American Journal on Intellectual and Developmental Disabilities

The key role of gestures in spatial tasks in students with intellectual disabilities

--Manuscript Draft--

Manuscript Number:	AJIDD-D-23-00042R2
Article Type:	Research Report
Keywords:	Gesture, Conceptualization, Mental rotation, Spatial reasoning, Intellectual Disabilities
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Abstract:	Background: The gestures produced by children with intellectual disabilities (ID) in spatial tasks are rarely considered, although they have a supporting role in the formation of thought. Aim: In this research, we analyzed the number of gestures, the type of gestures and their role in the expression of knowledge of students with ID. Method: Twenty students (12-17 years old) with ID and 40 students matched on visual-spatial level (n = 20) and on language level (n = 20) participated in the research. Results: Students with ID made significantly more gestures in relation to the number of words spoken compared to their typical peers (TD). Thirty percent of the expressive communication of students with ID came from gestures alone and 60% of the responses contained at least one gesture. Finally, the higher the level of task difficulty, the more gestures the pupils made.

The key role of gestures in spatial tasks for students with intellectual disabilities

Abstract

Background: The gestures produced by children with intellectual disabilities (ID) in spatial tasks are rarely considered, although they have a supporting role in the formation of thought. **Aim:** In this research, we analyzed the number of gestures, the type of gestures and their role in the expression of knowledge of students with ID. **Method**: Twenty students (12-17 years old) with ID and 40 students matched on visual-spatial level (*n* = 20) and on language level (*n* = 20) participated in the research. **Results:** Students with ID made significantly more gestures in relation to the number of words spoken compared to their typical peers (TD). Thirty percent of the expressive communication of students with ID came from gestures alone and 60% of the responses contained at least one gesture. Finally, the higher the level of task difficulty, the more gestures the pupils made.

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Background

The role of gestures in the conceptualization and expression of thoughts

Several researchers have shown that gestures are produced at different points in the conceptualization process and may provide information complementary to the person's verbal language (Kita et al., 2017; McNeill, 1992). While early studies focused on the role of "co-verbal" gestures, i.e. gestures produced alongside speech, more recent scientific research is focusing on "co-thought gestures" produced while the individual is thinking and analyzing a task. It has been shown that co-thought gestures influence cognitive processes, learning, mental representations and problem solving (Gordon & Ramani, 2021). Co-speech gestures and co-thought gestures can be subdivided into the four subcategories proposed by McNeill

(1992), three of which, of particular interest, are used in this study. 1. Iconic gestures have a close relationship with the semantic content expressed by speech (e.g. saying "I turned the key" and indicating the direction of rotation with the hand). They help illustrate concrete actions, objects or events (McNeill, 2005). 2. Metaphorical gestures refer to an abstract concepts or objects (e.g. saying "they are the same" and opening one's right and left hands to signify equality). 3. Deictic gestures point to concrete or abstract objects (e.g. saying "I went there" and pointing to show direction). Researchers are also interested in object manipulation, assuming that they may share common features and functions and be generated by the same system, a hypothesis leading to the construction of the theory of gestures as simulated actions (Hostetter & Alibali, 2019). According to Kita et al. (2017), the manipulations performed on an object, as well as the gestures, can be observed to see whether and if an individual activates spatial representations, manipulates information, explores possible responses, or organizes their explanatory discourse. In the context of this research, the physical manipulation of objects with the aim of explaining one's reasoning will be considered as "action gestures" as they also allow the individual's thinking to be observed.

Expressive communication produced in response to a question or during the resolution of a task may occur in three different ways (Mastrogiuseppe & Lee, 2017; Stefanini et al., 2007). Speakers may produce either unimodal gestures, also called "gesture-only", which correspond to responses produced in gestural form only; or gestures and speech at the same time, called "bimodal production"; or finally "speech alone", which contains only words. With respect to bimodal productions, the researchers has identified three functions that distinguish their role (Iverson et al., 2003): equivalent, complementary and supplementary. Equivalent gestures are gestures that give similar information through gestures and verbal language (e.g. saying "it makes a U" and showing the shape of a U with one's fingers); complementary gestures are gestures that clarify the verbal language. The referent of these gestures generally is the same as in the speech, but the gestures make the speech more explicit (e.g. saying "I turned it like this" and making a gesture showing the direction of rotation. Finally, supplementary gestures are gestures that provide additional information not present in verbal language (e.g. "I'm hungry" and pointing at bread). Figure 1 illustrates these concepts, in particular the distinctions that can be made according to the type of gestures, the combinations in which they are produced and the functions they have with language.

Insert Figure 1 about here

But how do students with mild to moderate intellectual disabilities use gestures to express knowledge ? And what about the support they might find in gestures when solving a spatial task? To answer these questions, we carried out three literature reviews. The first one focused on the role of gestures in the spatial domain (Lacombe & Dias, 2023), the second on the role of gestures in students with ID (Lacombe et al., 2021) and the third on the development of spatial skills in students with ID (Lacombe, 2022).

The role of gestures in the spatial domain

Spatial skills are both essential for everyday life and are strong predictors of students' future success in mathematics, science, technology, and engineering (Davis, 2015). With regard to spatial skills, two distinct sets of skills can be distinguished (Newcombe et al., 2013). On the one hand are the inter-object representation processes that enable the encoding of object locations, orientation and/or navigation in space or in relation to each other. On the other hand are the intra-object representations relating to the structure of the object itself, which can be identified by observing that object statically or by manipulating it concretely or in thought. Various research studies provide evidence that intra-object representation processes, in particular the ability to mentally rotate objects in space correctly and quickly (Bruce & Hawes, 2015) are predictive of the development of numerical cognition. In typical students, links have been found between mental rotation and understanding the number position system, placing numbers on a number tape, or solving gap addition (Crollen & Noël, 2017). In addition to predicting mathematical outcomes, mental rotation is frequently used in everyday life, i.e. to tidy a wardrobe, load the boot of a car before a holiday, or build a marble circuit. The results of a previous systematic review highlighted that effective interventions to improve mental rotation skills are object manipulation and the use of iconic gestures to simulate rotation (Lacombe & Dias, 2023). Regarding the use of gestures in the spatial domain, Lavergne and Kimura (1987) suggest that people use twice as many gestures when talking about space than when telling a story (e.g. describing a book) or describing their day. Gestures are thought to be particularly useful for providing quick and accurate spatial information, such as communicating a particular location, direction, or distances between objects (Sauter et al., 2012).. Finally, the literature review also points out that gestures express spatial concepts that are not expressed in language, which highlights the importance of taking people's gestures into account to better understand their thoughts, when they solve problems in everyday life or in specific environments, i.e. at school.

