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Evidence for gesture-speech mismatch detection impairments in schizophrenia

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ABSTRACT

Patients with schizophrenia suffer from impairments in the perception and production of gestures. The extent to which patients can access the semantic association between speech and co-verbal gestures in concrete or abstract/metaphorical meaning contexts is unknown. We investigated 1) how patients differ from controls in gesture matching performance, 2) how performance differs in the context of abstract versus concrete meaning, and 3) whether formal thought disorder (FTD) symptom severity predicts task impairment. Forty-five patients with schizophrenia spectrum disorders (two subgroups, "mild" and "severe") took part in this study. Participants were presented with video clips, each showing an actor saying a sentence while producing a gesture. Sentences contained either concrete or abstract/metaphorical information, and the accompanying gesture was either semantically related or unrelated to the sentence. Participants indicated via button press whether the gesture matched the content of the verbal utterance. Both patient subgroups demonstrated reduced performance in all comparisons. A significant interaction was found between patient subgroup and sentence abstractness. Task performance was worst for patients with severe positive FTD symptomatology in the abstract condition, while there were no patient subgroup differences in the concrete condition. These data shed new light on gesture-speech mismatch detection impairments in schizophrenia.

1. Introduction

In everyday life, gestures are a ubiquitous and important means of underpinning the content of a verbal message [(Nagels et al., 2013; Straube et al., 2013b); for a review see (Goldin-Meadow and Alibali, 2013)]. There is increasing evidence suggesting that patients with schizophrenia have dysfunctions in the perception and production of gestures (Berndl et al., 1986; Bucci et al., 2008a, b; Matthews et al., 2013; Troisi et al., 1998; Walther and Mittal, 2016; Walther et al., 2013), that gesture production deficits are more severe after multiple episodes (Stegmayer et al., 2016), and that such deficits are related to functional outcome (Walther et al., 2016). However, until now the ability to relate speech and gesture information in schizophrenia has received very little attention.

The information conveyed via semantically meaningful hand and arm movements is tightly connected to speech semantics, as when a person says "The ball is round" while simultaneously forming a round shape with his hands and arms. Here, a direct connection between the verbal message and the accompanying gestural information is evident. These concrete ("C") form-describing gestures are generally referred to as 'iconic', as opposed to abstract ("A") 'metaphorical' gestures. The latter category refers to gestures which convey the semantic meaning of an utterance in a metaphorical (abstract) sense, as when a person says "The talk was at a high level" while (metaphorically) indicating the elevated complexity of a talk by raising his hand. Given that there is no such physical relation between "high" and "talk", the hand raising gesture spatially underpins the metaphorical meaning. In this case, the literal meaning has to be transferred to a superordinate abstract level in order to establish semantic meaning. In everyday communication, these constructs are frequently used to refer to intangible abstract concepts such as emotions or spiritual notions. In order to make abstract information seem more explicit, physical experiences or directional references are established, e.g., with *down* indicating something negative (e.g., thumbs down: "he is really down these days", "salaries are falling") and *up* indicating something positive (e.g., thumbs up: "a high position in the company", "a rising star").

It is well-known that in patients with schizophrenia, in particular in those suffering from formal thought disorder (FTD), the interpretation of abstract metaphorical information is impaired (Straube et al., 2013a; Walther and Mittal, 2016). In such cases, patients tend to interpret abstract information in a literal and concrete way; this is frequently evaluated with the use of expressions involving idioms or proverbs. Here, the interviewer asks the patient to explain the meaning of a metaphorical expression such as "It's no bed of roses". Impairment in such cases is clinically referred to as *concretism* (Kircher et al., 2007), which can be assessed with particular proverb interpretation tests

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Table 1
Sociodemographic and clinical variables.

