significance ($\beta = -0.78$, SE = 0.29, $z = -2.71$, $p = .006$).

To locate the source of this interaction, nested contrasts were created to examine simple effects (see Appendix 7). The results showed that the *BME score* differently impacted the gesture comprehension of iconic gestures in the *gesture-only condition*

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Table 1. Descriptive statistics of participant characteristics, including verbal and non-verbal measures. Analyses were conducted on the group of younger participants

	Participants (N = 105)
Age (months)	
Mean (SD)	70.4 (15.8)
[Min, Max]	[34, 95]
Sex assigned at birth	
F	55 (51.4%)
M	50 (47.6%)
Parental Educational Level (min 1 – max 5)[a]	
Mean (SD)	4.72 (0.62)
Median [Min, Max]	[2, 5]
Receptive vocabulary (PPVT, z-score)[b]	
Mean (SD)	0.27 (1.10)
Median [Min, Max]	[−2.87, 2.30]
Non-verbal IQ (Ravens-2)[c]	
Mean (SD)	99 (12.8)
Median [Min, Max]	[70, 126]
Testing Language	
ENGLISH	21 (20.0%)
FRENCH	27 (25.7%)
GERMAN	36 (34.3%)
ITALIAN	21 (10.0%)
Balance of Multilingual Exposure (BME)	
Mean (SD)	34.8 (37.4)
[Min, Max]	20.0 [0, 100]

Note: PPVT = Peabody Picture Vocabulary Test.
[a]Parental educational level was measured on a scale from 1 to 5. The highest value of the two caregivers was selected.
[b]Data were missing for 14 participants (14.7%).
[c]Data were missing for 12 participants (12.4%).

(β = 1.04, SE = 0.49, z = 2.12, p = .03), but not in the *supplementary speech-and-gesture condition* (β = 0.35, SE = 0.25, z = –0.94, p = .35*)*: children with higher *BME score* recognized more iconic gestures than children with lower *multilingual exposure score* in the *gesture only* condition.

In addition, the *SO condition* exhibited better performance than the other conditions (β = –0.63, SE = 0.17, z = –3.61, $p < .001$), just as the *reinforcing speech-and-gesture* condition yielded better scores than the *supplementary speech-*

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Table 2. Fixed effects of the final model

	β	SE	Z	p
Intercept	2.79	0.15	18.24	<.001***
Balance of Multilingual Exposure (BME)	0.15	0.12	1.29	.20
GestureDeicticIconic	0.38	0.24	1.58	.11
GestureIconicConv	−0.92	0.23	−4.02	<.001***
CondSpeechToAll	−0.63	0.17	−3.61	<.001***
CondReinfToSupp	0.73	0.15	4.82	<.001***
CondGestOnlyToSupp	0.29	0.14	2.10	.04*
Age	0.61	0.11	5.69	<.001***
Sex_at_birth	−0.10	0.20	−0.48	.63
ParentalEducLevel	0.02	0.10	0.25	.80
NonVerbal_IQ	0.15	0.11	1.41	.16
Vocabulary	0.09	0.10	0.90	.37
Lang_English	−0.95	0.65	−1.46	.14
Lang_French	0.01	0.71	0.02	.99
Lang_German	0.86	0.64	1.33	.18
BME:GestureDeicticIconic	0.04	0.19	0.19	.85
BME: GestureIconicConv	0.00	0.18	0.00	1.00
BME: CondSpeechToAll	−0.26	0.15	−1.77	.08
BME: CondReinfToSupp	0.04	0.12	0.35	.73
BME: CondGestToSupp	−0.11	0.11	−1.09	.28
GestureDeicticIconic: CondSpeechToAll	0.05	0.44	0.11	.92
GestureIconicConv: CondSpeechToAll	−0.28	0.43	−0.65	.51
GestureDeicticIconic: CondReinfToSupp	−0.36	0.39	−0.92	.36
GestureIconicConv: CondReinfToSupp	0.34	0.36	0.96	.34
GestureDeicticIconic: CondGestToSupp	−0.48	0.36	−1.34	.18
GestureIconicConv: CondGestToSupp	0.84	0.35	2.43	.02*
GestureDeicticIconic:Age	−0.20	0.17	−1.18	.24
GestureIconicConv: Age	0.02	0.16	0.11	.91
BME: GestureDeicticIconic: SpeechToAll	0.04	0.38	0.11	.92
BME: GestureIconicConv: SpeechToAll	−0.17	0.36	−0.47	.64
BME: GestureDeicticIconic: CondReinfToSupp	−0.51	0.32	−1.59	.11
BME: GestureIconicConv: CondReinfToSupp	0.08	0.28	0.27	.78
BME: GestureDeicticIconic: CondGestToSupp	−0.78	0.29	−2.71	.006**
BME: GestureIconicConv: CondGestToSupp	0.57	0.27	2.11	.03*