The role of gestures in students with ID

A second systematic literature review showed that children with ID accompany their spoken language with more gestures than TD children (Lacombe et al., 2021) and that the difference is often explained by the presence of spoken language difficulties in students with ID (Stefanini et al., 2007; Galeote et al., 2011). A first hypothesis for this difference is that gestures would both facilitate and support the individual's expression when their language skills are limited or impaired. This hypothesis is corroborated by the fact that an increased use of gestures has also been observed in people with aphasia (Hadar & Butterworth, 1997) or specific language disorders (Lavelli & Majorano, 2016). Another variable that could influence the number of gestures produced is the level of complexity of the task. Yang et al. (2020) have shown that, in the neurotypical population, as the task complexity increases, the individual uses more gestures to think and verbalize their reasoning. Conceptually complex tasks would therefore elicit more gestures due to the individual's attempts to reduce their cognitive load (Hord & Xin, 2015). Conversely, several factors appear to reduce the frequency of gestures, in particular the presence of visual-spatial deficits. According to Hadar et al. (1998), difficulties in conceptual processes could be a cause of the difficulty in using iconic gestures. Finally, the literature review also showed that students with ID use the expressive modality "gestures alone" significantly more than neurotypical children and use the "speech alone" modality significantly less. A first hypothesis for this difference is that pupils with ID often have difficulty expressing their thoughts verbally (INSERM, 2016). So, the study of gestures proves to be central as it allows, if not a better evaluation, at least a finer assessment of the state of a child's knowledge in a particular field (Stefanini et al., 2007; Mastrogiuseppe & Lee, 2017).

The development of spatial skills in students with ID

While the importance of gestures is attested to in pupils with ID, studies on their effects in the spatial domain are clearly lacking. Previous literature reviews show that spatial and geometric research accounts for only 3% to 10% of the research carried out on pupils with ID (Spooner al., 2019). The little research that has been done shows that pupils with ID can make progress in acquiring spatial skills, even if, when compared with a group of neurotypical pupils, their performance is lower (Broadbent et al., 2014).

In the light of current knowledge, knowing the importance of gestures in the expression of pupils with ID and the support they provide for spatial tasks, we considered it essential to carry out empirical research combining these two concepts. The aims of the present research are therefore to observe both the performance and the use of gestures by students with ID in mental rotation tasks of two levels of difficulty, and compare them to matched groups of neurotypical students. The first group will be matched in terms of visual-spatial skills (TDVS), with the aim of observing the influence of visual-spatial abilities on the use of gestures, and the second in terms of language skills (TDL), to test the hypothesis of a link between the number of gestures used and the individual's verbal skills. Five specific aims and seven hypotheses were formulated:

- Aim 1: To compare the number of gestures and words used by participants with ID and by neurotypical peers. The following hypothesis was formulated: H1) The number of gestures is higher in participants with ID compared to neurotypical peers.
- Aim 2: To examine the links between the participants' personal characteristics (visual-spatial level, language level) and environmental factors (task complexity), and the use of gestures. The hypotheses were: H2a) The lower the language level of the participant, the higher the production of gestures; H2b) The lower the visual-spatial level of the participant, the lower the production of iconic gestures; H2c) The higher the level of complexity of the task, the more the participants use gestures to perform or explain the task.
- Aim 3: To identify the types of gesture and their links with the task performance. The hypothesis was: H3) There will be no correlation between pointing gestures and the successful completion of the task but we postulate a positive correlation between iconic gestures and the successful completion of the task.
- Aim 4: To analyze the modalities of expression (gesture-speech combinations) used by participants with ID versus neurotypical peers. The hypotheses were: H4a) The participants with ID use less "speech alone" than neurotypical peers; H4b) The participants with ID use more "gestures alone" than typical peers.

- Aim 5: To observe the functions of gestures that are used by participants with ID compared to typical ones. As the functions of gestures have been little studied, no hypothesis has been formulated.

Method

The research was authorized by the Commission on Ethics in Human Research (BASLEC no. 2019-00170) as well as by the relevant compulsory and special education departments. A 3x2 (3 groups x 2-level complexity task) Between Subjects Factorial Design has been used, which means that three groups were compared (students with a diagnosis of ID versus typical students matched on visual-spatial level or on spoken language level) in a task involving the mental rotation of volumetric objects of two levels of complexity.

Participants

A total of 24 participants with ID, recruited from four special schools, were randomly selected from those meeting the following criteria: a) diagnosed with intellectual disabilities; b) aged 12 to 18 years; c) French mother tongue or very high level of French (assessed by teachers); d) without binocular vision problems; e) without motor disorders. Only participants for whom double consent was obtained (their parents' and their own) were involved in the research. To confirm the diagnosis of ID, the Raven's Progressive Matrices test (Raven et al., 1998) was administered by the researcher, and the ABAS-II measuring adaptive behaviour was completed by the teachers. Students ($n = 4$) with scores above 70 in the ABAS-II (Harrison and Oakland 2003) were removed from the sample because their test scores did not match with the diagnosis of intellectual disabilities. Given the task and to avoid a possible bias, the standardized Ishihara color test (Ishihara, 1964) was used to verify the absence of color blindness, and a clinical task applied to verify good visual tracking in all participants. The final experimental sample with ID thus consisted of 20 students, 7 girls and 13 boys aged 12-17 years ($M=14.8$; $SD=1.69$) with mild or moderate ID. Five participants have moderate intelligence limitations (IQ between 41 and 55) and 15 participants have mild intelligence limitations (IQ between 56 and 70). Five participants were known for syndromic diagnoses:

two participants have Down syndrome, there were two diagnoses of autism spectrum disorder and ID, and one of fetal alcohol syndrome. The choice to include individuals with ID of various etiologies in the study, and not only syndromic subgroups, is motivated by the lack of literature justifying the choice of a particular subgroup to study our main research question, the existence of within-syndrome variability, and a concern for learners with ID in general, because most of them are challenged by conceptual and/or language difficulties.

Two control groups consisting of neurotypical students individually matched to participants with ID were formed (see Table 1). Because of the importance of visual-spatial reasoning and language on gesture use, control groups were selected on these two variables. The control students were selected from seven different general primary, kindergarten and preschool education classes. The researcher administered the three visual-spatial tests and the spoken language test to 133 pupils in order to find matched pupils to form the control groups. The first group – the Neurotypical Development group matched on Visual Spatial level [TDVS] – consisted of 20 neurotypical participants aged 4-10 years (*M*=*6*.6; *SD*=*1*.53), individually matched on gender and visual-spatial level measured by tests of visual-spatial reasoning (Raven's Progressive Matrices, Raven et al., 1998), visual-spatial memory (Corsi blocks, Corsi, 1972) and visual-motor coordination (Beery-VMI, Beery & Beery, 2010). Each control student had to achieve an identical raw score (+ or -2) on the three spatial tests. Preliminary analyses (Wilcoxon test) confirmed that this group did not differ from the group with participants with ID in analogical reasoning *(*z = 1.22, *p* = .229), visual-motor coordination (z = 0.11, *p* = .909) and visual-spatial memory (*z* = 0.54, *p* = .590), confirming the quality of the match. The second group – the Neurotypical Development group matched on Language level [TDL] – consisted of 20 participants aged 2 to 12 years (*M*=7.1; *SD* = 2.10), individually matched on gender and spoken language level measured with the BILO-3C (Khomsi et al., 2007). Each control student had to achieve an identical raw score (+ or -2) on the spoken language test. Preliminary analyses confirmed that this group did not differ from the group with participants with ID on spoken language (z = 0.70, *p* = .484), suggesting that the matching was appropriate (Table 1). All participants included received parental consent.

