Show your hands — Are you really clever? Reasoning, gesture production, and intelligence*

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Abstract

This study investigates the relationship of reasoning and gesture production in individuals differing in fluid and crystallized intelligence. It combines measures of speed and accuracy of processing geometric analogies with analyses of spontaneous hand gestures that accompanied young adults' subsequent explanations of how they solved the geometric analogy task. Individuals with superior fluid intelligence processed the analogies more efficiently than participants with average fluid intelligence. Additionally, they accompanied their subsequent explanations with more gestures expressing movement in non-egocentric perspective. Furthermore, gesturing (but not speaking) about the most relevant aspect of the task was related to higher fluid intelligence. Within the gestures-as-simulated action framework, the results suggest that individuals with superior fluid intelligence engage more in mental simulation during visual imagery than those with average fluid intelligence. The findings stress the relationship between gesture production and general cognition, such as fluid intelligence, rather than its relationship to language. The role of gesture production in thinking and learning processes is discussed.

1. Introduction

The aim of this study is to characterize the relationship of reasoning and gesture production and their interaction with intelligence. We focus here on gestures produced by the hands that represent semantic content, often called *representational gestures*. For convenience, we will refer to them as "gestures". When people engage in conversation, gestures that accompany speech are part of the communication system (Kendon 2005; McNeill 1992, 2005) and they reflect thinking processes (Beattie 2003; Garber and Goldin-Meadow 2002; Goldin-Meadow 2003; Emmorey and Casey 2001). Moreover, recent evidence suggests that gesturing plays a causal role in facilitating reasoning and learning

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(Broaders et al. 2007; Chu and Kita 2008; Goldin-Meadow et al. 2009; Wagner Cook et al. 2008). The present paper reviews evidence for the gesture-speech relationship and the gesture-thinking relationship. We argue for a relationship between reasoning, gesture, and intelligence, and we provide new empirical evidence for it. The findings are discussed within the context of the gestures-as-simulated action framework (Hostetter and Alibali 2008).

1.1. *Gesture, speech, and thinking*

The production of gesture and speech is tightly linked. Gestures are temporally and semantically coordinated with speech (Kendon 2005; McNeill 1992, 2005). They are produced while speaking rather than listening (e.g., Saucier and Elias 2001), and the most meaningful part of a gesture, the stroke phase, is synchronized with the co-expressive part of speech (McNeill 1992). The development of gesture and speech is also related. For example, children use gesture-word combinations before producing corresponding constructions in speech alone (Özcalıskan and Goldin-Meadow 2005; Iverson and Goldin-Meadow 2005). Furthermore, difficulties in speech are accompanied with adjusted gesture behavior. Speech disfluencies change the temporal execution of gestures (Seyfeddinipur 2006), gestures are held during stuttering (Mayberry et al. 1998), and verbal deficits in aphasic patients are correlated with gestural deficits (e.g., Duffy 1981).

Several theories of gesture production assume that gestures strictly depend on the communicative situation. They are suggested to be primarily produced to communicate (McNeill 1992, 2005; de Ruiter 1998, 2000) or to facilitate speaking (Krauss et al. 2000). However, Kita and Özyürek (2003; cf. also Kita 2000) propose that gestures can be influenced by linguistic properties of the accompanying spoken utterance but are not determined by them. This view can also account for gestures that are not produced for communicative or speaking purposes (for evidence of gestures that do not accompany speech, cf. Chu and Kita 2008; Kessell and Tversky 2005).

Also in line with a broader perspective on gesture production is the gestures-as-simulated action framework (Hostetter and Alibali 2008) that will serve as the theoretical background for this paper. This theory views gesture production as not necessarily intended to communicate or to facilitate speech production although gestures usually accompany speech. According to this theory, gesture and speech both are based on the same underlying system of thinking. More specifically, they are based on mental simulation or simulated action in mental imagery (Barsalou 1999; Glenberg 1997; Glenberg and Kaschak 2002). Usually, when a person engages in mental imagery a simulated action is planned but not executed. However, if the activation is sufficiently strong, it can spread from the planning to production stage, and result in an observable movement — a gesture. In other words, if the simulation is very intensive, an action is performed. According to Hostetter and Alibali, the necessary strength of activation for a gesture to be produced is determined by several factors. One such factor is the individual's neural architecture, for example, the connection strengths between premotor planning and motor production areas that develop due to genetics and experience. Another is the speaker's *gesture threshold*, which in turn is assumed to depend, for example, on the gesturer's level of cognitive effort and beliefs about the current social situation and the use of gestures. For example, if speakers think that gesturing is impolite or that it expresses an inability to verbalize their thoughts, the threshold increases to inhibit gestures. Finally, the gestures-as-simulated action framework contends that gesture production is enhanced by the simultaneous involvement of the complex motor demand of speech production. Hence, gestures often accompany speech. However, is the influence from thinking to gesturing only unidirectional?

Recent evidence suggests that producing gestures also affects thinking and learning. Wagner and her colleagues (Goldin-Meadow et al. 2001; Wagner et al. 2004) showed that gesturing facilitates memory performance. When participants explained math problems while trying to keep in mind verbal or spatial stimuli, their memory performance increased when they were allowed to gesture compared to when gesturing was prohibited. Also, when participants used gestures spontaneously without any instruction regarding gesturing, their performance was better in trials in which they gestured compared to trials in which they did not. The findings suggest that gesturing affects working memory, that is "the collection of mental processes that permit information to be held temporarily in an accessible state, in the service of some mental task" (Cowan 2005: 77; cf. also Baddeley 1995; Conway et al. 2005). Gesturing while counting also helps both, children and adults, to keep track and to coordinate the items to be counted and the corresponding number words or functional roles (Alibali and DiRusso 1999; Carlson et al. 2007).

Other studies reported that gesturing enhances learning in children (Broaders et al. 2007; Goldin-Meadow et al. 2009; Wagner Cook et al. 2008). Broaders and her colleagues instructed children to gesture while they were learning how to solve a new math problem. As a result, the children tended to indicate new correct strategies in their gestures. Most important, these children learned better compared to children who were not told to gesture. The results demonstrate that children who have some implicit knowledge about how to solve a problem express it in their gestures, and that this expression in turn facilitates their problem solving process.

Finally, Chu and Kita (2008) showed that gesturing affects adults' development of strategies in a mental rotation task. Over the duration of the experiment, participants' gestures developed from first-person pantomimes that expressed how the participants would rotate the objects to gestures that expressed the rotations of the objects themselves (in Chu and Kita's terms *hand-object interaction gestures* and *object movement gestures*, respectively). According to the authors, this process of *deagentivization* is important in the development towards an efficient strategy in mental rotation tasks.

Generally speaking, movement can be expressed in gesture from the first-person perspective or in a more abstracted way showing how something moves. The first is equivalent to *character viewpoint* and the second sometimes — but not necessarily — corresponds to *observer viewpoint* (cf. McNeill 1992). Lausberg (2007; cf. also Lausberg et al. 2007) suggests the following terminology to categorize gestures expressing movements into *pantomimes* and *kinetographs.* Gesturers expressing their own actions produce pantomimes. They use their hands as if doing the actions themselves. In contrast, when describing how something moves kinetographs depict how it moves (as opposed to how the gesturers move it). The gestures-as-simulated action framework (Hostetter and Alibali 2008: 504) makes predictions about the type of simulation and mental imagery the gesturer is engaged in and about the viewpoint of a gesture where ". . . character-viewpoint gestures are produced as a result of simulated motor imagery (. . .) [and] observer-viewpoint gestures result from simulated visual imagery." According to the authors, *motor imagery* always involves simulated *action*, whereas *visual imagery* can involve simulated *perception* and/or simulated *action*. Especially when engaged in visual imagery of mental transformation, action is likely to be simulated. We will explore the influence of simulated action in motor imagery versus visual imagery in this study and categorize gestures into (character viewpoint) pantomimes that are assumed to result from mental simulation in motor imagery and kinetographs that are sometimes produced in observer viewpoint and that are assumed to result from mental simulation in visual imagery when describing mental transformations.