	Sociodemographic and clinical variables for each group			Between-group comparisons (ANOVA: HC, m-pFTD, s-pFTD)		Independent samples *t*-test: m-pFTD, s-pFTD	
	HC	m-pFTD	s-pFTD	*F*	Sig.	*t*	Sig.
N	20	25	20	_	_	_	_
Sex (m/f)	18/2	19/6	13/7	$\chi^2 = 1.70$ n.s.	$\chi^2 = 0.65$ n.s.		
Age	35.35 (9.5)	41.92 (12.5)	34.65 (11.9)	2.80	$p = 0.07$	1.97	0.06
Years Edu	11.95 (1.6)	10.24 (1.7)	10.45 (1.6)	6.83	$p = 0.002$	−0.42	0.67
Verbal IQ	31.25 (3.0)	26.92 (5.3)	25.60 (5.3)	7.89	$p = 0.001$	0.83	0.41
Concretism	1.05 (0.12)	2.01 (0.75)	2.14 (0.78)	13.35	$p > 0.001$	−0.58	0.56
SAPS sum	_	19.20 (15.1)	33.90 (18.7)	_	_	−2.91	<0.01*
SANS sum	_	23.96 (16.1)	30.65 (18.7)	_	_	−1.28	0.21
pFTD (SAPS)	_	1.20 (1.26)	11.40 (8.04)	_	_	−6.26	<0.001**
BAG scores							
I. Perception	15.65 (2.72)	15.24 (2.09)	14.90 (2.97)	0.424	0.66	0.45	0.65
II. Production	11.25 (3.71)	12.28 (2.85)	12.25 (3.49)	0.65	0.53	0.03	0.98
III. Social Production	8.05 (1.54)	7.72 (1.49)	8.15 (1.60)	0.49	0.61	−0.93	0.36
IV. Social Perception	4.45 (1.76)	4.64 (2.00)	4.50 (1.47)	0.07	0.93	0.27	0.80

Df $_{(2,62)}$, HC = Healthy Controls, m-pFTD = mild positive formal thought disorder, s-pFTD = severe positive formal thought disorder, Edu = Education (A-Level = 1, Vocational Diploma = 2, Secondary School Level = 3, Secondary Modern School Level = 4, No Graduation = 5; Note: Educational systems and school levels are different in Germany as compared to Anglo-American systems), *F* = between groups comparisons (ANOVA: HC, m-pFTD, s-pFTD), *t* = between groups comparisons (independent samples *t*-test: m-pFTD, s-pFTD). Concretism was assessed with the Proverb Interpretation Task (see Experimental Design and Procedure).

(Barth and Kufferle, 2001).

The majority of past studies of patients with schizophrenia have focused on various higher-order pragmatic levels, such as irony comprehension (Bosco et al., 2012; Parola et al., 2018; Rapp et al., 2010, 2013) or ambiguity discrimination (Ketteler et al., 2012). There is converging evidence for a general impairment of abstract information interpretation in such patients, which may partly be due to aberrant semantic processing associated with FTD symptomatology (Holshausen et al., 2014; Kiefer et al., 2009). It is thus not surprising that deficits can be found throughout the different categories of abstract (pragmatic) information processing, also including the interpretation of idioms and proverbs (Barth and Küfferle, 2001), which differ structurally and pragmatically from the aforementioned metaphorical constructions. However, all these constructions have in common that a certain meaning needs to be inferred within a given, mostly social, context as a reaction to a semantic conflict. For example, the idiom “speak of the devil,” spoken when a recently-mentioned person enters a room, is false in a strictly literal sense. The same holds for typical sayings and proverbs offering useful truths or advice. For instance, the saying “a chain is only as strong as its weakest link” is generally not uttered in a technical context but rather in a social situation such as a context involving teamwork. This is in spite of the fact that the word-for-word meaning is clearly physical. Collectively, metaphors, idioms and proverbs represent a variety of forms of figurative language, with varying degrees of semantic abstractness and lexicalization (or familiarity). Therefore, when studying the psychology underlying such language forms it is very important to either control for these factors or to use unfamiliar constructions, as has been done in the development of the proverb interpretation tool introduced by Barth and Küfferle (2001). This instrument allows for the assessment of different degrees of concretism in psychiatric patient groups (Nagels et al., 2016). This permits the assessment of people's ability to correctly interpret abstract semantic information, along with additional information such as that provided by accompanying manual gestures. This in turn enables an evaluation of concretism symptom severity. This information is of fundamental interest for the present study, as FTD phenomenology and concretism are highly intertwined (Kircher et al., 2014; Nagels et al., 2016).

At a linguistic level, semantic retrieval performance was reported to be negatively associated with FTD symptoms in schizophrenia patients (Jamadar et al., 2013), especially in patients with positive FTD (pFTD), also referred to as “disorganized language” (Liddle et al., 2002) or “verbal disorganization” (McGuire et al., 1998). Taken together with evidence of a general gesture dysfunction in schizophrenia (Rossetti et al., 2018), it seems clear that specific impairments at the semantic level are tightly connected to positive FTD symptoms (Kuperberg et al., 2007; Manschreck et al., 1988). The question of whether aberrations in speech-gesture semantics are specifically related to positive FTD symptom severity remains unanswered. Moreover, it is unclear to what degree the level of semantic abstractness plays a role in speech-gesture mismatch detection in patients with positive FTD. Since speech and gesture information are inherently intertwined, it can be assumed that positive FTD symptomatology may also affect the ability to derive abstract meaning from speech-gesture contexts. In other words, supramodal semantic processing (Nagels et al., 2013; Straube et al., 2013b) deficits may lead to a general dysfunction in the interpretation of abstract/metaphorical information.

