Sleeping Stones and Other Implausible Agents: Agency of Subjects and Eye Movements in Schizophrenia Spectrum Disorders

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This study aimed at testing the presence of a disrupted lexical representation of verbs thematic grid in people with Schizophrenia Spectrum Disorders (SSD).

A silent-reading task was administered to 32 people with SSD and 32 matched healthy participants (HP). Stimuli were sentences including or not a semantic violation of the animacy trait of the subject. Data on Gaze Duration (GD), Total Fixation Duration (TFD) on verbs, and probability of go-back movements from the verb were recorded.

When the anomalous grammatical subject was the Agent of the event, we found a significant increase of GD in HCs, but not in SSDs. In addition, when the anomalous subject was a Theme, SSDs displayed an increased probability of regressions, unlike HCs.

These results are suggestive of a higher tolerability for anomalous Agents in SSD compared to the normal population, possibly derived from a disrupted lexical representation of the verb thematic grid.

Keywords: Schizophrenia Spectrum Disorders, eye movements, verb thematic roles, language

1. Introduction

Language anomalies are pervasive among people with Schizophrenia Spectrum Disorders (SSD) (DeLisi, 2001), and abnormal verbal communication is one of the core diagnostic features of schizophrenia as indicated both by the DSM-5 (APA, 2013) and the ICD-10 (1992). In the past decades, evidence has been cumulating towards a scenario in which all levels of language are impaired in SSD (Bellani et al., 2009), from phonetics (Stein, 1993) to pragmatics (Covington et al., 2005). To explain the anomalous language performance in SSD, a fundamental disorder of the semantic system has been hypothesized (Goldberg et al., 1998; Paulsen et al., 1996; Rossell & David, 2006).

Previous studies have indeed reported an underperforming word retrieval (Covington et al., 2005) as well as defective processing of words coming from high lexical competitor environments (high density and high-frequency lexical neighbourhoods) (Titone & Levy, 2004) among people with schizophrenia. Studies on verb naming seem to converge towards a significant impairment of action fluency in this clinical population (Badcock et al., 2011; Kambanaros et al., 2010; Marvel et al., 2004; Smirnova et al., 2017; Woods et al., 2007), with a specific difficulty in the attribution of “agency”, occurring within the cortical network responsible for the representation of actions (Jeannerod, 2009).

However, when considered in the context of a sentence, verb processing entails both semantic and syntactic processing, and previous research in this clinical population identified a relative insensitivity to linguistic violations requiring the contribution of both syntax and semantics (Kuperberg et al., 1998). When listening to oral sentences that were rendered anomalous by pragmatic, semantic or syntactic violations, results indicated that healthy controls and schizophrenic patients without thought disorder took longer to recognize target words (in this case, the direct object of the verb) preceded by linguistic anomalies, compared with words in normal sentences. On the contrary, thought-disordered patients showed

significantly smaller differences in reaction times, suggestive of relative insensitivity to linguistic violations. Thought disorder in schizophrenia has been also linked to suboptimal use of linguistic context to process and produce speech. In a self-paced reading task (Kuperberg et al., 2006a), people with schizophrenia showed shorter reaction times than controls to sentence-final words when the Agent subject of the sentence was replaced with an inanimate noun, making the sentence implausible (e.g. “*For breakfast the *^leggs would only eat toast and jam*”), as well as in case of morpho-syntactically violated sentences (e.g. “*For breakfast the boys would only *eats toast and jam*”). Such relative insensitivity to these violations was interpreted as suggestive of a specific difficulty, in schizophrenic patients, in combining semantic and syntactic information to build the linguistic context necessary to interpret the sentence. Electrophysiological shreds of evidence (Kuperberg et al., 2010) further suggest that, when studying the processes underlying the building up of sentence and discourse structure, it is not possible to separate, on the one hand, the structure and function of semantic memory and, on the other hand, the ability to combine and integrate words. Rather, language impairment in schizophrenia would result from a dysfunctional interaction between these systems to build up to higher-order meanings.

It must be noted, however, that the differential impact of different thematic roles in the preverbal subject position has not been tested in any of these studies. The understanding of “*who is doing what to whom*” in an action event is called “Thematic Role knowledge” (Wu et al., 2007), and the function that each participant plays in the action described by the verb is stored in the so-called “Thematic Grid” of the verb (Grimshaw, 1990). In the event, the participant who causes something to happen is generally understood to occupy the thematic role of “Agent”, while the “Theme” is the entity passively involved in the event expressed in the predicate. To our knowledge, no studies have considered whether, and how, the so-called

¹ Following the standard linguistic usage, an * indicates an anomalous syntactic sentence or a lexical mistake.