As we have discussed, gestures not only reveal what gesturers are thinking (Goldin-Meadow 2003) but they also influence cognitive processes, such as memory, learning, and reasoning. There are considerable individual differences concerning the frequency of gesture production as studies investigating gesture frequencies report that some participants did not produce any gestures while the rest of them did to different extents (e.g., Melinger and Kita 2007). Although to our knowledge no study has specifically investigated this, some people are assumed to generally produce gestures more frequently than others. Individuals who gesture habitually might be better learners, especially when integrating new information and solving new problems. It follows then that people who habitually gesture more might be better trained for reasoning than people who do not engage in gesturing so much. It is thus an important question whether individuals with different levels of cognitive ability engage in gesturing to different extents.

1.2. *Individual differences and gesture production*

In terms of individual differences, studies investigated the relationship of spatial skills and gesture production (Ehrlich et al. 2006; Hostetter and Alibali 2007). In these studies, spatial skills were measured with tasks involving mental transformations that are also central operations in many general reasoning tasks. Gestures are produced predominantly while speaking about spatial concepts (Alibali 2005). Thus, individual differences in spatial reasoning are likely to be related to differences in gesture behavior.

Ehrlich and her colleagues (Ehrlich et al. 2006) investigated 5-year-old children's spatial reasoning performance on a mental transformation task. The children were also asked to explain their strategies after each trial. They talked about several strategies that they also expressed in their gestures. However, they did not always express the same strategy simultaneously in speech and in gesture, making so-called *gesture-speech mismatches* (Goldin-Meadow 2003). Expressing movement in gestures was uniquely related to correct performance (with or without the same strategy in speech). Thus, children with better spatial skills expressed movement more often in their gestures than children who performed less well on the spatial task.

Hostetter and Alibali (2007) asked participants to describe a short cartoon video and to describe how to wrap a package. In addition, their spatial skills were assessed with a mental transformation task. Participants with superior spatial skills produced more gestures in the descriptions compared to those with average or low spatial skills. Although the authors did not describe the content of gestures produced in detail, we can assume that a substantial part of the gestures was also expressing movements related to the actions of the characters in the video and involved in wrapping a package.

In summary, previous evidence suggests that spatial skills in mental transformation tasks are positively related to gestures expressing movement. According to the gestures-as-simulated action framework (Hostetter and Alibali 2008), many reasoning and problem-solving activities involve the engagement in simulation of perceptions and actions that result in gestures. It is still unclear whether these findings translate to more general cognitive abilities that might be related to mental transformations, such as general *fluid* and *crystallized intelligence* (Horn and Cattell 1966).

Fluid intelligence refers to the ability to solve new problems efficiently. Individuals with high fluid intelligence are assumed to focus on the central information and on a limited set of task-relevant cognitive operations (e.g., Vernon 1983). Furthermore, there is a positive relationship between fluid intelligence and executive processes of working memory (Engle et al. 1999). Executive processes comprise the setting of intentions and planning, selection of relevant information and inhibition of irrelevant information, the generation of strategies, and monitoring. These executive processes, that also play a role in spatial reasoning, are critical components in analogical reasoning. Hence, psychometric tests of fluid intelligence usually include analogical reasoning tasks (e.g., Raven Advanced Progressive Matrices, RAPM; Raven 1958).

Crystallized intelligence refers to the ability to accumulate, store, and retrieve knowledge, such as facts and general rules (Horn and Cattell 1966). Therefore, crystallized intelligence might also play a crucial role in reasoning. For example, preexisting knowledge on specific strategies or global rules for solving problems could support performance.

How could the use of gestures affect fluid and crystallized intelligence? The development of fluid and crystallized intelligence could benefit from gesturing about strategies. Gesturing could help exploring new strategies or consolidate them within the gesturer's repertoire. Furthermore, the load on working memory could be decreased by externalizing some of the information that has to be processed. Gesturing could also assist in focusing attention on relevant information or in learning how to access relevant knowledge. However, the relationship between reasoning performance and gestures in individuals differing with respect to fluid and crystallized intelligence is yet unclear. To explore this relationship, we first investigated performance (response times and error rates) in individuals solving a prototypical reasoning task, namely judging geometric analogies. We expected participants with superior fluid and crystallized intelligence to outperform those with average intelligence. More specifically, we expected fluid intelligence to predict performance better than crystallized intelligence because fluid intelligence is assumed to be more central for analogical reasoning (cf. van der Meer et al. 2010). Second, we assessed gesture frequencies and gesture types (expressing movement vs. not expressing movement, pantomimes and kinetographs) while individuals reported what they experienced to be relevant in solving the geometric analogy task. Based on the literature reviewed above, we expected that gestures expressing movement are produced more often by participants with superior compared to average fluid and crystallized intelligence. We also explored whether this difference could be characterized more specifically. We therefore further distinguished between gestures expressing movement from an egocentric perspective (pantomimes) that are assumed to result from mental simulation in motor imagery and those from a non-egocentric, *more abstracted*, perspective (kinetographs) that are assumed to result from mental simulation in visual imagery.

2. Method

2.1. *Participants*

This study was part of another research project (van der Meer et al. 2010). A subset of fifty-one high school students contributed to the gesture analyses (40 males and 11 females; age [$M \pm SD$]: 16.5 ± 0.5). Because of technical problems, we had to exclude the behavioral data sets of the geometric analogy task from three participants. All participants were right-handed (Oldfield 1971), native speakers of German, and attended the 11th grade of one of three Berlin schools specialized in mathematics and natural sciences. They were paid for their participation. The students and their parents gave written consent before the investigation according to the Declaration of Helsinki of 1964 (World Medical Organization 1996).

Three months prior to the experiment, all participants were screened for their fluid intelligence by administering the RAPM (Heller et al. 1998; Raven 1958) and for their crystallized intelligence by administering the subpart *verbal knowledge* of the *Intelligenz-Struktur-Test 2000 R* (I-S-T, Amthauer et al. 2001). Each participant was assigned to one of two groups based on their RAPM scores and also one of two groups based on their I-S-T scores. The cut-off between the two groups was one standard deviation (15) above the norm (100). This means that for both types of intelligence, participants were assigned to the superior group if their scores were 115 or above and they were assigned to the average group if their scores were below 115. No participant had scores more than one standard deviation below the norm (i.e., 85). First, four female and 24 male participants were assigned to the superior fluid intelligence group (129.9 ± 8.2; range: 145–118.5), whereas seven female and 16 male participants were assigned to the average fluid intelligence group (102.7 ± 7.9; range: 110–87). Second, six female and 20 male participants were assigned to the superior crystallized intelligence group (121.7 ± 6.9; range: 140.5–115), whereas five female and 20 male participants were assigned to the average crystallized intelligence group (99.1 ± 5.8; range: 106–88).

2.2. *Stimuli*

Participants were presented with stimuli quadruplets. Each quadruplet consisted of a source pair (A:A′) and a target pair (B:B′) of geometric chess-board like patterns. Each pattern consisted of an 8 × 8 grid of squares with each square being grey or black (Chipman 1977; Offenhaus 1983) (Figure 1). The stimuli quadruplets were presented on a light gray background. The complexity of patterns was controlled. Three types of relation were applied: mirroring on the vertical, the horizontal, or the diagonal axis. These types of relation vary in difficulty (low [vertical] < medium [horizontal] < high [diagonal]) (Offenhaus 1983; Royer 1981; van der Meer 1996). The experiment consisted of 8 practice and 60 test items. Source pair and target pair had either the same type of relation (analogy items) or different types of relation (distracter items). Participants had to decide as quickly and accurately as possible whether there was the same type of relation both in the source pair and the target pair.