Insert Table 1 about here

Measures

The material consisted of four standardized tests used to match the groups:

- The BILO-3C (Khomsi et al., 2007). This computer-based standardized test allows a language profile of the child to be established. Three subtests were used to measure the participants' lexical stock, pronunciation quality and the ability to formulate semantically correct sentences. For each item answered correctly, the participant received one point. The maximum score was 96 points.
- The Corsi block test (Corsi, 1972) was used to measure visual-spatial memory abilities. In the Corsi block test, participants are asked to reproduce in the same order, and then in reverse order, a sequence of pointing movements towards different cubes shown by the observer. Each correctly repeated series of pointing movements gives the child one point; the test stops when the participant fails twice to repeat a certain number of locations. A maximum of 9 points corresponding to a series of 9 blocks can be obtained for the right-side up memorization and 9 points for the reverse memorization.
- The Beery-VMI (Beery & Beery, 2010) tests visual-motor coordination. In the Beery-VMI, the individual must reproduce increasingly complex geometric shapes based on a model. Each correctly drawn shape is worth one point, with a maximum score of 30. The internal consistency measured by Cronbach's alpha is very good .96 (Beery & Beery, 2010).
- Raven's Progressive Matrices (Raven et al. 1998) assess visual-spatial reasoning. The version of Raven's Matrices used was the colored embeddable version (CPM-BF) that allows participants to manipulate the 6 different response possibilities to complete a sequence correctly. The test takes 20 minutes to complete, and the maximum score is 36. Pupils obtain a score of "1" if they complete the series correctly and "0" if the answer is incorrect. This test was standardized for the first time in 1949 by Raven and has a test-re-test reliability of .80. Internal consistency (0.83) measured with Cronbach's alpha for the scale as a whole is good (Bildiren, 2017).

The experimental tasks

The participants were asked to perform two mental rotation tasks, especially developed for the study and involving the mental rotation of volumetric objects (full details of the task can be found here Lacombe, 2022). The tasks differed in their level of complexity. Level 1 is designed so that the participant rotates the shape with one criterion (a coloured face), while Level 2 involves the participant rotating the shape and considering two criteria (the coloured side of the roof and the coloured shutter). The Level 1 task was always presented before the Level 2 task.

Procedure

Participants were individually tested in a dedicated room in the presence of the researcher, who met them three times for 45 minutes. The participants were asked to completed the standardized tests in the first two sessions and the mental rotation tasks in the third session, which was filmed using two cameras (one focused on the left hand and the other on the right hand). The procedural fidelity of data collection was assessed by an outsider to the research to ensure that the conditions of administration were similar across participants. The procedural fidelity criteria used were based on the steps of Ledford & Gast (2014) and were coded on 100% of the videos. Seven criteria were selected: objects used, object presentation conditions, experimenter positioning, participant positioning, instructions given, procedure, latency between an initial question and its reformulation by the experimenter. The average fidelity rate per participant was 99% for the whole sample (N = 60), which represents a high and satisfactory degree of procedural fidelity, with scores ranging from 86% to 100%.

Coding

ELAN software, version 6.0 from Nijmegen (2020) was used for coding the videos. Eleven indicators were considered. The details of each category can be found in Lacombe (2022).

The verbal responses (spoken words) produced by the participant during each of the two mental rotation tasks were exhaustively recorded, classified and counted as occurrences to obtain the sum total of all words used by the participant during each task. They were coded during the entire experimental task. The task began when the experimenter placed the two shapes in front of the pupil and asked if they were identical. The end of the task corresponded to the end of the participant's explanation of the last exercise proposed. Here are some examples of criteria : do not code if the pupil is talking about something other than the spatial task; do not count "yes" and "no" in the number of words; also code words that are not pronounced correctly.

The gestures produced by the participant were coded into four categories: pointing gestures (e.g. the index finger showing a link between two shapes, pointing can also be done with the open hand or by touching the object.); iconic gestures (e.g linear or circular movement of the hand or finger, movement representing (simulating) movement or rotation); metaphorical gestures (e.g. opening one hand and then the other, saying "they're the same") (McNeill, 1992) and action gestures when the student directly manipulates the object (e.g. moving the object, turning it over). Gestures and verbal utterances were then recategorized to characterize the expressive modality according to the classifications proposed by Mastrogiuseppe & Lee (2017) and Stefanini et al. (2007).

Three modalities of expression were also distinguished, namely "unimodal gestural productions" corresponding to responses produced in gestural form only; "bimodal productions" corresponding to responses combining gestures and speech simultaneously; and "unimodal verbal productions" which contained only words. Communicative functions of gestures in relation to speech were coded into three categories according to the distinction made in the literature (Mastrogiuseppe & Lee, 2017; Iverson et al., 2003). The first category of coded function was the redundancy between words and gestures, that is the "equivalent function". Here the gesture gives the same information as that conveyed by speech. For example the speech says “it makes a U” and the gesture makes a U or the gesture shows the blue thing and the person says "the blue thing". The second coded function was precision, that is the "complementary function". In this situation, the gesture adds precision to the language, which allows for a better understanding of the language. For example: the speech says: “that one” and the gestures shows the shape or the speech says “that turns” and the gestures shows the direction of rotation. Finally, the supplementary function was coded when the gesture conveys information that is absent from the verbal language. This happened when the student was not able to express his/her thoughts verbally or when his/her gestures went faster than their verbal speech. For example : the speech says "It's not the same" and the child puts the two objects back together correctly so that they are the same.

Reliability

Inter-coder coding, carried out by a coder independent of the research who wasn't aware of the research questions or group membership of participants, took place on 30% of the videos (n = 18). The double-coded videos were randomly selected, with equal proportions for each group. The procedure started with a training session on the "example" part of a test run, as this was not part of the processed results. The total percentage of inter-rater agreement was 93% for words coding the agreement was 96%, for the number of gestures (95%), for the types of gestures (94%), for the modality of expression (90%), for the functions (92%). All correlations between the two coders for each of the coded variables were significant at the $p < 0.01$ level and ranged from .888 to 1.