“disorder of the self”, whose presence has been theorized in SSD population (Sass & Parnas, 2003), might come into play in this context, considering that the notion of “agency” is usually conveyed by the thematic role of “Agent” stored in the lexical representation (the thematic grid) of the verb. According to the Self-Disorder theory, the basic experience of being a self appears to be unstable in schizophrenia, resulting in a markedly diminished sense of “mine-ness” of one’s thoughts, body, as well as actions (Henriksen & Noordgard, 2014). Studies investigating the association between Self Disorder and neurocognitive dysfunction in SSD population found that high levels of Self Disorder were associated with verbal memory impairments, but not with other neurocognitive functions (Haug et al., 2012). Thus, the ability to process incoming verbal information and organize it efficiently concerning pre-existing self-knowledge appears to be suboptimal in SSD population, possibly hindering the ability to comprehend, direct, remember and reason about one’s thoughts and self-knowledge, which are functions known to be related to several aspects of Self Disorder. Abnormalities in agency inference have been observed in SSD patients (Prikket et al., 2018) and research on misattribution of agency in schizophrenia yielded to identify an imprecise internal prediction about sensory consequences of one’s action in this population (Synofzik et al., 2010).

A complex scenario emerges, in which psychopathology and syntactic-semantic processing seem to intertwine for language processing in people with SSD. Eye-tracking techniques can provide the opportunity to collect quantitative measures that are thought to mirror moment-to-moment cognitive processes demands (Rayner, 1998) during text comprehension, providing information on the temporal order of such processes. The assumption behind eye-tracking techniques is that changes in the pattern of fixations, such as, for example, increased processing time or larger number of regressing movements, are associated with the portion of text requiring higher processing demands, as in the case of semantic incongruency. It has been demonstrated that readers tend to fixate longer those

regions of the text that are the locus of inconsistency, and that, in these cases, the probability of making a regressive eye movement increases as well (Rayner et al., 2006). Early studies on eye-movement during verb processing showed that, instead of immediately adopting a meaning based on context and frequency information, people tend to delay the interpretation of verbs and resolve them considering subsequent as well as preceding context (Pickering & Frisson, 2001).

A better characterization of the cognitive processes underlying Thematic Role comprehension might shed some light on the link between Self Disorder and language in this clinical population. The present study aimed to assess eye-movement patterns in people with SSD when reading sentences with semantic violations affecting the “animacy” trait of different thematic roles (i.e., Agent vs Theme). Given the presence of Self Disorder (Henriksen & Noordgard, 2014) and based on previous results pointing to a specific tolerance to semantic violations involving verb processing (Kuperberg et al., 2006a), we expected people with SSD to show increased tolerance to semantic violations affecting the animacy trait of the Agent. This tolerance would be visible in eye-tracking indexes of access to the lexical properties of the verb (Bock & Levelt, 1994).

2. Material and Methods

2.1. Participants

Thirty-seven participants with a diagnosis of SSD according to DSM 5 were recruited at the IRCCS Istituto Centro San Giovanni di Dio Fatebenefratelli, Brescia, Italy, between February 2018 and April 2019. Diagnoses were made by the treating clinician (staff psychiatrist). Participants were aged 18-65, able to give informed consent, right-handed, and had normal or corrected-to-normal visual acuity. The diagnosis on Axis I had to be unique, but co-morbidities on Axis II were admitted. Exclusion criteria were: neurological disorders, head

trauma with cognitive sequelae, mental retardation, substance abuse in the 3 months preceding the enrolment. Seven participants were excluded, leaving a final sample of thirty participants (20 men and 10 women). Reasons for exclusion were: unexpected technical (software) issues preventing the acquisition of eye-movement data ($N = 2$), refusal to undergo the eye-tracking experiment ($N = 2$), severe nystagmus ($N = 1$), poor quality of reading glasses ($N = 2$). At recruitment, patients had been on treatment with at least one antipsychotic medication for at least the previous six months. Mean illness duration for the SSD group was 22.6 years ($SD = 11.6$). For one SSD participant, it was not possible to date the age of onset.

Thirty-two control participants, matched by age-class (18-30, 31-40, 41-50, and 51-65), gender, and education, were recruited among the hospital staff and through public announcements in the Brescia area. Two participants were excluded from the analysis (refusal to complete data acquisition), leaving a final paired sample of thirty Healthy Controls (HC). The exclusion criteria for the control group were the same as those for the groups of participants with SSD, plus any documented psychiatric disorders or being first-degree relative of a patient with a diagnosis of SSD.