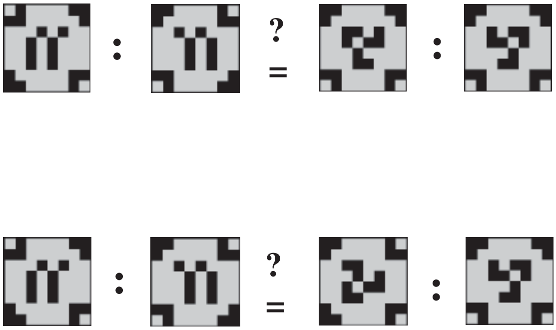

Figure 1. *Examples of an analogy item (mirroring on the vertical axis) and a distracter item (mirroring on the vertical axis vs. mirroring on the diagonal axis).*

2.3. *Design*

The following independent variables were considered in the *geometric analogy* analyses: difficulty of type of relation (low, medium, high; within subjects), fluid intelligence (superior vs. average; between subjects), and crystallized intelligence (superior vs. average; between subjects). Source pair and target pair had either the same type of relation (analogy items, 50%) or different types of relation (distracter items, 50%). For analogy items (n = 30), the type of relation between source and target pair was varied: mirroring on the vertical (n = 10), on the horizontal (n = 10), or on the diagonal axis (n = 10). Distracter items (n = 30) were included in the experiment so that participants would not only be exposed to analogy items. However, they were not analyzed because we did not have specific hypotheses regarding the processing of distracter items. All items were presented in a randomized order. The following dependent variables were recorded: response times (RTs; measured as the time between appearance of the item and the response), and error rates (ERs). Note that for RTs only the data for correctly detected analogy items were analyzed.

The following independent variables were considered in the *gesture* analyses: fluid intelligence (superior vs. average; between subjects) and crystallized intelligence (superior vs. average; between subjects). Gesture rates were the dependent variables.

2.4. *Procedure and apparatus*

The experiment took place in a quiet and moderately illuminated room. All phases of experimentation were performed automatically under the control of a laboratory interface system (see below). At the beginning of the experiment, participants filled out a questionnaire that ascertained demographic data. Participants were seated comfortably in front of a computer screen with a distance of approximately 1 m.

Each trial started with a fixation cross that was presented for 1 s. Then, the item was presented. Participants had to decide as quickly and accurately as possible whether there was the same type of relation both in the source and the target pair. If there was, participants were instructed to press the right mouse button with the index finger of the left hand; if there was not, they were instructed to press the left mouse button with the middle finger of the left hand. As soon as the participant pressed a response button, the item disappeared from the screen to prevent subsequent processing or rumination. The participants started the next trial by pressing one of the two buttons.

Prior to the analogy task, participants received written instructions presented on the computer monitor. They also completed a practice session with similar stimulus material to become familiar with the task as well as with the experimental procedure. During the practice session, feedback on the correctness of the responses was given after each trial. Overall, it took about 20 min to finish the geometric analogy task.

After the experiment, the participants were accompanied to a different room and asked to explain their strategies. The experimenter asked the following questions:

1. How did you proceed solving the analogy task?
2. Did you pay attention to particular aspects of the patterns?
3. Did you notice anything else that you would like to report?

The aim to analyze their gesture behavior was only revealed to them after the end of this task. Overall, it took about 5 min to finish this part of the study.

Stimuli were presented using the experimental control software Presentation 9.01 (Neurobehavioral Systems Inc, Albany, CA) running on a Microsoft Windows XP® operating system. The computer used for stimulus presentation collected the behavioral data (RTs and ERs). Participants were video-recorded while giving their strategy explanations and the tapes were digitized later on. Gestures were analyzed using the annotation software ELAN (EUDICO

Linguistic Annotator), developed at the Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands.

2.5. *Coding*

Gestures were coded within the environment of ELAN using the Neuropsychological Gesture Coding System (NEUROGES, Lausberg and Sloetjes 2009; Lausberg 2007; Lausberg et al. 2007). Gesture types were coded for 100% of the data by one rater, and 50% of the participants were second-coded independently by two additional raters (25% by each). While coding, none of the raters were familiar with participants' intelligence scores or performance on the analogy task. Similarly, the content of the participants' verbal explanations was unknown to the raters; gesture coding was performed without sound, and speech was only transcribed after all gesture coding was completed. Inter-rater reliability was established with Cohen's kappa (Cohen 1960). Agreement between the first and the second coding for gesture types produced with the right hand was $\kappa = .69$, for the left hand $\kappa = .67$, and for gestures produced by both hands $\kappa = .75$.

Figure 2 presents the gesture types coded for addressing the issues raised in this study. More detailed information about how the gesture types from NEUROGES system correspond to these categories can be obtained from the first author.

We distinguished between gestures that did not express a movement and those that did. The latter was further subdivided into pantomimes and kinetographs, which in turn were distinguished between those without a rotational component and those expressing rotation.

Gestures are produced — with rare exceptions — in the presence of a speaker's turn in a conversation and they usually accompany speech. Naturally,

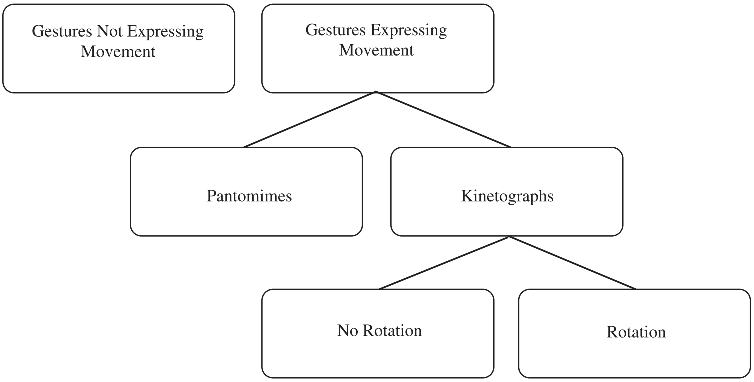

Figure 2. *Representational gesture categories*

the participants in this study all talked for a slightly different time interval (46 s ± 23)[1] with different speech rates, that is, number of words per second of speaking time (3.21 ± 0.37). To limit these two confounding variables for our measure of gesture frequency, we compared individual gesture frequency as gesture rates defined as the number of gestures per 100 spoken words (cf. Hostetter and Alibali 2007). Also, we compared speech rates and the number of clauses between participants with different levels of fluid and crystallized intelligence. The participants' speech was transcribed verbatim. Filler words, such as *em* and *uh*, were not counted as words. The number of clauses per participant was established for 100% of the data by one rater, and 50% of the participants were second-coded independently by an additional rater. The raters perfectly agreed on the number of clauses in 69% of participants. They differed in their counts only by one clause (23%) or by two clauses (8%). On average, participants produced 149 words (±88) and 19 clauses (±12). We categorized words as references to the most central mental transformation for solving the geometric analogies (i.e., mirroring the patterns on one of the three axes) into four different types (Table 1): (1) Explicit references to mirroring, (2) reference to other related transformations, (3) reference to the relationship between patterns, and (4) reference to the mirror axes or their directions. Word rates were calculated as number of words in each of these categories per 100 total words.