To date, few patient studies have directly compared abstract metaphorical vs. concrete sentence comprehension (Brune and Bodenstein, 2005; Kircher et al., 2007), in particular with respect to gesture employment (Straube et al., 2014). As no behavioral measures were assessed in previous investigations, there has been no previous examination of the possible association between psychopathological phenomena, i.e., FTD, and speech-gesture task performance at different semantic levels. In order to investigate these questions, a bi-modal gesture-mismatch detection task was developed, manipulating semantic abstractness and concreteness. Participants were asked to decide whether gestural information fit the content of a verbal message. It was hypothesized 1) that patients differ from healthy controls in speech-gesture mismatch detection performance, 2) that this difference should be largest when speech and gesture are associated on an abstract level, and 3) that positive FTD symptomatology should show a particularly large influence on task performance in the context of abstract/metaphorical utterances.

2. Methods

2.1. Participants

Patients met ICD-10 criteria for schizophrenia (F20.x, $n = 45$) and were divided into two subgroups according to their positive FTD symptomatology. The first subgroup consisted of patients showing no or mild positive FTD ($n = 25$), and the other consisted of patients showing severe positive FTD ($n = 20$); a healthy control group ($n = 20$) was also recruited (see Table 1). Symptom severity and positive FTD dichotomy was based on the SAPS positive FTD assessments (Global Rating of

Positive Formal Thought Disorder ≥ 4) (for a similar approach see (Barrera et al., 2005)).

Patients were recruited and interviewed at the Department of Psychiatry and Psychotherapy, Philipps-University Marburg (in- and outpatients) and the PTR Bischoff Clinic, Neukirchen (chronic in- and outpatients). Experienced psychiatrists and clinical psychologists conducted the interviews and determined the ratings directly after the assessments were completed. Participants gave written informed consent and received 30 Euros for their participation in the study. The study was approved by the local Ethics Committee.

2.2. Stimuli

The stimuli consisted of 80 German sentences presented to the participants as short video clips (5 s each) of four different types, defined by combining opposing qualities along two dimensions. The first such opposition, abstract vs. concrete semantic meaning, was explained in the Introduction. The second, related vs. unrelated, refers to a situation in which a co-speech gesture either matches or mismatches the semantic content of the verbal message. Accordingly, the four stimulus types were: 1) Abstract metaphorical co-verbal gesture, related (AR), 2) Abstract metaphorical co-verbal gesture, unrelated (AU), 3) Concrete iconic co-verbal gesture, related (CR) and 4) Concrete iconic co-verbal gesture, unrelated (CU). The grammatical structure (subject-predicate-object) was consistent across stimuli. The sentences and co-speech gestures were presented in a naturalistic way. The male actor neither spoke nor moved for 0.5 s at the beginning and end of each clip.

In order to mitigate possible sequence effects, two different pseudorandomized versions of the stimulus set were created. Each stimulus set consisted of 80 video clips in total (20 abstract metaphorical co-verbal gestures, related; 20 abstract metaphorical co-verbal gestures, unrelated; 20 concrete iconic co-verbal gestures, related; 20 concrete iconic co-verbal gestures, unrelated), with each clip lasting exactly 5 s.

2.3. Behavioral pre-study/rating experiment

Prior to the main study, a preliminary behavioral experiment was conducted. In this pre-study, a separate sample of 20 healthy native German-speaking subjects performed a rating task to evaluate the study materials according to predetermined questions.

First, the semantic relatedness of the audiovisual (verbal and gestural) material was evaluated on a scale from 1 to 7, where 7 referred to a high degree of correspondence; participants were asked “Does the gesture fit the content of the verbal utterance?” Second, participants were asked to rate the abstractness of the message, again on a scale from 1 to 7, following the instruction “Please evaluate the abstractness of the utterance.” Additional information was provided to make sure that participants understood this task clearly. Thus, abstractness was defined as something not perceptible with human senses, including concepts like “truth” or “freedom”, whereas the term *concrete* was defined as referring to touchable, easy-describable physical objects. Third, participants were asked to evaluate the familiarity of the utterance, again on a scale from 1 to 7, by answering the question “How familiar is the utterance to you?”. Participants were instructed to perform their evaluations on each video clip as a whole.