Note: *BME* stands for balance of multilingual exposure score; *CondSpeechToAll* refers to the contrast of the condition speech-only compared to reinforcing, gesture-only, and supplementary conditions combined; *CondReinfToSupp* reflects the contrasts between conditions reinforcing and supplementary speech-gesture combinations; *CondGestToSupp* reflects the contrast between the conditions gesture-only and supplementary; *GestureDeicticIconic* refers to the contrast between deictic versus iconic; *GestureIconicConv* refers to the comparison of iconic versus conventional gestures; *ParentalEducLevel* means parental educational level. *Lang* means testing language. *shows significant p values at .05 level, **at .01 and ***at .001. β stands for estimates, *SE* for standard error, and z for Z-value.

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and-gesture conditions ($\beta = 0.73$, SE $= 0.15$, $z = 4.82$, $p < .001$). As expected, performance significantly increased with age ($\beta = 0.61$, SE $= 0.11$, $z = 5.69$, $p < .001$). However, it did not interact significantly with the type of gesture ($p > .05$). None of the other covariates, such as non-verbal IQ, vocabulary breadth, parental education level, or sex assigned at birth, predicted gesture comprehension (all p values $> .05$).

Discussion

This study explored whether balance of cumulative multilingual exposure impacts how children above preschool age understand deictic, iconic, and conventional gestures, while accounting for key variables (i.e., age, sex assigned at birth, parental educational level, vocabulary breadth, and non-verbal IQ). The novel gamified task performed in four languages allowed a nuanced picture of the impact of multilingualism on the comprehension of these gestures by exploring the comprehension of gestures in different conditions, closer to how they are naturally encountered in daily communicative situations. Findings revealed a positive effect of *balance of multilingual exposure* on the comprehension of iconic gestures presented without speech.

Impact of multilingual exposure on gesture comprehension

Balance of cumulative multilingual exposure differently affected the comprehension of iconic gestures when these were presented without speech. More precisely, children with greater balance in their multilingual exposure since birth recognized significantly more iconic gestures than their peers who were less balanced in their multilingual exposure, when iconic gestures were not accompanied by speech. This finding is consistent with previous work (e.g., Yow & Li, 2024; Yow & Markman, 2011) and aligns with theoretical frameworks (Fan et al., 2015; Wermelinger et al., 2024), suggesting that multilingual individuals develop a *heightened sensitivity* to the communicative contexts and the non-verbal cues they entail. Children with higher multilingual exposure may develop increased attentiveness to visual and contextual cues, such as iconic gestures that directly link to the environment, through regular interactions in situations where non-verbal signals often support communication. According to the COME perspective (Wermelinger et al., 2024), multilingual individuals experience greater variability in both effective and non-effective communicative situations, leading to a larger repertoire of communicative means, and the flexibility to apply them appropriately. Multilingual children may frequently encounter situations requiring them to infer meaning from gestures in the absence of accompanying speech, thereby strengthening their comprehension of iconic gestures presented without verbal support. For instance, they may interact with adults who speak their language less fluently or with peers and educators using a language in which they are less proficient. In such contexts, communication may rely more heavily on gestures and contextual cues. These scenarios align with the ***Compensation Hypothesis*** (van Wonderen et al., 2023), which proposes that multilingual children may attend more to non-verbal cues to compensate for occasional gaps in linguistic knowledge. *The* ***Monitoring Hypothesis*** (van

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Wonderen et al., 2023) further suggests that multilingual children develop heightened sensitivity to communicative cues, including gestures, because they routinely track which language to use with whom, in order to avoid misunderstandings. As this process likely draws on attentional resources (e.g., monitoring and selectively attending to the visual cue, retrieving its meaning, and linking it to the context), future work may investigate whether this effect is mediated by attention skills in children with different balances of multilingual exposure.

It is also possible that multilingual and monolingual children may differ in their processing strategies, for instance, in the extent to which they rely on gesture as a scaffold (see Botting et al., 2010, for a similar suggestion in children with developmental language disorder). However, since all target words in the present study were highly familiar, and vocabulary was controlled in the analyses, we interpret the effect of balance of multilingual exposure as reflecting broader differences in sensitivity to non-verbal cues (van Wonderen et al., 2023; Wermelinger et al., 2024).