Statistical Analyses

Although the results of the Kolmogorov-Smirnov and Shapiro-Wilk tests showed no significant difference and suggested a normal distribution, the Q-Q plots and Gaussian curves indicated that the variables were not normally distributed. That's why, considering the relatively small number of participants per group, and the non-normal distribution, non-parametric statistical analyses were conducted to compare the groups. In fact, unless otherwise indicated, the alpha level was set at $p < .05$. A Bonferroni correction was applied to all post-hoc tests to correct for cumulative error. Effect sizes are reported using Cohen's d.

Aim 1. Relationship between gestures and speech production in ID versus TD. To test the first hypothesis (H1), the statistical analyses were as follow: nonparametric Friedman's test for several dependant samples (DI vs TDVS vs TDL).

Aim 2. Links and influence of personal characteristics and task complexity on the use of gestures. For the second and third hypotheses (H2a, H2b), regression analysis were carried out on the entire sample. To analyze the number of gestures in different levels of complexity (H2c), a non-parametric Wilcoxon test for two dependent samples was conducted. The sample was analyzed as a whole.

Aim 3: Links between the type of gesture and the task performance. For hypothesis H3, Spearman correlation analyses and a regression analysis were performed on the entire sample.

Aim 4: The type of expression modalities used in ID versus TD participants. Finally, to test hypotheses H4a and H4b, nonparametric Friedman tests for dependent samples (ID, vs TDVS vs TDL) were carried out.

Results

Aim 1. Relationship between gestures and speech production in ID versus TD. The first research question was concerned with the number of gestures and words used by participants with ID in comparison to their typical peers. The results of Friedman's non-parametric tests presented in Table 3 show that the average number of gestures used by the three groups did not differ significantly, while the number of words did. The Dunn-Bonferroni *post-hoc* test indicates that participants with ID speak significantly fewer words than the two control groups.

Insert Table 3 about here

To get a clearer picture of the use of gestures in relation to words in the three groups, further analyses were conducted. The number of gestures per word was compared and found to differ significantly between the three groups. By conducting Dunn-Bonferroni *post-hoc* tests, it appears that the ID group uses significantly more gestures per word than the two control groups.

Aim 2. Links and influence of personal characteristics and task complexity on the use of gestures: Regression analyses were conducted on the 60 participants to study the relationships between their language and visual-spatial skills, or the task complexity, and the use of gestures. A first model tested the influence of four variables (language level, visual-spatial span, visual-motor coordination and analogical reasoning) on the use of iconic gestures. A significant general pattern ($p < .01$) emerged. This model shows that language abilities positively predict the use of iconic gestures ($B = 0.112$ ($SE = 0.052$), $\beta = .295$, $t = 2.148$, $p < .05$). A second regression analysis was conducted to investigate the influence of the same variables on action gestures. This second model, also significant ($p < .001$), indicated that language level was a negative predictor of the use of gesture actions ($B = -0.178$ ($SE = .045$), $\beta = -.485$, $t = -3.923$, $p < .001$). Similar analyses were carried out for pointing gestures and metaphorical gestures, but the models were not significant. The results corresponding to the H2c hypothesis show that the more complex the task, the more the student uses gestures to perform or explain the task (Table 4).

Insert Table 4 about here

The results of the non-parametric Wilcoxon tests show that, in task 1, participants with ID make significantly fewer gestures than in the Level 2 task. This difference, with a very high effect size, is found in the TDVS group and in the TDL group. Gestures are therefore used more by all students when the task becomes more complex. Conversely, the number of words between the two tasks did not differ significantly for any of the three groups.

Aim 3: Links between the type of gesture and the task performance. In terms of gesture types, Table 3 shows a greater use of pointing gestures than other gesture categories in all groups. Metaphorical gestures were used rarely used across all groups. Spearman correlation analyses were performed to test hypothesis H3, which postulates that the number of iconic gestures is correlated with success in the task and not pointing gestures. The results indicate that success in the mental rotation task is highly correlated with the number of iconic gestures ($r = .68$, $p < .01$). Conversely, the correlation between pointing gestures and success in the task was non-significant. Regression analysis showed that the number of iconic gestures predicted task success (B= 0.09 (SE = 0.041), β = .40, t = 2.28, $p = .05$), which was not the case for pointing gestures ($p = .445$). Interestingly, the number of words used was not a predictor of task success ($p = .195$).

Aim 4: The type of expression modalities used in ID versus TD participants. Gestures alone are manifested differently between the groups (x^2 (2) = 6.61, $p < .05$). *Post-hoc* tests showed a difference approaching significance ($p = .053$) between the group with ID and the TDL groups. Altogether the results suggest that students with ID produce more gestures alone than their peers, although the difference is only marginally significant. Figure 2 shows the speech-gesture modalities produced by students with ID and their neurotypical peers respectively.

Insert Figure 2 about here

In all three groups, the bimodal modality is the most frequently used modality (Figure 2) In the group with ID, the results show that we can reject the null hypothesis that the participants use the different modes of expression with equal frequency (x^2 (2) = 35.56, $p < .001$, d = 2.39. In the group with ID, the bimodal combination (x^2 (2) = 35.56, $p < .001$, d = 2.394) is used more often than gesture alone (p = .002, d = 2.07) and speech alone ($p < .001$, d = 4.49) and these students also used gestures alone significantly more than speech alone ($p < .05$, d = 1.44). All three differences have a large effect size. The total of productions including gestures (gestures alone and bimodality) is equivalent to 90% of their responses; 30% of the information comes from gestures alone and 60% of their responses contain at least one gesture. In the TDVS group, the null hypothesis that the participants use the different modes of expression with equal frequency is also rejected (x^2 (2) = 36.943, $p < .001$, d = 2.517) as the bimodal expression is used more than gestures alone ($p < .001$, d = 3.174) and more than speech alone ($p < .001$, d = 3.904). However, the difference between gestures alone and speech alone is not significant (p = 1.00). In the TDL group, *post-hoc* tests indicate that TDL students produce significantly more bimodal productions (x^2 (2) = 35.506, $p < .001$, d = 2.388) than gestures alone ($p < .001$, d = 3.888) and speech alone ($p < .001$, d = 3.065). However, as with the TDVS group, the difference between gestures alone and speech alone is not significant (p = 1.00). These within-group differences are interesting and highlight that students with ID are the only ones to make significantly greater use of gestures alone than speech alone.

Aim 5: The functions of gestures in the different groups. Regarding the functions of gestures, the results of the Kruskal-Wallis test indicate that students with ID make significantly more gestures in order to clarify their language (x^2 (2) = 38.77, $p < .001$, d = 2.69) than in order to provide redundant ($p < .001$, d = 3.23) or additional information ($p < .001$, d = 4.15). The same differences are observed for the TDVS group (x^2 (2) = 38.10, $p < .001$, d = 2.63) and for the TDL group (x^2 (2) = 42.22, $p < .001$, d = 3.10) (see Figure 3). In the ID group, the totality of gestural productions that are used to provide information in addition to verbal language (precision and supplementation) corresponds to 81% of gestures.