2.3.1. Semantic relatedness

The following statistics apply collectively to all 160 video clips (2 sets, 4 conditions with 20 videos each). Semantic relatedness was rated high in both related conditions, concrete iconic co-verbal gesture, related (mean = 6.08, SD = 0.59) and abstract metaphorical co-verbal gestures, related (mean = 6.01, SD = 0.41), compared to the concrete iconic co-verbal gesture, unrelated (mean = 2.22, SD = 0.73) and abstract metaphorical co-verbal gesture, unrelated (mean = 2.30, SD = 0.78) conditions. The figures for the abstract and concrete related conditions (AR, CR) differed significantly from those of the abstract and concrete mismatch manipulation conditions (AU, CU) ($p < 0.001$). No significant differences were found for the factor of gesture category (abstract (A) vs. concrete (C)) with respect to semantic relatedness ratings ($p = 0.98$) (see Supplemental Material).

2.3.2. Abstractness

With respect to abstractness ratings, concrete (C) stimuli were generally evaluated as more concrete; results were as follows: related concrete iconic co-verbal gestures (CR) (mean = 6.28, SD = 0.28), related abstract metaphorical co-verbal gestures (AR) (mean = 3.15, SD = 0.74), unrelated concrete iconic co-verbal gestures (CU) (mean = 5.96, SD = 0.39) and unrelated abstract metaphorical co-verbal gestures (AU) (mean = 2.80, SD = 0.79). The comparison for the factor of abstractness revealed significant differences between the abstract (A) and concrete (C) gesture categories ($F_{(1,\ 156)} = 1063.77$, $p < 0.001$).

2.3.3. Familiarity

No statistical differences were found with respect to familiarity for the concrete (C) vs. abstract (A) stimuli but a main effect relatedness indicate that related stimuli (R) were evaluated more familiar than unrelated (U) stimuli ($F_{(1,\ 156)} = 2343.977$; $p = 0.013$); results for these were as follows: related concrete iconic co-verbal gestures (CR) (mean = 5.58, SD = 0.65), related abstract metaphorical co-verbal gestures (AR) (mean = 5.43, SD = 0.41), unrelated concrete iconic co-verbal gestures (CR) (mean = 2.42, SD = 0.60), unrelated abstract metaphorical co-verbal gestures (AU) (mean = 2.39, SD = 0.56).

2.4. Experimental design and procedure

Prior to the testing procedure, participants completed four practice trials to ensure that the task was understood properly. Stimuli used for this purpose were not part of the experimental material presented subsequently.

Stimuli were presented at the center of the video screen using Presentation software (Neurobehavioral Systems, Inc.). The 20 videos for each of the four conditions were presented in a pseudorandomized and counterbalanced way across subjects. Subsequent to the presentation of each video, a blank grey screen with a variable duration of 3750–6750 ms (M = 5000 ms) followed.

For each video clip, participants were asked to decide whether the gesture matched the content of the verbal utterance, when taking all presented information into account. Participants were asked to press the left arrow key for ‘yes’ (= match) or the right arrow key for ‘no’ (= mismatch) on a laptop keyboard.

After finishing the experiment, subjects completed the “Brief Assessment of Gesture (BAG)” questionnaire (Nagels et al., 2015) by evaluating statements about gesture-specific issues in everyday situations (e.g., “I like it when people use gestures in order to reinforce what they are saying.”). This subjective rating instrument gives information on individual gesture production and perception, either in a social or in a general communicative situation [for further details on psychometric measures and item construction see (Nagels et al., 2015)].

The proverb interpretation questionnaire is a multiple-choice paper and pencil task, and was conducted immediately after the completion of the BAG questionnaire. On this task, lower scores indicate better performance. The proverb interpretation tool is validated for German and allows for the assessment of different degrees of concretism in psychiatric patient groups [for further information, see (Nagels et al., 2016)].

2.5. Statistical analyses

Statistical analyses were performed using SPSS version 25.0 for Windows (IBM SPSS). Paired Whitney-*U*-tests, *t*-tests, ANOVAs, and correlation analyses were used in these analyses. A Greenhouse–Geisser

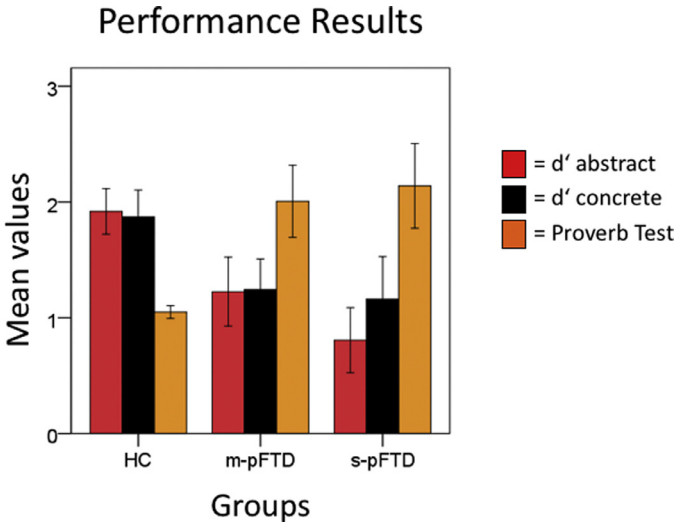

Fig. 1. Groups differences in mismatch detection for abstract (red) and concrete (black) contexts. Proverb interpretation task results are depicted in orange. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