Table 1. *Different types of references to mirroring in speech (words used and English translations)*

	Words Used For Referring to Mirroring	English Translation
Explicit Mirroring	Spiegelung(en), gespiegelt, spiegelbar, Spiegelebene, Spiegelbild	mirroring(s), mirrored, "mirrorable", "mirror level", mirror image
Other Transformation	drehen, gedreht, Drehung, geklappt, verschoben, vertauscht, gewandert, den Platz wechseln	turn (verb), turned, turn (noun), folded, shifted, exchanged, moved, change places
Relationship between Patterns	Zusammenhang / Zusammenhänge, Relation, Verhältnis(se), Beziehung(en), Verbindung(en), verbunden, zueinander stehen, Ebene, Methode	relation(s), relation, relationship(s), relationship(s), connection(s), connected, be in relation to each other, level, method
Mirror Axes or Direction	Achse(n), Richtung, vertikal, horizontal, diagonal, waagerecht, senkrecht, schräg, Diagonalität, Diagonale	axis / axes, direction, vertical, horizontal, diagonal, horizontal, vertical, diagonal, "diagonality", diagonal (noun)

2.6. *Data analysis*

Behavioral data (RTs, ERs, gesture rates, speech rates, clauses, and word rates) were analyzed using the Statistical Package for the Social Sciences 14 (SPSS Inc., Chicago, USA). Incorrect responses in the geometric analogy task were excluded from RT analyses. The distribution of RTs of all remaining items was determined per participant. Trials with RTs less or greater than two standard deviations of the individual's mean were excluded from the statistical analyses. Overall, 4.7% of the analogy trials were eliminated. Concerning these outliers, there were no significant differences between difficulty levels of the type of relations (vertical, horizontal, diagonal).

Repeated measure analyses of variance (ANOVAs) for RTs, ERs, gesture rates, and word rates were conducted. Interactions were further analyzed by separate *t*-tests. RTs and ERs were correlated with gesture rates across participants. Fluid intelligence scores and crystallized intelligence scores were also correlated. Multiple regression analyses were performed on RTs and ERs with intelligence scores as predictors. One-factorial independent ANOVAs were performed on rotational kinetograph gesture rates, speech rates, and number of clauses. Additionally, Mann-Whitney-U tests were performed on rotational kinetograph gesture rates. A rejection criterion of $p < .05$ (two-tailed) was chosen for all analyses (Bonferroni-corrected for multiple comparisons). Effect sizes are given as partial eta squared (η_p^2) for multi-factorial analyses, point biserial correlation (r_{pb}) for parametric one-factorial analyses, and r for non-parametric analyses.

3. Results

First, the results from the analyses concerning intelligence and performance in the geometric analogy task are reported. Second, we present results concerning intelligence and the production of gestures. These are reported for gestures with increasing detail: movement or no movement expressed in gesture, the degree of abstraction expressed in movement gestures (egocentric pantomimes and non-egocentric kinetographs), and rotation expressed in kinetograph gestures. Third, results are presented examining the relationship between intelligence and participants' verbal responses. Finally, we present the results of the relationship between performance in the geometric analogy task and gesture production.

3.1. *Intelligence and performance (RTs and ERs)*

Descriptive statistics are displayed in Figures 3 and 4.

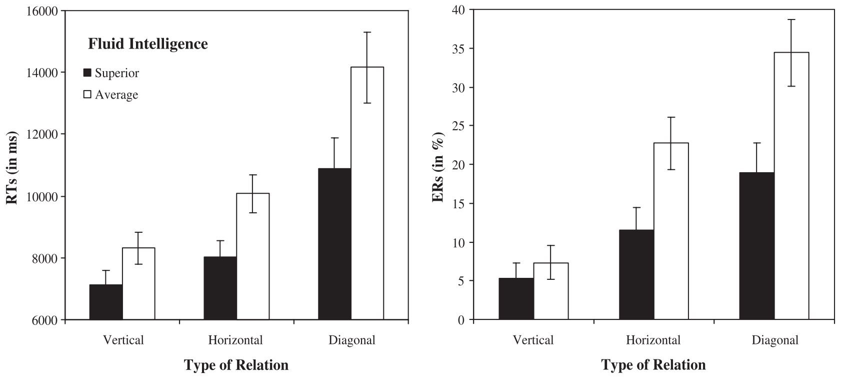

Figure 3. *Mean response times (RTs, in ms) and error rates (ERs, in %) ± standard errors in the geometric analogy task depending on difficulty of type of relation from participants with superior and average fluid intelligence.*

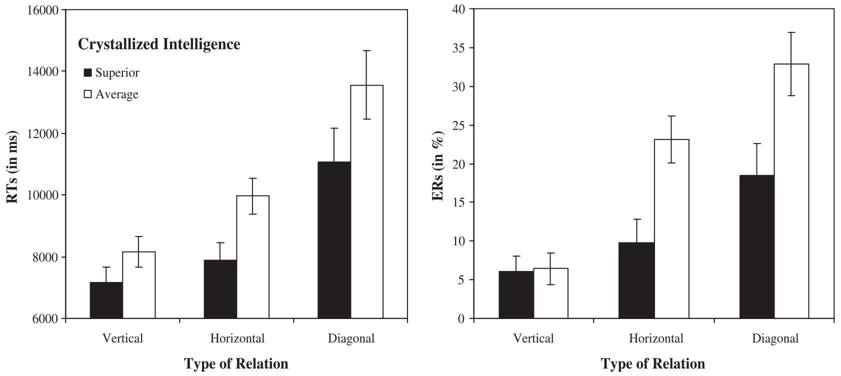

Figure 4. *Mean response times (RTs, in ms) and error rates (ERs, in %) ± standard errors in the geometric analogy task depending on difficulty of type of relation from participants with superior and average crystallized intelligence.*

3.1.1. *Fluid intelligence.* To analyze the influence of fluid intelligence on performance, 2 (fluid intelligence group: superior vs. average) × 3 (difficulty of type of relation: low, medium, high) repeated measures ANOVAs on RTs and ERs were performed. The RTs analysis revealed significant main effects of the difficulty of type of relation ($F[2,45] = 51.133$; $MSE = 5643107$; $p < .001$; $\eta_p^2 = .53$) and of fluid intelligence ($F[1,46] = 5.471$; $MSE = 30581194$; $p < .05$; $\eta_p^2 = .11$). RTs increased for more difficult analogy tasks, and participants with superior fluid intelligence were faster than participants with average fluid intelligence (Fig. 3). The interaction between difficulty of type of relation and fluid intelligence was not significant (*F*[2,46] = 2.371, *MS* = 13377309, $p > .05$, $\eta_p^2 = .05$).

The ERs analysis revealed significant main effects of the difficulty of type of relation (*F*[2,45] = 26.213; *MSE* = 186.097; $p < .001$; $\eta_p^2 = .36$) and fluid intelligence (*F*[1,46] = 9.013; *MSE* = 359.703; $p < .01$; $\eta_p^2 = .16$), as well as a significant interaction (*F*[2,46] = 3.005; *MS* = 559.290; $p < .05$; $\eta_p^2 = .06$). Accuracy decreased with increasing task difficulty and participants with superior fluid intelligence made fewer errors than participants with average fluid intelligence (11.93% vs. 21.49%). However, participants with superior fluid intelligence only made significantly fewer errors when processing more difficult tasks (mirroring on the horizontal axis: *t*[46] = 2.512; $p < .05$; $\eta_p^2 = .121$; mirroring on the diagonal axis: *t*[46] = 2.671; $p < .05$; $\eta_p^2 = .13$). A correlation analysis revealed that there were no speed-accuracy trade-off effects in the data ($r = .022$, $p > .05$).