Insert Figure 3 about here

Discussion

Our results will be discussed separately, aim by aim, and compared to the literature.

Aim 1: Relationship Between Gestures and Speech Production. With regard to the number of gestures that students with ID make compared to neurotypical students, the results show that the three groups of students perform the same number of gestures on average. This finding contradicts the first hypothesis, based on the results of previous research (Galeote et al., 2011; Mastrogiuseppe & Lee, 2017; Stefanini et al., 2007). It also contradicts the first hypothesis, which postulated a greater use of gestures in students with ID. But it corroborates the results of studies by Stefanini et al. (2007), Bello et al. (2004) and Iverson et al. (2003), who reported an equivalent number of gestures in students with ID and control students matched on mental and verbal age. These results also concur with the findings of Vandereet et al. (2011), who show in their longitudinal study that the number of gestures used by students with ID remains stable over time even as their chronological age increases.

Furthermore, while the average number of gestures is equivalent between the groups, our results show that students with ID use significantly more gestures per word spoken than students in the two control groups. This greater reliance on gestures in students with ID corroborates findings from the literature (Lacombe et al., 2021), in particular, the study by Galeote et al. (2011) which argues that gestures facilitate the expression of meaning when language skills are impaired. It is therefore possible that in cases of verbal expression difficulties, gestures express spatial features of the desired concept and facilitate access to the mental lexicon (Bello et al., 2004).

Aim 2: Links and influence of personal characteristics and task complexity on the use of gestures. With regard to the different variables influencing the use of gestures, it appears that our results do not support the hypothesis that students with lower language levels use more gestures. In our study, language ability positively predicts iconic gesture use, while a low language level predicts a greater use of action gestures. This result allows us to clarify the hypothesis: the higher the student's language level, the greater the production of iconic gestures, and the lower the language level, the greater the need to manipulate objects. As iconic gestures refer to elements of discourse, this could explain why they are more likely to be produced at higher language levels. Galeote et al. (2011) also identified this link and found that as expressive vocabulary increases, students use more iconic gestures.

Our third hypothesis stated that students with a lower visual-spatial level produce significantly fewer iconic gestures. Our result validates the hypothesis and corroborates those in the literature. For Hadar et al (1998), the cause of the difficulty in using iconic gestures results from difficulties in conceptual processes in students with a low visual-spatial level. Our results also show that these students use significantly more action gestures. This observation is consistent with Wakefield et al. (2019), who confirmed that students with lower visual-spatial ability rely on and benefit more from performing real-life manipulations.

With regard to the influence of the level of complexity of the task, our results validate our hypothesis and show that the more the level of complexity of the task increases, the more the students resort to gestures to carry it out or make it explicit. In the study by Hord et al. (2015), gestures increase in particular when the task requires working memory and multi-step performance. For Hostetter et al. (2007), gesture production functions as an unconscious tool that reduces cognitive effort while providing support for the child's internal spatial visualization. Interestingly, in our research, the number of words did not vary significantly between the two levels of complexity, which seems to suggest that gestures and not speech support spatial visualization and the expression of task-solving strategies.

Aim 3: Links between the type of gesture and the task performance. With regard to differential gesture use, we observed a greater use of pointing gestures among all students compared to other gesture types. These results corroborate those of the literature on the different types of gestures (Bello et al., 2004; Iverson et al., 2003; Stefanini et al., 2007). The authors highlight that the important use of pointing gestures allows the child to indicate to the adult the referent on which he/she wishes to give information (Stefanini et al., 2007). For Stefanini et al. (2007), pointing gestures can also trigger the semantic knowledge of a search word in memory. However, pointing gestures are not correlated with task success, unlike iconic gestures, which validates our initial hypothesis. This link between performance in a mental rotation task and iconic gestures is strongly found in the literature (Levine et al., 2018; Wakefield et al., 2019). Indeed, the results are unanimous in saying that iconic gestures are the most effective way to develop mental rotation skills. The reason put forward by the authors is that iconic gestures allow a simulation of physical rotation without the physical constraints of a real manipulation and without having access to the visible result of the rotation.

Aim 4: The type of expression modalities used in ID versus TD participants. With regard to differential use of expressive modalities, we postulated that students with ID used less “speech alone” than neurotypical students. In the present research, the results indicate that students with ID do use less “speech alone” than neurotypical students, but the differences are not significant. Our first hypothesis (H4a) is therefore not validated. The significant difference in the chronological ages of the students could explain this result.

Our hypothesis (H4b) postulated a greater use of “gestures alone” by students with ID. Our results confirm this hypothesis and corroborate those in the literature (Galeote et al., 2011; Mastrogiuseppe & Lee, 2017; Stefanini et al., 2007). However, the gap remains smaller, probably due to the small number of single gestures produced in the task at hand. Moreover, students with ID prefer “gestures alone” to “speech alone”, which is not the case for the two control groups. This observation was echoed by Mastrogiuseppe & Lee (2017), who confirmed that only participants with ID (Williams syndrome) produced gesture-only communication. The authors had interpreted their participants' preference for “gestures only” as an indication of the compensatory role of gestures when language difficulties are present. In our research, the “gestures only” modality also correlated negatively with the students' language level, indicating that the lower the language level, the more students used “gestures only”.

Aim 5: The functions of gestures in the different groups. With regard to the function of gestures, students with ID used gestures mainly to clarify their verbal language. In the literature two studies indicated that students with ID favored redundant gestures over precision or supplemental gestures (Iverson et al., 2003; Stefanini et al., 2007). In the gesture development of neurotypical students, redundant combinations are the first to be used and then complementary combinations appear at around 20 months, along with the combination of two words (Capirci et al., 1996). In our research, as the students with ID already produce multi-word combinations and are older (12-17 years) than those of Iverson et al. (2003) and Stefanini et al. 2007 (2-8 years), this may explain the greater use of gestures to specify language. We also found that the totality of gestural productions that are used to provide information in addition to verbal language (precision and supplementation) corresponds to 81% of gesture. These observations are in line with findings in the literature that agree that gestures make visible many narrative meanings that remain uninterpreted if observers reduce communication to the verbal channel alone (Radford et al., 2017).

Conclusions

The results of this research confirmed the significant role of gestures in solving mental rotation tasks, particularly for students with ID. It was found that: a. Students with ID make significantly more gestures in relation to the number of words spoken compared to their neurotypical peers; b. In the sample as a whole, language level and visual-spatial level are predictive of the number of iconic gestures used; c. In the sample as a whole, iconic gestures predict task success, unlike pointing gestures; d. In the ID group, 30% of the expressive communication is done solely through gestures alone and 60% of the responses contain at least one gesture. Words alone are used in only 10% of the responses; e. Students with ID use the expression modality "gestures alone" significantly more than "speech alone" and use gestures more to clarify their speech than skill-matched peers.