correction was applied when appropriate. In order to identify differences in detection performance of speech-gesture relatedness independent of differences in response biases between the abstract and concrete experimental conditions, both discrimination performance ("*d*-prime," *d'*) and response criterion (*c*) were calculated (*d'* = z (correct related [hit]) - z (incorrect unrelated [false alarm]); c = ½[z (hit) + z (false alarm)]; e.g., Stanislaw and Todorov, 1999). As *d'* was calculated based on related (hits) and unrelated (false alarms) conditions, the factor of relatedness was only considered in the analyses of reaction times, not in the analyses regarding *d'*. Statistical analyses were two-tailed with a level of significance of $p < 0.05$. First, patients were compared to healthy control subjects in *d'* parameters (2 groups × 2 conditions [abstract/concrete]). Next, the patient group was divided into two subgroups, namely 25 patients with mild positive Formal Thought Disorder (m-pFTD) and 20 patients with severe positive Formal Thought Disorder (s-pFTD) (3 groups × 2 conditions for *d'* analyses and 3 × 2 abstractness × 2 relatedness for RT analyses; see Table 1, Fig. 1). To account for group differences in verbal IQ and years of education, we included these measures as covariates of no interest in the analyses of the *d*-prime scores.

3. Results

3.1. Task results

In order to detect general dysfunctions in mismatch detection performance, all patients – independent of positive FTD symptomatology–were compared to healthy controls. In general, groups differed in their detection performance (i.e., *d*-prime scores) in both the concrete and abstract conditions (see Table 2).

3.1.1. Proverb interpretation task

Between-group differences were found with respect to proverb interpretation performance (Mann-Whitney *U* test: $z = 5.59$, $p < 0.001$), as discussed below.

3.1.1.1. Patients with m-pFTD vs. patients with s-pFTD vs. healthy controls. As noted earlier, participants with FTD differed with respect to their positive formal thought disorder (pFTD) symptom severity, and were separated into two subgroups, one with mild positive formal thought disorder (m-pFTD) and the other with severe positive formal thought disorder (s-pFTD). Task performance was compared for these two patient subgroups (see Table 3).

Table 2
D-prime scores.

	HC ($N = 20$)	SZ ($N = 45$)	Independent samples *t*-test: HC, SZ between-group comparisons		Interaction between group (SZ/HC) and stimulus type (IC/MP)	
			t	Sig.	*F*	Sig.
Abstract (MP)	1.92 (0.42)	1.04 (0.70)	−6.28	< 0.001	3.93	0.052
Concrete (IC)	1.87 (0.50)	1.21 (0.70)	−4.364	< 0.001		

Values refer to mean *d*-prime scores; values in parentheses refer to the standard deviation.
HC = healthy controls, SZ = schizophrenia patients, IC = iconic co-verbal gesture, MP = metaphoric co-verbal gesture.

Differences among conditions and groups did not reach significance ($F_{(1, 62)} = 3.41$, $p = 0.07$, repeated measures ANOVA, Bonferroni corr.). However, a significant group by condition interaction was found ($F_{(2, 62)} = 4.28$, $p = 0.018$). Patients with severe positive FTD achieved the lowest *d*-prime scores in the abstract task condition (see Fig. 1). This effect remained stable when controlling for differences in IQ and years of education ($F_{(2, 62)} = 4{,}28$, $p = 0.018$).

3.1.1.2. Reaction times. A trend towards slower reaction times (RTs) in relation to positive FTD symptom severity (i.e., participant group) was found (see Table 4); the slowest reaction times were found in the AU (abstract metaphorical co-verbal gesture, unrelated) condition for the severe positive FTD group. Significant main effects for reaction times (determined through repeated measures ANOVA) were found for the within group comparison of abstract vs. concrete categorization performance ($F_{(1, 62)} = 18.64$, $p < 0.001$) as well as for the related vs. unrelated comparison ($F_{(1, 62)} = 12.69$, $p < 0.001$).