Interestingly, no effect of balance of multilingual exposure was detected for conventional gestures, despite their greater arbitrary and culturally shared components that could favor children with greater balance in multilingual exposure. Scrutiny at the item level revealed great variability and overall lower performance across the four conventional gestures tested (Appendix 8), specifically in the *gesture-only* condition (see Appendix 9 for the details of the errors produced). This suggests that conventional gestures in the current task may have been more ambiguous and therefore more difficult to recognize overall, eventually not discriminating between children with greater and lower multilingual exposure.

Previous research had shown that bilingual children integrated multimodal cues such as eye gaze presented with speech in order to locate an object more efficiently than monolingual peers (Yow & Markman, 2015). In contrast, no effect of balance of multilingual exposure was detected in our task in the condition requiring multimodal integration (i.e., *supplementary speech-and-gesture combination*). However, the absence of this effect is actually consistent with previous work conducted with monolingual and bilingual preschoolers (Wermelinger et al., 2020): In a gesture perception task where a speechless iconic gesture completed a sentence, no difference between groups was found in the participants' ability to integrate both verbal and gestural streams of information.

Altogether, these findings raise the possibility that an effect of multilingualism on multimodal integration may not be ubiquitous but rather tied to situations and tasks requiring more salient communicative intent. Indeed, multilingual children generally present enhanced Theory of Mind skills (i.e., defined as the ability to attribute mental states; Premack & Woodruff, 1978) compared with their monolingual peers (Schroeder, 2018; but see Baumeister et al., 2025; Dahlgren et al., 2017). Arguably, both the 2015 task by Yow and Markman, which required participants to infer the experimenter's intent by integrating a word and the experimenter's gaze (Yow & Markman, 2015), and the 2011 task, where participants attended to pointing or eye gaze to locate an object (Yow & Markman, 2011), mobilized higher pragmatic and mentalizing skills as compared to the study by Wermelinger et al. (2020) and the current work. This, consequently, may explain the lack of multilingual effect observed on multimodal integration on the one hand, and on deictic gestures that directly pointed to the referent, on the other.

In the future, studies using eye-tracking may help to shed light on the multimodal integration in children with diverse multilingual backgrounds. For instance, eye tracking can reveal whether children efficiently coordinate their gaze between gestures and speech, and whether multilingual children show greater flexibility or faster gaze shifts when integrating these modalities. Prior work suggests that looking at gestures plays a critical role in supporting comprehension, particularly when the linguistic input is more difficult to process (Zielinski & Wakefield, 2021). Moreover, multilingual children may attend more readily to gestures when the verbal input is ambiguous or cognitively demanding (Demir-Lira et al., 2018; Yow & Markman, 2011). Such gaze patterns could clarify whether multilingual experience enhances children's ability to dynamically integrate verbal and non-verbal communicative signals.

Additional effects

As expected and previously reported (Perrault et al., 2019), age was a significant positive predictor of gesture comprehension ability, with participants demonstrating improved performance with age. This effect seemed consistent across the different gesture types, as there was no evidence of an interaction between age and gesture type in the current study.

Unsurprisingly, the *SO condition* yielded better performance for all participants than all other conditions, irrespective of their balance of cumulative multilingual exposure. Similarly, recognizing a gesture when it was accompanied by reinforcing speech (i.e., REINF condition) was easier than when the gesture was presented with supplementary speech, consistent with previous work in preschoolers (Dimitrova et al., 2017).

Limitations and considerations for future research

While this study offers valuable insights into how multilingualism modulates gesture comprehension, it is important to acknowledge some limitations.

First, for the sake of clarity, gestures were classified into three types, following McNeill (1992). However, some overlaps between these categories exist, and the types of gestures rather lie on a continuum (also known as *Kendon's continuum*; McNeill, 1992). Therefore, some flexibility in the gesture classification is warranted because, for instance, iconic gestures can become conventionalized with context and use (Müller, 2017). Conversely, conventional gestures can vary in their iconicity (Kendon, 2004). This suggests that the conventional gestures in this study, assumed to be present in all the Western countries where the study was conducted, might vary in their iconic and conventional dimensions. More broadly, as the present sample was limited to European languages and Western cultural contexts, caution is warranted in generalizing these findings to non-European languages and cultures, where gesture use and its interaction with multilingual experience may differ (Kita, 2009).