While this study has several strengths, it also has limitations. The first limitation is the representativeness of the sample. Indeed, twenty students with ID participated in this research, which represents a rather small number of participants and imposes caution in the generalization of the results. Secondly, unlike most of the studies listed in the systematic review on the role of gestures in students with ID (Lacombe et al., 2021), this study did not include a chronologically age-matched control group. The fear of ceiling effects in the three-dimensional tasks, as well as in the tests measuring the independent variables in neurotypical students aged 12 to 18, motivated this decision even though such a comparison would have made it possible to observe whether the use of gestures differed between neurotypical students and students with ID at equivalent chronological age. Finally, an open question lies in the choice of selecting a sample of students who were heterogeneous in terms of intellectual disabilities. On the one hand, this choice allowed the observation of interesting differences, on the other hand it makes it difficult to define precisely, sometimes, the exact origin of the differences observed, and if they are explicable by the etiology. Further research will therefore be necessary in order to compare the use of gestures in specific etiologies and with larger samples.

Educational Implications

Given that, in students with ID, many thought contents are not directly evoked via verbal language, special education challenges professionals to understand these students beyond their words by observing what they communicate in actions before observing what they miss (Manghi Haquin et al. 2019). As noted in the INSERM's collective expertise in 2016, considering the gestural dimension in the analysis of conceptualization processes opens up new perspectives in terms of assessment and intervention. The creation of tasks or situations favoring the manipulation of three-dimensional material, the observation of gestures and the setting up of a sufficient space-time for students to express themselves can change teaching practices and improve learning. Our research thus invites us to reconsider the evaluative approach to learning in the geometric and spatial domain, to give gestures their rightful place in the cognitive processes of pupils.

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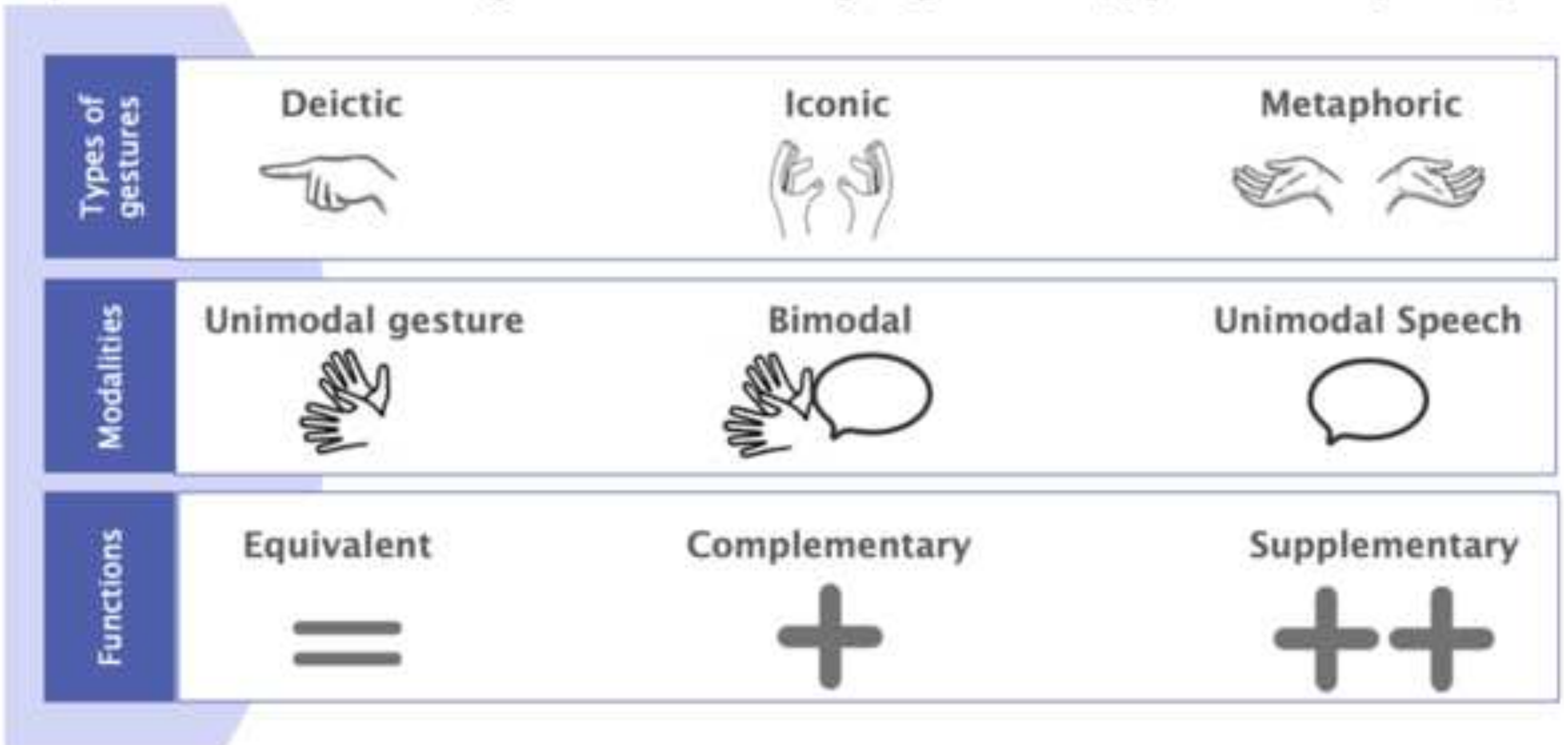
Figure 1

Synthesis of theoretical knowledge about co-thought gestures (type, modality and function)