No group interactions for RTs were found for group by abstractness ($F_{(2, 62)} = 0.46$, $p = 0.64$), group by relatedness ($F_{(2, 62)} = 0.63$, $p = 0.91$) or group by abstractness by relatedness ($F_{(2, 62)} = 0.24$, $p = 0.79$).

3.1.1.3. Proverb interpretation test. Proverb interpretation task results revealed significant between-group differences (Kruskal-Wallis Test: $\chi^2_{(2)} = 31.29$, $p < 0.001$) (see Fig. 1). No significant differences were found between the two patient subgroups (Mann–Whitney *U* test: $z = -0.54$, $p = 0.59$). However, both patient subgroups differed significantly from the healthy control group: HC vs. m-FTD (Mann–Whitney *U* test: $z = -5.22$, $p < 0.001$) and HC vs. s-FTD (Mann-Whitney *U* test: $z = -4.63$, $p < 0.001$).

Correlation analyses with *d*-prime (*d'*) scores for the abstract mismatch detection condition and mean scores from the proverb metaphor test revealed differential group effects. For the healthy control group (HC) we found no significant correlation ($r = 0.1$, $p = 0.68$, Pearson), in contrast with the two patient subgroups. For the mild positive FTD subgroup, correlation showed a non-significant negative trend ($r = -0.22$, $p = 0.30$), and for the severe positive FTD subgroup, correlation was negative ($r = -0.59$, $p = 0.006$) (see Fig. 2). There was no significant difference between correlations ($z = 1.406$, $p = 0.160$).

3.2. Brief Assessment of Gesture (BAG) scores

No between-group differences in the evaluation of gesture behavior were found for the four BAG gesture dimensions (I. Perception: $F_{(2, 62)} = 0.42$, $p = 0.66$; II. Production: $F_{(2, 62)} = 0.65$, $p = 0.53$; III. Social Production: $F_{(2, 62)} = 0.49$, $p = 0.61$; Social Perception: $F_{(2, 62)} = 0.07$, $p = 0.93$) (see Table 1).

Correlation analysis (Spearman's rho) between BAG scores and

Table 3
D-prime scores.

	HC (N = 20)	m-Pftd (N = 25)	s-pFTD (N = 20)	Between- group comparisons (ANOVA: HC, m-pFTD, s-pFTD)		Independent samples t-test: m-pFTD, s-pFTD		Interaction* between group (HC, m-pFTD, s-pFTD) and stimulus type (IC/MP)	
				F	Sig.	t	Sig.	F	Sig.
Abstract	1.92 (0.42)	1.23 (0.72)	0.81 (0.60)	17.27	< 0.001	2.08	0.044	4.538	0.015
Concrete	1.87 (0.50)	1.24 (0.64)	1.16 (1.16)	7.33	0.001	0.39	0.700		

Values refer to mean *d*-prime scores; values in parentheses refer to the standard deviation. *Within subject ANOVA for between group differences were corrected for individual differences in age and years of education.
HC = healthy controls, m-pFTD = mild positive formal thought disorder, s-pFTD = severe positive formal thought disorder, IC = iconic co-verbal gesture, MP = metaphoric co-verbal gesture.

behavioral measures revealed a trend for the mild positive FTD patient subgroup between task performance in the abstract unrelated condition and BAG scores for the Social Production dimension ($r = -0.31$, $p = 0.13$). Neither trends (Spearman's rho $> +/-0.3$) nor significant relationships between BAG scores and behavioral measures were found with respect to the severe positive (s-pFTD) subgroup. However, a positive trend was found in the s-pFTD subgroup for the correlation between the BAG Production dimension and proverb task results ($r = 0.42$, $p = 0.07$).

4. Discussion

This study sought to determine differences in detection performance of speech-gesture relatedness between patients with schizophrenia and healthy controls in both concrete and abstract semantic contexts. Based on previous research, we expected a general impairment in mismatch detection, which should be particularly pronounced in the abstract context. In order to investigate whether concretistic thought is associated with impaired mismatch detection performance, a proverb interpretation test was also administered. In addition, it was hypothesized that patients with severe (vs. mild) positive formal thought disorders (pFTD) would show greater aberrations when abstract content was presented.

As expected, patients showed deficits in gesture-speech mismatch detection, relative to healthy controls. Interestingly, differences were found even in the concrete iconic domain (e.g., noticing a mismatch when “The ball is round” is spoken by someone performing arbitrary movements with his hands). This dysfunction in mismatch detection supports the hypothesis that patients with schizophrenia are impaired in gesture comprehension and global semantic processing, not only encompassing spoken or written language. In line with previous studies focusing on single word pairs (Jamadar et al., 2013), lexical decisions (Laurent et al., 2010) or priming effects (Kiefer et al., 2009) [for a review, see (Pomarol-Clotet et al., 2008)], our results support the conjecture that aberrations occur on a higher-order or superordinate semantic level. Thus, impairments are not only restricted to spoken or written language, but also in a pragmatically rich multi-modal context.