Second, the very nature of the verbal information provided with the gesture in the *reinforcing speech and gesture* condition was different between deictic gestures on the one hand, and iconic and conventional gestures on the other (i.e., a noun or a verb, respectively) to best reflect how gesture and speech are most commonly naturalistically paired. Previous research suggests that while deictic gestures predict and precede the acquisition of spoken nouns (Iverson & Goldin-Meadow, 2005), iconic gestures representing actions may emerge after the acquisition of corresponding verbs (Özçalişkan et al., 2014), possibly constituting a confound between *gesture type* and *word form* in the current task. Investigating predictive relationships between gestures and speech acquisition falls outside the scope of this study, which aimed at better understanding gesture comprehension and its interaction with speech in children after preschool age from various multilingual backgrounds. As all words were selected from a validated checklist of early-acquired words (i.e., MacArthur-Bates Communicative Development Inventories), it is unlikely that any observed differences in gesture comprehension are attributable to variations in word familiarity. Nonetheless, future studies should include a greater number of gesture items within each type, along with more consistent verbal pairings across gesture types, in order to confirm and extend these findings.

Third, in order to address common limitations in previous studies using binary approaches to bilingualism (see e.g., de Bruin, 2019; Kremin & Byers-Heinlein, 2021; Leivada et al., 2023; Surrain & Luk, 2019 for discussions), the current work sought to operationalize more transparently a continuous bilingual variable according to the study hypotheses, namely the balance of exposure to several languages since birth. However, multilingualism is a multifaceted and heterogeneous phenomenon, with no two multilingual individuals identical in their language combinations, proficiency, amount and balance of use or exposure, age of onset, attitudes toward their languages, mean and context of acquisition, among other factors (De Cat et al., 2023; Luk, 2015; Marian & Hayakawa, 2021). The *BME score* used in the current study, while informative in indicating how balanced a child's exposure to two languages has been, does not capture other dimensions of multilingual experience, such as participants' mastery of their additional languages or actual use. Moreover, it focuses on the balance between the testing language and the most prominent additional language, and therefore does not fully reflect the complexity of multilingual profiles in children exposed to more than two languages. Future work may consider whether more comprehensive measures, such as entropy-based indices (Gullifer & Titone, 2020), better capture this variability. Adequately characterizing and measuring multilingualism *is* challenging. Transparently reporting sample characteristics and specifying and justifying the bilingual measures considered may be first steps toward ensuring the interpretability and generalizability of the findings across diverse populations (De Houwer, 2023; Hantman et al., 2023; Kremin & Byers-Heinlein, 2021).

Research perspectives

Given the positive role of multilingualism found in the comprehension of iconic gestures, it would be valuable to investigate *whether* this effect is also present in children experiencing specific challenges in this realm. For instance, difficulties in

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gesture production (Ramos-Cabo et al., 2019) and comprehension (Perrault et al., 2019; Silverman et al., 2010) have been reported in children diagnosed with autism spectrum disorder. However, findings remain mixed (Dimitrova et al., 2017; Wolfer et al., 2025) and may vary depending on gesture type, presentation context, and methodological approach (McKern et al., 2023). Exploring the potential benefits of multilingual exposure in such populations could offer promising insights for both research and clinical practice. Autistic children, in particular, may benefit from evidence-based recommendations about dual-language exposure (Beauchamp & MacLeod, 2017).

Conclusion

This work is grounded in a framework hypothesizing that individuals with greater multilingual exposure may be more sensitive to the communicative situation and to their interactional partners, enabling them to detect and better use the socio-pragmatic cues at their disposal (e.g., Wermelinger et al., 2024). This study investigated how balance of multilingual exposure since birth impacted the comprehension of deictic, iconic, and conventional gestures in children aged 3 to 8, with a gamified task available in four language versions. Gestures were presented in different conditions commonly encountered in real-life situations, and all participants were considered on a multilingual scale to circumvent the caveats of group comparisons with an arbitrary bilingual criterion. Findings indicated that greater balance of multilingual exposure positively influenced the comprehension of speechless iconic gestures.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/S0142716425100192

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Replication package. Data and code are available at the following URL: https://osf.io/cusfk/, [DOI 10.17605/OSF.IO/CUSFK]. The analyses presented were not preregistered.

Ethical standards. This study was approved by the Swiss Association of Research Ethics Committees *Swissethics* (Project ID-2022-00878), the Institutional Review Board of the University of Connecticut (US), the Psychology Research Ethics Committee of the University of Edinburgh (UK), and the Institutional Review Board of Emerson College, Boston (US). All parents provided informed written consent for their child's participation prior to their inclusion in the study.

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