3.1.2. *Crystallized intelligence.* To analyze the influence of crystallized intelligence on performance, 2 (crystallized intelligence group: superior vs. average) × 3 (difficulty of type of relation: low, medium, high) repeated measures ANOVAs on RTs and ERs were performed. The RTs analysis revealed a significant main effect of the difficulty of type of relation (*F*[2,45] = 48.053, *MSE* = 8576255, $p < .001$, $\eta_p^2 = .51$). But neither the main effect of crystallized intelligence, nor the interaction were significant (*F*[1,46] = 3.959; *MSE* = 315 06789; $p > .05$; $\eta_p^2 = .08$; *F*[2,46] = 1.221; *MS* = 10474973; $p > .05$, $\eta_p^2 = .03$, respectively).

The ERs analysis revealed a significant main effect of the difficulty of type of relation (*F*[2,45] = 24.951; *MSE* = 206.453; $p < .001$; $\eta_p^2 = .35$), a significant main effect of crystallized intelligence (*F*[1,46] = 8.807, *MSE* = 361.060, $p < .01$, $\eta_p^2 = .16$), and a significant interaction (*F*[2,46] = 3.994; *MS* = 824.577; $p < .05$, $\eta_p^2 = .08$). In general, participants with superior crystallized intelligence made fewer errors than participants with average crystallized intelligence (11.42% vs. 20.42%). But they only made significantly fewer errors when processing more difficult tasks (mirroring on the horizontal axis: *t*[46] = 3.126; $p < .01$; $\eta_p^2 = .18$; mirroring on the diagonal axis: *t*[46] = 2.475; $p < .05$; $\eta_p^2 = .12$).

Overall, our results indicate that individuals with superior fluid intelligence are faster and more accurate — and thus more efficient — in judging geometric analogies than individuals with average fluid intelligence. Superior crystallized intelligence, on the other hand, predicts higher accuracy but not a significant benefit in processing speed compared to average crystallized intelligence. Nevertheless, fluid intelligence is positively correlated with crystallized intelligence ($r = .410$, $p < .01$). To determine which factor of intelligence predicts the performance best we entered the factors fluid intelligence and crystallized intelligence into multiple regression analyses. The overall RTs and overall ERs served as dependent variables. Fluid intelligence was a significant predictor of overall RTs ($R^2 = .120$; $\beta = -346$; $p < .05$) but crystallized intelligence did not make a significant contribution to the model ($\Delta R^2 = .003$; $\beta = -059$; $p > .05$). For ERs we found similar results. Fluid intelligence proved to be a significant predictor of overall ERs ($R^2 = .261$; $\beta = -430$; $p < .01$) but crystallized intelligence did not make a significant contribution to the model ($\Delta R^2 = .027$; $\beta = -184$; $p > .05$). Thus, as expected, multiple regression analyses indicated fluid intelligence as most important to predict performance (RTs and ERs) in solving geometric analogies.

3.2. *Intelligence and gestures*

Descriptive statistics are presented in Table 2 including the mean (M) and standard errors (SE) of gesture rates.

Table 2. *Means (M) and standard errors (SE) of gesture rates (defined as gestures per 100 words)*

Gesture type	*M*	(*SE*)
Gestures not Expressing Movement	1.97	(0.27)
Gestures Expressing Movement	4.98	(0.49)
Pantomimes	1.11	(0.19)
Kinetographs	2.99	(0.37)

3.2.1. *Intelligence and movement expressed in gestures: Fluid intelligence.* To test whether movement in gesture was produced more often by participants with superior fluid intelligence compared to average fluid intelligence, we performed a 2 (fluid intelligence group: superior vs. average) × 2 (gesture type: non-movement, movement) repeated measures ANOVA on gesture rates. The analysis revealed a significant main effect of gesture type ($F[1,49] = 46.176$; $MSE = 4.55$; $p < .001$; $\eta_p^2 = .49$), a significant main effect of fluid intelligence ($F[1,49] = 4.628$, $MSE = 5.121$, $p < .05$, $\eta_p^2 = .09$), and a significant interaction ($F[1,49] = 8.725$; $MS = 39.70$; $p < .01$; $\eta_p^2 = .15$). Movement gestures ($M = 4.98$, $SE = 0.49$) were produced more often than non-movement gestures ($M = 1.97$; $SE = 0.27$). More important, while non-movement gestures were produced similarly often by speakers with superior and average fluid intelligence ($M = 2.02$; $SE = 0.34$ vs. $M = 1.91$; $SE = 0.45$), movement gestures were produced more often by participants with superior fluid intelligence compared to participants with average fluid intelligence ($M = 6.16$; $SE = 0.64$ vs.

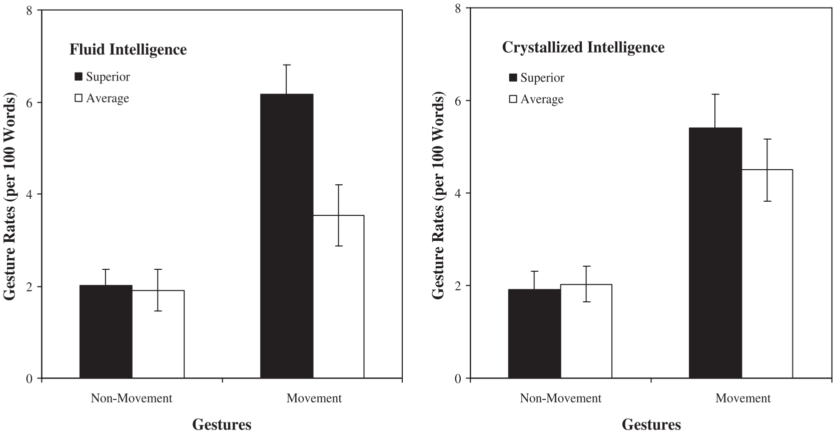

Figure 5. *Mean gesture rates ± standard errors for nonmovement and movement gestures produced by participants with superior and average fluid and crystallized Intelligence.*

$M = 3.54$; $SE = 0.66$) (see Fig. 5). A post hoc *t*-test established that this difference was significant ($t[49] = 2.818$; $p < .01$; $r_{pb} = .37$).

3.2.2. *Intelligence and movement expressed in gestures: Crystallized intelligence.* To test whether movement in gesture was produced more often by participants with superior compared to average crystallized intelligence, we performed a 2 (crystallized intelligence group: superior vs. average) × 2 (gesture type: non-movement, movement) repeated measures ANOVA on gesture rates. The analysis revealed, again, a significant main effect of gesture type ($F[1,49] = 43.783$, $MSE = 5.231$, $p < .001$, $\eta_p^2 = .47$, i.e., more movement-gestures than non-movement gestures were produced). The main effect of crystallized intelligence and the interaction were not significant ($F[1,49] < 1$; $F[1,49] = 1.212$; $MS = 6.341$; $p > .05$; $\eta_p^2 = .02$) (see Fig. 5).

In summary, movement gestures were produced more often than gestures not expressing movement. More important, as predicted, participants with superior fluid intelligence produced more movement gestures than participants with average fluid intelligence. Participants who differed in crystallized intelligence did not differ in the production of gestures.