In addition, concretistic thought was associated with reduced mismatch detection performance in FTD patients, particularly in those with severe positive FTD symptoms. As expected, positive FTD or ‘disorganized symptoms’ (Liddle et al., 2002) were found to be related to task performance deficits, in particular with regard to the semantically abstract gesture-speech mismatch conditions. Here, patients with severe positive FTD (s-pFTD) performed poorly compared to the other patient subgroup as well as healthy controls. Interestingly, no difference was found for discrimination performance in the abstract vs. concrete domain for patients with mild positive FTD. Only the s-pFTD subgroup displayed a specific impairment at the abstract semantic level. This specific effect was further highlighted by the relationship between speech-gesture detection performance for abstract utterances and the results of the proverb interpretation questionnaire. The results of the proverb interpretation task point to a global deficit at the abstract (metaphorical) processing level across both patient subgroups, as no differences in performance were found in the between-group comparison.

Thus, group differences in the speech-gesture mismatch task cannot be solely explained by dysfunctions at the level of “language semantics.” While abstract semantic processing was found to be impaired in FTD patients, concretism was particularly notable in the unrelated abstract metaphorical co-verbal gesture condition (AU), i.e., when semantically abstract speech was accompanied by mismatching gesture information. However, the correlation analysis with speech-gesture detection performance and concretism scores from the proverb interpretation task revealed a significant relationship only for the severe positive FTD patient subgroup, though a similar trend was also found in the mild positive FTD subgroup.

Table 4
Reaction times.

	HC (N = 20)	m-pFTD (N = 25)	s-pFTD (N = 20)	Between-group comparisons (ANOVA: HC, m-pFTD, s-pFTD) F	Sig.	Independent samples t-test: m-pFTD, s-pFTD t	p-value	Interaction between group (HC, m-pFTD, s-pFTD), abstractness (IC/MP) and relatedness (R/U) F	p-value
AR	6.01 (0.29)	6.10 (0.50)	6.20 (0.75)	0.62	0.54	−0.52	0.60	0.22	0.81
AU	6.11 (0.28)	6.19 (0.48)	6.22 (0.74)	0.24	0.79	−0.19	0.85		
CR	5.97 (0.25)	6.01 (0.48)	6.10 (0.79)	0.30	0.75	−0.47	0.64		
CU	6.05 (0.28)	6.11 (0.50)	6.16 (0.78)	0.21	0.82	−0.40	0.79		

Values refer to mean reaction times in sec.; values in parentheses refer to the standard deviation.
HC = healthy controls, m-pFTD = mild positive formal thought disorder, s-pFTD = severe positive formal thought disorder, IC = iconic co-verbal gesture, MP = metaphoric co-verbal gesture, R = related, U = unrelated.

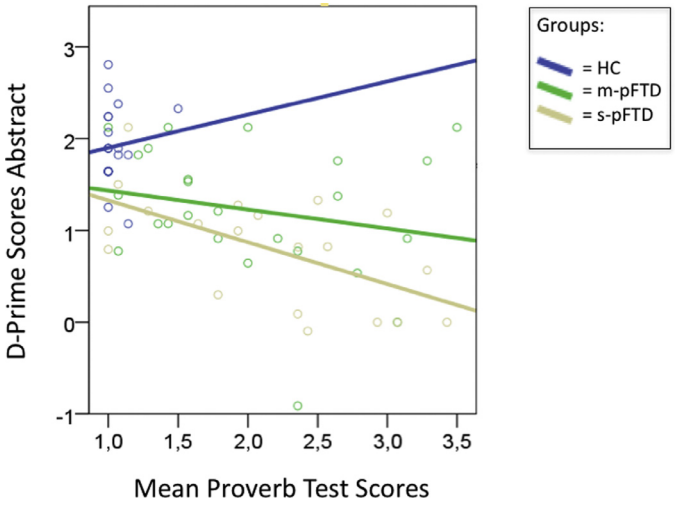

Fig. 2. Correlations between d-prime scores for the evaluation of speech-gesture matching (y-axis) and mean scores for the proverb interpretation task (x-axis). HC = Healthy Controls, m-pFTD = mild positive Formal Thought Disorder, s-pFTD = severe positive Formal Thought Disorder.