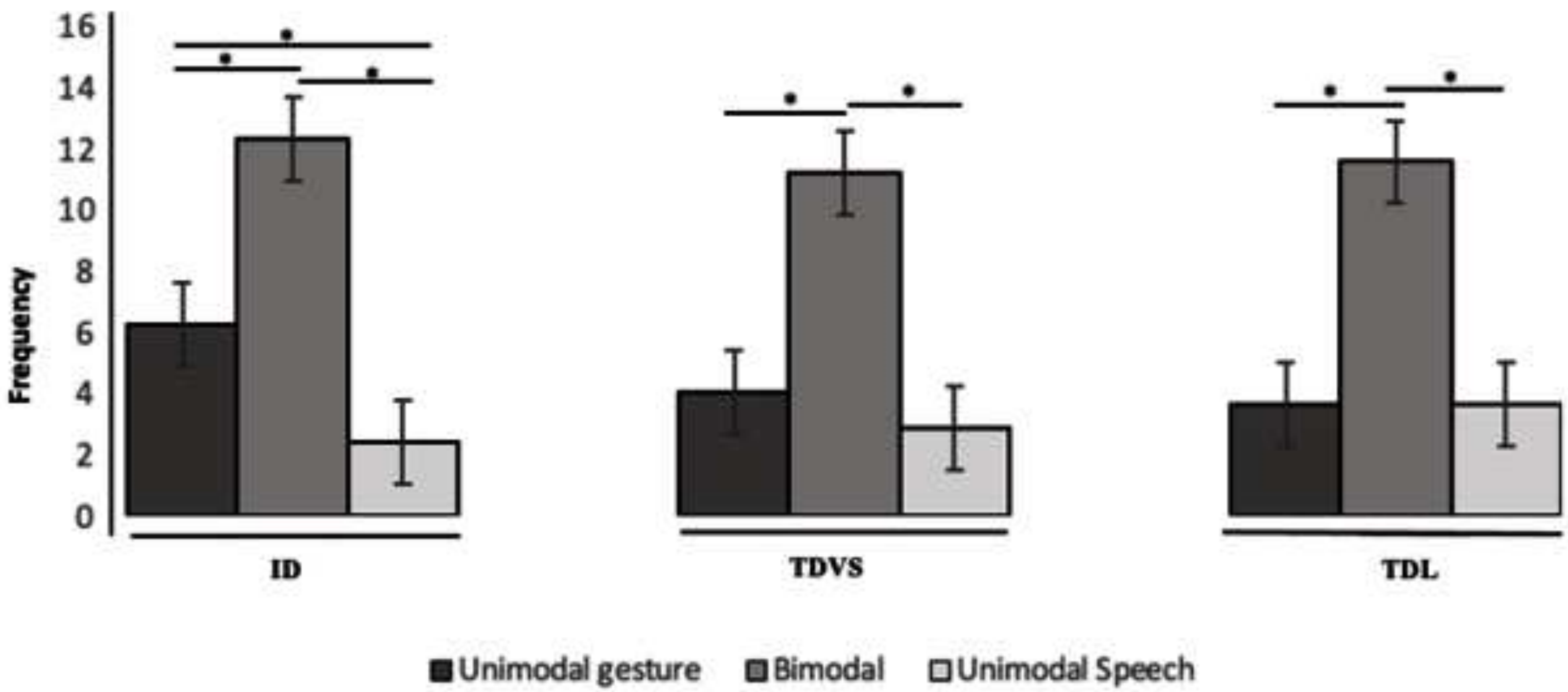


Figure

Click here to access/download;Figure;Figure 2.png

Figure 2

Modalities of expression by group



Figure

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Figure 3

Functions of gestures by group

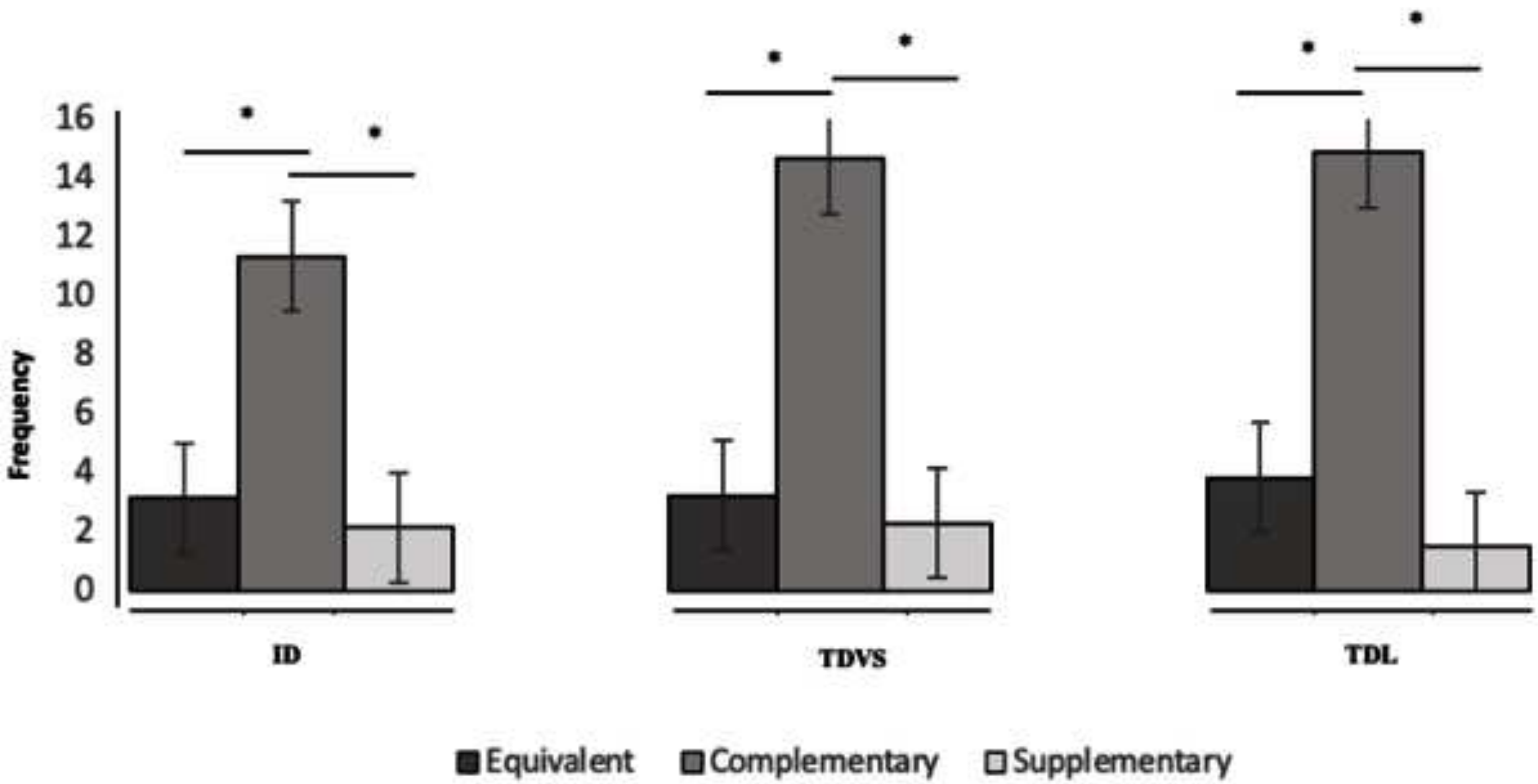


Table 1

Characteristics of the participants

Tests	ID *M* (*SD*)	TDVS *M* (*SD*)	TDL *M* (*SD*)	*z*	*p*
Ages	12-17 years *M* = 14.8	4-10 years *M* = 6.6	3-11 years M= 7.2		
Gender	Girls : *n* = 7 Boys *n* = 13	Girls : *n* = 7 Boys : *n* = 13	Girls : *n* = 7 Boys : *n* = 13		
Mother language	French *n* = 18 Other *n* = 2	French *n* = 19 Other *n* = 2	French *n* = 16 Other *n* = 2		
Visual-spatial level					
Visual-spatial reasoning*	23.15 (6.76)	23.45 (6.67)		1.22	.229
Visual-spatial memory**	7.2 (1.79)	7.0 (1.21)		0.54	.590
Visual-motor coordination***	19.60 (4.13)	19.60 (4.03)		0.11	.909
Oral expressive language level**					
Lexical stock, pronunciation and sentence formulation	66.85 (15.23)		68.52 (13.84)	0.70	.484

Notes. ID = Intellectual disability; TDVS = typical development group matched on visual-spatial level; TDL = typical development group matched on language level; *Raven's Progressive Matrices, max. score = 36; **Corsi Block, max. score = 18; Beery-VMI, max. score = 30;**** BILO-3C, max. score = 96.