3.2.3. *Intelligence and degree of abstraction expressed in gestures: Fluid intelligence.* To examine whether gestures with different degrees of abstraction were expressed to different extents by participants with superior fluid intelligence compared to participants with average fluid intelligence, we performed a 2 (fluid intelligence group: superior vs. average) × 2 (gesture type: pantomime, kinetograph) repeated measures ANOVA on gesture rates. The

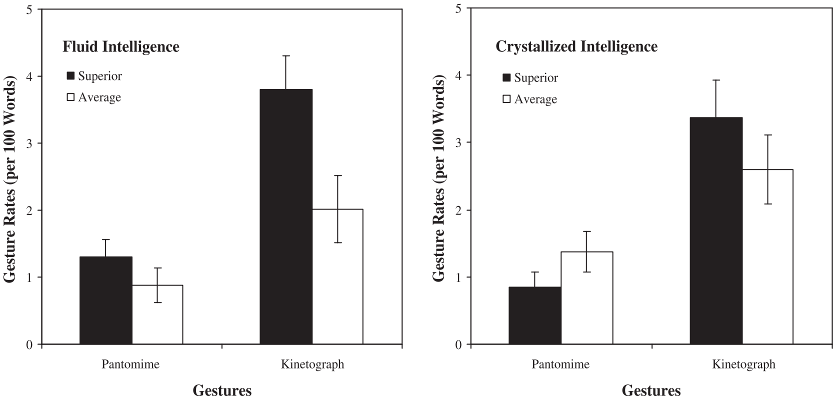

Figure 6. *Mean gesture rates ± standard errors for pantomime and kinetograph gestures produced by participants with superior and average fluid and crystallized intelligence*

analysis revealed a significant main effect of gesture type ($F[1,49] = 21.715$; $MSE = 3.832$; $p < .001$; $\eta_p^2 = .31$). Kinetograph gestures ($M = 2.99$; $SE = 0.37$) were produced more often than pantomimes ($M = 1.11$; $SE = 0.19$). The main effect of fluid intelligence was also significant ($F[1,49] = 7.034$; $MSE = 2.175$; $p < .05$; $\eta_p^2 = .13$). The participants with superior fluid intelligence produced more pantomime and kinetograph gestures ($M = 5.10$; $SE = 0.58$) compared to participants with average fluid intelligence ($M = 2.89$; $SE = 0.59$). The interaction of gesture type and fluid intelligence was not significant ($F[1,49] = 3.040$; $MS = 11.651$; $p > .05$; $\eta_p^2 = .06$) (see Fig. 6). However, a post hoc *t*-test revealed that kinetograph gestures were produced more often by superior fluid intelligent participants compared to average fluid intelligent participants ($t[49] = 2.492$; $p < .05$; $r_{pb} = .34$).

3.2.4. *Intelligence and degree of abstraction expressed in gestures: Crystallized intelligence.* To assess the effect of crystallized intelligence, we performed a 2 (crystallized intelligence group: superior vs. average) × 2 (gesture type: pantomime, kinetograph) repeated measures ANOVA on gesture rates. The analysis revealed, again, a significant main effect of gesture type ($F[1,49] = 23.121$; $MSE = 3.851$; $p < .001$; $\eta_p^2 = .32$; i.e., kinetograph gestures were more often produced than pantomimes). The main effect of crystallized intelligence and the interaction were not significant ($F[1,49] < 1$; $F[1,49] = 2.778$; $MS = 10.700$; $p > .05$; $\eta_p^2 = .05$] (see Fig. 6).

In summary, participants produced more kinetographs than pantomimes. Participants who differed in crystallized intelligence did not differ in the production of gestures.

3.2.5. *Intelligence and rotation expressed in gestures.*

Kinetograph gestures produced in this study often expressed rotational movement. However, it was striking that about a third of the participants did not produce any of these rotational gestures at all. We think that these gestures expressed the movement some participants imagined when mirroring the geometric patterns (the latter being necessary to determine whether the two pattern pairs were analogous or not). To examine whether participants with different levels of fluid and crystallized intelligence produced kinetographs that expressed rotations to different extents, we performed two independent ANOVAs with the two groups (superior and average fluid intelligence and superior and average crystallized intelligence, respectively) on gesture rates that expressed rotations in kinetograph gestures. Participants with superior fluid intelligence expressed more rotations in their kinetograph gestures ($M = 1.85$; $SE = 0.32$) than those with average fluid intelligence ($M = 0.89$; $SE = 0.35$; $F[1,49] = 4.174$; $p < .05$; $r_{pb} = .28$). Participants who differed in crystallized intelligence did not differ in the production of rotational kinetograph gestures (superior: $M = 1.36$; $SE = 0.34$; and average: $M = 1.48$; $SE = 0.35$; $F[1,49] = 0.055$; $p > .05$; $r_{pb} = .03$). Because several of the participants did not produce rotational gestures, we also confirmed the results with non-parametric Mann-Whitney-U tests (for fluid intelligence: $U = 186.0$; $p < .05$; $r = -.37$; for crystallized intelligence: $U = 308.5$; $p > .05$; $r = -.04$).

3.3. *Intelligence and speech*

To determine whether participants with different levels of fluid intelligence and crystallized intelligence differed in their speech rates and in the number of clauses they uttered, we performed two one-factorial independent ANOVAs on speech rates and two one-factorial independent ANOVAs on the number of clauses. None of the four tests indicated significant differences in speech rates or number of clauses between groups (all $p > .05$).

Because gesturing about the process of mirroring the patterns in the geometric analogy task (i.e., expressing rotations in gestures) distinguished between superior and average intelligent participants in our study, we examined whether this was a reflection of what participants were *talking* about (cf. Chu and Kita 2008). We found that participants referred to mirroring (1) explicitly, or implicitly through mentioning (2) other types of corresponding transformations, (3) the relationship between patterns, or (4) the mirror axes or their directions (see Section 2.5 and Table 1). Only three participants did not talk about mirroring at all. Two of them had superior fluid intelligence and one of them also superior crystallized intelligence. Thus, the mere presence or absence of mirroring expressed in speech did not differentiate between superior and average intelligence as it did in gesture. In addition, we tested whether referring to mirroring by one of the four word categories distinguished between participants with superior and average fluid and crystallized intelligence. Descriptive statistics are presented in Table 3 including the mean (M) and standard errors (SE) of word rates.

Table 3. *Means (M) and standard errors (SE) of word rates (defined as words per 100 total words) for explicit mirroring, other transformation, relationship between patterns, and axis or direction for participants with superior and average fluid and crystallized intelligence*

		Explicit Mirroring		Other Transfor-mation		Relationship between Patterns		Axis or Direction	
		M	(*SE*)	*M*	(*SE*)	*M*	(*SE*)	*M*	(*SE*)
Fluid Intelligence	Superior	0.95	(0.21)	0.30	(0.11)	0.43	(0.16)	0.93	(0.22)
	Average	1.17	(0.26)	0.23	(0.08)	0.34	(0.17)	1.10	(0.26)
Crystallized Intelligence	Superior	1.17	(0.26)	0.17	(0.08)	0.54	(0.20)	0.89	(0.21)
	Average	0.92	(0.21)	0.36	(0.12)	0.22	(0.11)	1.13	(0.27)

3.3.1. *Fluid intelligence.* To test whether words of the four categories of word types that describe the central information of the task were produced differently often by participants with superior and average fluid intelligence, we performed a 2 (fluid intelligence group: superior vs. average) × 4 (word type: explicit mirroring, other transformation, relationship between patterns, mirror axes or direction) repeated measures ANOVA on word rates. The analysis revealed only a main effect for word type ($F[3,47] = 8.091$; $MSE = 1.311$; $p < .001$; $\eta_p^2 = .34$). Explicit mirroring ($M = 1.05$; $SE = 0.17$) and mirror axes or direction ($M = 1.01$; $SE = 0.17$) were produced more often than other transformation ($M = 0.27$; $SE = 0.07$) and relationship between patterns ($M = 0.39$; $SE = 0.12$). The main effect of fluid intelligence and the interaction were not significant (Fs < 1).