This result may be due to influences from the following limitations of the proverb task. First, the task contained only speech-related metaphorical expressions, lacking a supporting context or other pragmatic information. Second, only pre-formulated answers were presented, none of which involved mismatching information; instead, answers varied only with respect to their degrees of concretism. Third, proverbs and little-known sayings were used, instead of well-known everyday expressions like those used in the gesture mismatch detection paradigm.

Previous studies have found that semantic information processing at the linguistic level is particularly disturbed in positive FTD patients (Liddle et al., 2002; McGuire et al., 1998). A number of investigations point to a global impairment in the semantic domain or at higher linguistic levels (Ketteler et al., 2012). The failure on the part of the severe positive FTD patient subgroup to correctly identify the (non-) correspondence of abstract speech-gesture information points to a more general deficit in 'higher order' semantic processing (Barrera et al., 2005; Dwyer et al., 2014). These aberrations in FTD patients were associated with general integration impairments at the lexico-semantic level, when stimuli were embedded into specific contexts (Dwyer et al., 2014).

In line with our results, it can be argued that FTD symptomatology directly affected task performance in a contextually rich, multi-modal environment. An alternative explanation relates to the previously discussed dysfunction in the suppression of irrelevant information, particularly in FTD patients (Arcuri et al., 2012). Specifically, patients might not have been able to distinguish relevant from irrelevant information in our videos. This possibility is further supported by patient imaging results which point to a deficit in the activation of frontotemporal neural networks (Arcuri et al., 2012). A comparison between FTD patients and non-FTD patients using a masked priming paradigm revealed increased priming in the FTD group (Kiefer et al., 2009). This effect was explained by an increase of spreading semantic activation leading to the co-activation of related (though contextually irrelevant) semantic information. Kiefer and colleagues further argue that this phenomenon may interfere with goal-directed thinking.

There is also a long-standing debate on whether impairments in semantic access or storage of information lead to the well-known speech and language dysfunctions in schizophrenia (Rossell and David, 2006). In addition, the vast majority of previous studies have not distinguished between the different dimensions of FTD (positive vs. negative) symptomatology, which makes it difficult to ascribe semantic processing deficits to specific FTD phenomena. Further investigations are necessary to disentangle the complex interplay between FTD phenomenology and "supramodal semantic information integration" (Straube et al., 2013b) deficits.

4.1. Limitations

With this study, we are unable to disentangle dysfunctions related to speech from those related to gesture processing, since we focused on perception in a multimodal speech-gesture context. This novel speech-gesture detection task has the advantage that both information sources have to be taken into account to successfully perform the task. The paradigm also allows for the manipulation of speech-gesture relatedness and semantic abstractness. Unimodal speech or gesture trials, however, cannot be implemented within this experimental approach.

Results of the proverb language task suggest that the present findings cannot be explained by language dysfunctions alone. Furthermore, previous findings indicate that in general, patients with schizophrenia have no problems interpreting the speech of abstract sentences *per se*. Future studies might benefit by combining the speech-gesture matching paradigm with unimodal speech and gesture comprehension tasks to disentangle speech- and gesture-related dysfunctions in patients with schizophrenia.

Another potentially important factor is the possible influence of medication on task results, which cannot be ruled out. However, while this confounding factor could possibly have affected reaction times, it is unlikely to have influenced the actual decisions participants made when performing the mismatch tasks.

Our data suggest a general dysfunction in speech-gesture matching performance in patients with schizophrenia and a specific impairment in patients with severe FTD when asked to specify the semantic relationship of speech and gesture in abstract informational contexts. Dysfunctions in gesture processing in an abstract sentence context have been related to differential activation patterns in the left frontal cortex (Straube et al., 2013a, 2014). In a recent study, it was shown that anodal transcranial direct current stimulation (tDCS) of the left frontal cortex led to a behavioral advantage (decreases in reaction times and

relatedness ratings) in healthy subjects (Schulke and Straube, 2017). Furthermore, tDCS has been successfully applied to improve speech-gesture relatedness evaluations in patients with schizophrenia spectrums disorder. Therefore, further studies should probe the therapeutic potential of tDCS for reducing gesture processing deficits in patients with schizophrenia and severe FTD.

In contrast to the specific speech-gesture matching impairment in patients with severe FTD, all patients in this study demonstrated reduced performance in the proverb task relative to healthy control subjects. Thus, despite the significant correlation of proverb performance and speech-gesture matching performance, these data indicate that aberrations at the language level alone cannot explain group differences in speech-gesture matching performance. Thus, the results presented here suggest deficits in patients with severe FTD at a (superordinate) co-speech gesture level, with a specific influence of abstractness in a pragmatically rich multi-modal context.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.psychres.2018.12.107.

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