Table 2

Tasks in the battery measuring mental rotation skill

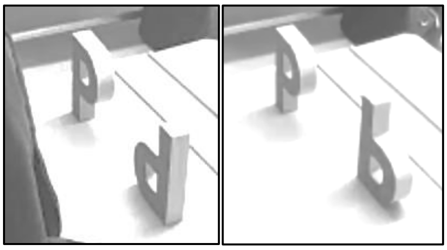
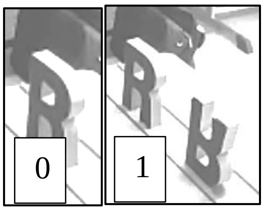
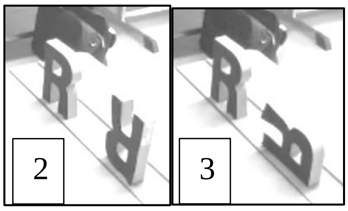
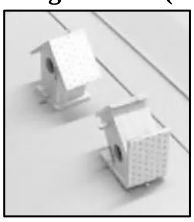
Example 	The student is given a three-dimensional shape representing a letter P (blue paper is glued to one side). Pupils can hold the shape in their hands and manipulate it however they wish to observe and rotate it. The glued paper helps to differentiate the shapes. If the paper is stuck on the same side, the letters will be the same, if the paper is stuck on the other side, the letters will be in a symmetrical position and therefore not identical. The example is not used to code gestures and speech, but to ensure that the pupil has understood the task.
Performing the task (Level 1)  	Level 1: The student stands in front of a table on which a letter R is placed (image 0). Then the experimenter places a second letter R next to the first (image 1). A brown piece of paper is stuck to one side of the R. By performing a mental rotation, the student has to identify the letters that have the paper on the same side and are identical to the model (similarly oriented shape). The experimenter asks the student if the two shapes can be superimposed (be the same with the paper on the same side). The student must not touch the shapes and must give the experimenter an answer. The experimenter then asks the pupil to explain how he/she arrived at their answer (at this point the pupil is free to manipulate the shapes or use gestures to explain their reasoning). Gestures and language are coded throughout the task (when the student thinks, when they give their answer and when they explain their answer to the experimenter). Three R letters are presented to the student during the first level: 1. 180° rotation with two different shapes; 2. 180° rotation with two identical shapes; 3. 90° rotation with two different shapes).   **Examples of what two identical shapes and two different shapes mean.** In these two photos, the shapes are not the same because the brown paper is not stuck on the same side of the two shapes. When they are placed in the same direction, the colour only appears on one of the two shapes, so the two shapes are not the same for the mental rotation exercise.  Here the R shapes are superimposable (brown paper on the same side), so the shapes are the same.
Performing the task (Level 2) 	Level 2: A house is placed in front of the pupil: one side of the roof is coloured and one of the shutters is blue. The student has to compare it to another house in a different position and answer the question: are these two houses the same? Different houses are shown (1. 135° rotation wrong; 2. 225° rotation wrong; 3. 135° rotation right) some are identical to the model (roof and shutters) while others have the roof, the shutters or neither of the two markings on the same side as the model.

Table 3

Gesture types, modality, and functions by groups

							Post-Hoc comparisons (Dunn-Bonferroni)			
	ID group	TDVS group	TDL group	ANOVA *Friedman*			ID versus TDVS		ID versus TDL	
Indicators	*M (SD)*	*M (SD)*	*M (SD)*	X^2	*ddl*	*p*	*p*	*Cohen's d*	*p*	*Cohen's d*
Behaviours										
Total words	67.30 (24.76)	112.00 (45.36)	116.45 (46.17)	*15.87*	*2*	*.000*	.034	0.25	.000	0.39
Total gestures	30.75 (7.59)	31.90 (10.09)	29.60 (10.88)	.34	2	.841	.001	0.37		
Total gestures per speech	0.50 (0.18)	0.31 (0.12)	0.28 (0.13)	27.15	2	.000				
Gestures types										
Deictic	17.40 (6.00)	16.00 (9.04)	14.45 (6.37)	.31	2	.854				
Iconic	7.65 (4.34)	7.75 (6.10)	8.05 (5.80)	.24	2	.885				
Metaphoric	0.20 (0.89)	0.05 (0.22)	0.05 (0.22)	.00	2	1.00				
Actions	4.80 (5.47)	5.85 (4.90)	5.15 (5.48)	.71	2	.700				
Modalities										
Unimodal gestural	6.30 (4.55)	4.05 (2.89)	3.65 (3.18)	2.65	2	.265				
Bimodal	12.35 (3.13)	11.25 (2.88)	11.60 (3.18)	.52	2	.771				
Unimodal spoken	2.45 (1.87)	2.90 (2.29)	3.65 (2.36)	6.60	2	.037	.464		.053	
Functions										
Equivalent	3.15 (2.20)	3.25 (2.24)	3.85 (2.30)	1.16	2	.559				
Complementary	11.35 (4.28)	14.65 (7.54)	14.90 (7.41)	4.44	2	.109				
Supplementary	2.15 (1.30)	2.30 (2.17)	1.50 (1.96)	4.44	2	.109				

Notes.ID = Intellectual Disability; TDVS = typical development group matched on visual-spatial level; TDL = typical development group matched on language level

Table 4
Number of gestures and words spoken (occurrences) according to the level of complexity of the task

	Task 1 less complex *M* (*SD*)	Task 2 more complex *M* (*SD*)	Wilcoxon		
			z	*p*	*Cohen's d*
Participants with ID	11.20 (4.42)	19.40 (6.96)	2.95	.003	1.05
Participants TDVS	11.50 (4.19)	18.90 (7.06)	3.49	.000	1.32
Participants TDL	11.00 (5.38)	17.10 (6.47)	3.10	.002	1.12
Total number of gestures	**11.18 (4.64)**	**18.45 (6.96)**	5.59	.000	1.18

Notes. ID = Intellectual Disability; TDVS = typical development group matched on visual-spatial level; TDL = typical development group matched on language level