3.3.2. *Crystallized intelligence.* To test whether words of the four categories of word types that describe the central information of the task were produced differently often by participants with superior and average crystallized intelligence, we performed a 2 (crystallized intelligence group: superior vs. average) × 4 (word type: explicit mirroring, other transformation, relationship between patterns, mirror axes or direction) repeated measures ANOVA on word rates. Again, the analysis revealed only the main effect for word type ($F[3,47] = 7.876$; $MSE = 1.311$; $p < .001$; $\eta_p^2 = .34$). The main effect for crystallized intelligence and the interaction were not significant (Fs < 1).

In summary, participants' speech rates, number of clauses, or the presence of words referring to mirroring in speech did not distinguish between participants with different levels of fluid or crystallized intelligence. Moreover, participants with superior fluid or crystallized intelligence talked about mirroring, other transformation, relationships between patterns and their axes as frequently as participants with average fluid or crystallized intelligence, respectively.

3.4. *Performance in the geometric analogy task and gesture production*

We examined correlations of the different gesture types with RTs and ERs from the geometric analogy task. Table 4 presents the correlation matrix. Contrary to our prediction, we did not find any correlations between gesture rates and performance. To make sure that we did not miss a relationship due to ceiling effects in performance, we also correlated the performance on the most difficult task separately (mirroring on the diagonal axis) with gesture rates. There were no significant correlations (all $N = 48$; r between −.100 and .100; $p > .05$).

Table 4. *Correlation matrix including Pearson's r for different gesture types, response times (RTs) and error rates (ERs) (all N = 48, p > .05)*

	Gestures Not Expressing Movements	Gestures Expressing Movement	Pantomimes	Kinetographs
RTs	−.087	−.033	.029	−.096
ERs	.103	−.103	.136	−.078

4. Discussion

The goal of the study was to determine the relationship of reasoning, gesturing, and intelligence. We collected performance data from young adults while they were engaged in a geometric analogy task, we recorded their gestures while they described afterwards what they felt was important for solving the task, and we administered psychometric tests measuring fluid and crystallized intelligence. The study yielded the following main results: First, participants with superior fluid intelligence were faster and more accurate in solving the more difficult analogies compared to participants with average fluid intelligence. Second, participants with superior fluid intelligence produced more gestures expressing movement than participants with average fluid intelligence. More specifically, participants with superior fluid intelligence produced more non-egocentric movement gestures (kinetographs) compared to those with average fluid intelligence. Third, gesturing about mirroring — but not talking about it

— distinguished between superior and average fluid intelligence. Finally, there were no correlations between performance in the analogy task and subsequent gesture production.

4.1. *Intelligence and performance in the geometric analogy task*

Superior fluid intelligence predicts shorter response times and lower error rates in the geometric analogy task. In particular, this was significant only for the more difficult relations (mirroring on the horizontal and diagonal axis). This observation underlines that individuals with superior fluid intelligence perform more complex cognitive tasks faster compared to individuals with average fluid intelligence and thus outperform the latter in cognitive efficiency (Jensen 1998; Neubauer et al. 1995; Vernon 1983). In contrast, superior crystallized intelligence did not predict shorter response times in processing the geometric analogy task compared to average crystallized intelligence. Effects of crystallized intelligence were only reflected by error rates. The results of regression analyses also presented evidence for the assumption that fluid intelligence is more central for analogical reasoning than crystallized intelligence. Overall and consistent with the literature (French 2002; Halford 1992; Hofstadter 1995; Holyoak and Thagard 1996; Klix 1993), we confirmed that fluid intelligence is a central component in analogical reasoning (van der Meer et al. 2010).

4.2. *Intelligence and movement gestures*

This study clearly demonstrates that participants with superior fluid intelligence produce more gestures expressing movement compared to those with average fluid intelligence. This difference could not be explained by differences in participants' speech rates or in the number of clauses they uttered because speech rates and number of clauses did not differ significantly between the two groups. Thus, we generalized findings from the relationship of gesture production and spatial skills (Ehrlich et al. 2006; Hostetter and Alibali 2007) to more general cognitive ability, namely fluid intelligence. Furthermore, this relationship was found for movement in non-egocentric kinetographs, not for pantomimes. Within the gestures-as-simulated action framework (Hostetter and Alibali 2008), gestures are produced as a result of simulated actions and/or simulated perceptions. More specifically, kinetographs are assumed to result from mental simulations during visual imagery (as opposed to motor imagery). This finding indicates that young adults with superior fluid intelligence simulate more when engaged in visual imagery compared to their peers with average fluid intelligence when describing relevant aspects of solving geometric analogies. This might reflect that participants with superior fluid intelligence engage to a greater extent in mental simulation during the actual task because gestures accompanying subsequent explanations of a task are assumed to index strategies while solving them (e.g., Goldin-Meadow et al. 1993).

Others have argued for reasoning development in terms of a transition from an egocentric mental representation towards a representation independent of first-person viewpoint during childhood (e.g., Piaget and Inhelder 1971) and in adulthood for novel tasks (Chu and Kita 2008). This transition of abstraction allows an individual to become less restricted by physical constraints to arrive at more flexible and efficient strategies. Schwartz and Black (1996) demonstrated this by presenting participants with several sets of interlocking gears in a row. They asked in which direction the last gear turned if the first turned either clockwise or counter-clockwise. While participants thought about the solution in the first trials, they used *depictive models* externalized by gestures when they were not yet aware of the *formal model* (i.e., for an odd number of gears, the last gear turned in the same direction as the first; for an even number of gears, the last gear turned in the opposite direction than the first). The gestures in the first trials were very elaborate, indicating the directions of turns of the gears. However, they quickly became less defined pointing gestures in subsequent trials. Furthermore, participants additionally started counting before they finally arrived at the formal model and solved the following problems faster and more accurately. Similarly, for the analogy task in the present study, participants with superior fluid intelligence seemed to rely on an abstracted but also depictive model to a greater extent compared to participants with average fluid intelligence.

4.3. *Intelligence and mirroring in gesture and speech*

Individuals with superior fluid intelligence are assumed to focus more efficiently on information relevant for the task at hand. In this study, the most relevant information was the mental transformation of mirroring the geometric patterns. Participants with superior fluid intelligence focused more on the mental rotational movement of the object as indicated by their gestures afterwards. Gesturing about mirroring — but not talking about it — distinguished between participants with superior and average fluid intelligence. In contrast, Chu and Kita (2008) found that both, gestures and speech, indicated a change of strategies in the course of an experiment. However, the present data suggest that gesture is more informative about a person's cognitive ability than speech is, similar to Ehrlich et al. (2006).

Although our results cannot provide direct evidence for it, we might assume a causal relationship between gesture and fluid intelligence (but see below for alternative, not mutually exclusive, interpretations). Using the hands to visualize and externalize an object's movement might play a crucial role in forming abstract mental representations that underlie much of human cognition. For example, a similar development from pantomimes to kinetographs has been reported for children and adults. Younger children retelling a story produce more character viewpoint pantomimes than older children and adults (McNeill 1992). In addition, adults becoming more experienced with a novel problem show a transition from hand-object interaction gestures (pantomimes) to object movement gestures (kinetographs; Chu and Kita 2008). Furthermore, evolutionary accounts of language assume a similar development of communicative gestures from pantomimes to more abstract gestures (and finally to even more abstract spoken language; Corballis 2002; Gentilucci and Dalla Volta 2007). Recent studies reported that gesturing can benefit the acquisition of new concepts (Broaders et al. 2007; Wagner Cook et al. 2008). The development of fluid intelligence could benefit from gesturing about strategies, by exploring new strategies or by the consolidation of strategies within the gesturer's repertoire. Furthermore, gestures can draw attention to relevant features and working memory load could be decreased by externalizing some of the relevant information in gesture (Wagner et al. 2004; Wilson 2002). This would allow more information to be processed simultaneously. More research is necessary to establish if gesturing indeed benefits the development of reasoning ability and what the underlying mechanisms are.

One alternative explanation for the results is that the relationship between gesturing and fluid intelligence is driven by differences in the level of activation between the two groups of participants. According to Hostetter and Alibali (2008), the gesture threshold can be surpassed more easily with a higher level of activation. This activation might be related to the level of the individual's general resource allocation during a task. Just et al. (2003) have demonstrated that the pupillary response reflects an overall mental resource allocation that is not limited to a specific part of the cognitive system. Pupil dilation, among other things, is assumed to indicate the amount of resources allocated in a cognitive task (Ahern and Beatty 1979; "phasic mode" in Aston-Jones and Cohen 2005). Results from a study investigating differences in resource allocation as measured with pupillometry demonstrate that participants with superior fluid intelligence show greater task-related pupil dilation and thus are assumed to engage more strongly in the difficult geometric analogy tasks (i.e., mirroring on the diagonal axis) than their peers with average fluid intelligence (van der Meer et al. 2010). This stronger engagement during a taxing task means that individuals with superior fluid intelligence might also activate the underlying mental representations more strongly. Within the gestures-as-simulated action framework, people with high fluid intelligence who strongly activate their cognitive resources might be expected to gesture more compared to people with average fluid intelligence because in explanations of subsequent cognitive tasks participants are assumed to reactivate similar processes to solving the tasks (Goldin-Meadow et al. 1993).

In addition, people with high fluid intelligence also show larger pupil baseline diameters compared to their peers with average fluid intelligence without performing any task (van der Meer et al. 2010). According to Aston-Jones and Cohen (2005), this "tonic mode" of pupil size corresponds to a general exploration of the environment. With respect to the strength of an activation of an individual, it is plausible that people with a higher tonic mode surpass their gesture threshold more easily compared to people with a lower tonic mode. Thus, within the gestures-as-simulated action framework, people with high fluid intelligence who show a larger pupil in tonic mode are expected to gesture more than their peers with average fluid intelligence and a smaller pupil in tonic mode.

Yet another more general explanation of our findings is the possibility that the two groups of participants could differ in their gesture thresholds, for example, due to differences in brain structure, such as in Broca's area in the left hemisphere (cf. Hostetter and Alibali 2008). Wartenburger et al. (2010) have found that participants with superior fluid intelligence show greater cortical thickness in the pars opercularis (a part of Broca's area), superior frontal cortex, and temporal cortex of the left hemisphere. Note that all explanations presented here are not mutually exclusive and they might interact.

4.4. *Performance in the geometric analogy task and gestures*

Unlike Ehrlich et al. (2006) in children, we did not find a direct relationship between performance in the analogy task and gesture production. This null result is unlikely to be due to ceiling effects because we also did not find a relation between gesture rates and the most difficult analogy task (mirroring on the diagonal axis). There are several differences between Ehrlich et al.'s study and the present study that could explain the different findings. First of all, the relationship between performance on a task and gesture production might be restricted to children and might not generalize to adults. However, because we found a relationship between young adults' fluid intelligence and gesture production, other performance measures and gesture production could be related in adults also. Also, Ehrlich et al. (2006) measured performance at a more coarse level than the present study; only error rates were recorded from eight trials in contrast to response times and error rates from 60 trials in the present study. Thus, gesture behavior might only be related to a more coarse level of performance or ability. Another and probably the most important difference of the two studies to explain the different findings is that children in Ehrlich et al. (2006) explained their strategies repeatedly after each trial in concrete relation to the preceding problem. The participants in the present study only gave one overall account of what they felt was important for the task after the analogy experiment. Thus, in the meta description the frequency of gestures possibly did not reflect performance as reliably as in a situation in which participants were asked to describe how they solved each particular problem. Furthermore, the children's gestures could have facilitated their performance on the following trials.

4.5. *Gesturing and thinking*

Although gestures are regularly used for communication purposes (e.g., Bavelas et al. 2008; Kendon 2005; McNeill 1992), they also reflect and influence thought. This study clearly shows that gesture production is related to general cognitive ability, namely fluid intelligence. Young adults with superior fluid intelligence gestured more about movement and, in particular, about movement from a non-egocentric perspective. While in gesture research the tight relationship between gesture and speech is often stressed, it is recognized that children and adults regularly commit gesture-speech mismatches (Goldin-Meadow 2003). In this study, participants occasionally expressed rotations in their gestures while not talking about mirroring at the same time. For example, they verbally described features of the geometric patterns while indicating rotation in their gestures, presumably representing how these features would move from one position in the pattern to another when mirrored. Thus, they described two different aspects of the task in gesture and in speech. Unlike researchers viewing gestures as strictly dependent on the linguistic context (de Ruiter 1998, 2000; Krauss et al. 2000; McNeill 1992, 2005), our data emphasize the interactive relationship between gesture production and reasoning processes. Thus, our findings (and those provided by others, e.g., Chu and Kita 2008; Ehrlich et al. 2006) are more compatible with the view that the production of gestures originates from thinking processes (Hostetter and Alibali 2008). Only then can we explain the relationship between gesturing and fluid intelligence found in our study. Similarly, Núnez (2004: 66) argued that "gesture constitutes the forgotten dimension of thought and language". On the one hand, thinking processes can result in expressions of gesture and speech that share a close semantic and pragmatic relationship. On the other hand, thinking can involve quite different representations simultaneously (e.g., two strategies, truth and lie, etc.), and thus gesture and speech can simultaneously express different concepts resulting in gesture-speech mismatches. In this way, gesture and speech can focus on different aspects of things in the world like a problem or a task. Together they can form a more elaborate representation, which in turn could facilitate problem solving or learning.

While this study demonstrates a relationship between reasoning, gesture production, and fluid intelligence, there are some issues that have to be addressed in future research. For example, it is necessary to generalize the findings over different tasks and participants, for example, whether individuals with average fluid intelligence also produce more gestures indicating simulated action than individuals with *poor* fluid intelligence in a comparable task. Also, the sample in our study consists mainly of male participants, which reflects the distribution at their schools (specialized in mathematics and natural sciences). However, the results presented here should generalize to a more balanced sample of males and females. Previously reported sex differences for gesture production were either directly related to spatial skills (five-year-old boys produced more movement gestures than girls and also performed better in a spatial transformation task; Ehrlich et al. 2006) or they were found for gestures in general but not specifically for representational gestures that are under investigation in the present paper (Hostetter and Hopkins 2002). Finally, it is important to establish whether individuals with different levels of fluid intelligence differ in their engagement of mental simulation in cognitive tasks and whether this is a causal relationship.

4.6. *Conclusion*

We investigated the relationship between the production of representational gestures, analogical reasoning, and intelligence. We found that young adults with superior fluid intelligence outperform their peers with average fluid intelligence in judgments of geometric analogies. Individuals with superior fluid intelligence also produce more representational gestures, and in particular gestures that express movement from a non-egocentric perspective. Moreover, unlike their peers with average fluid intelligence, they indicated the most relevant information for solving the task in gesture. In line with the gestures-as-simulated action framework (Hostetter and Alibali 2008), we have shown that individuals with superior fluid intelligence reveal more mental simulation than those with average fluid intelligence. Thus, the findings expand our knowledge about gesture production beyond their relationship with speech, spatial skills, and mental simulation to the domain of fluid intelligence as a general cognitive ability.

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Notes

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[1] This is the actual *speaking* time of the participants. The time interval in which gestures were coded was a little longer because it started with the beginning of the participant answering the first question and ended with the end of answering the last of the three questions. Thus, the time in which gestures were coded also included the time when they were listening while the interviewer was speaking ($M = 70$ s ± 27), but note that the gestures analyzed here rarely occur when listening.

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