All participants were native speakers of Italian. Socio-demographic and clinical data of the study sample are reported in Table 1.

After having presented the study, informed consent to participation was obtained from all participants. For patients with a legal representative, participation in the study was first discussed with the patient; then, written consent was obtained both from the patient and the legal representative. The study was approved by the IRCCS Ethical Committee (Opinion 61/2017) and followed the principles of the Helsinki Declaration.

[Table 1 about here]

2.2. Stimuli

A set of 112 sentences was created. In half ($N = 56$) of the stimuli, the grammatical subject was a Proto-Agent argument (“Agent” from now on) and in the other half ($N = 56$) a Proto-Patient, i.e., the Theme grammatical subject of an unaccusative verb (“Theme” from now on). Half of the sentences ($N = 56$) were semantically acceptable, and the other half ($N = 56$) not acceptable, whereby the semantic anomaly was an incongruent animacy feature of the grammatical subject (Table 2 reports examples of the stimuli). Semantic violations always affected the grammatical subject in the pre-verbal position to avoid a possible confounding effect related to word position within the sentence². The same experimental list was administered to all participants, with sentences appearing in random order. Items had been validated through a rating study: twenty healthy participants were asked to rate each sentence on a 5-point scale, where 1 indicated a “totally unacceptable” and 5 a “totally acceptable” sentence. Sentences that were rated differently from the expected categorization were replaced. The complete set of stimuli is provided in the Supplementary Materials.

[Table 2 about here]

Given that frequent words are processed faster than less frequent words (Brysbaert et al., 2011), and that long words slow down reading times (Rayner et al., 2011), frequency and length of target words (verbs) were matched across conditions. Length of target verbs in the correct condition ($M = 7.50$, $SD = 1.93$) was not statistically different from length of the target verbs in the condition with violations ($M = 7.48$, $SD = 1.96$), as tested through a t-test ($p = 0.96$). Frequencies of target words were taken from Subtlex-IT (available at <http://crr.ugent.be/subtlex-it/>), an annotated corpus of around 130 million words of the Italian language based on movie subtitles, with a frequency range from .01 – 17,854 tokens per

² The expected position of the animated Agent in canonical *transitive* sentences is the first one (Paczynski & Kuperberg, 2011), while post-verbal slots are generally reserved to other arguments. In sentences with *unaccusative* verbs, word order is the result of a syntactic movement that takes the direct post-verbal object and moves it to the position of the pre-verbal grammatical subject (Burzio, 1986; Perlmutter, 1978). A relevant feature of unaccusative verbs relies on their semantic underpinnings, in the sense that unaccusative verbs require a non-agentive argument (Dowty, 1991; Van Valin, 1997).

million. Frequency of target verbs (transformed by taking the base 10 logarithm of the absolute frequency plus one, following Brysbaert et al., 2011) in the correct condition ($M = 4.48$, $SD = 5.10$) was nearly identical to that of target words in the condition with violations ($M = 4.48$, $SD = 5.10$). Frequencies of words were log-transformed and differences between conditions (correct vs with violation) were tested with a χ^2 test. The result was not significant ($p = 0.25$), indicating that the frequency of verbs was matched across conditions (Table 3).

[Table 3 about here]

Twenty-four sentences containing morphological violations were included as fillers and randomly presented to participants along with target sentences. The subset of morphologically violated sentences was structured as follows: eight sentences contained a violation on the subject-verb number agreement (i.e., singular subject with a plural verb, and vice-versa; e.g. “**Nel bosco le volpi scappa dal cacciatore*”/ “*In the woods the foxes runs away from the hunter”), eight sentences contained a violation on the determiner-noun agreement (e.g. “**Nel mare le pesci nuotano liberi*”/ “*In the sea the_{FemPlu} fishes_{MasPlu} swim free”), and eight sentences contained a violation of the agreement between clitic and its NP-antecedent (e.g. “**Il cane insegue il gatto e la rincorre fin sotto il tavolo*”/ “*The dog chases the cat_{MasSin} and runs after her_{FemSin} under the table”). The complete set of items is provided in the Supplementary Materials.

2.3. Eye-Tracking Procedure

An Eye-link 1000 Plus® was employed to collect data on eye-movement (1,000Hz with a single 35mm lens), calibrated using a three-point grid before each acquisition. All participants used chin-rest support to stabilize head position. Experimental stimuli were presented on a Display PC. Sentence presentation was preceded by a fixation point and triggered manually by the experimenter. Sentences were presented in white Courier New font, against a black background. Participants were asked to silently read each sentence and then evaluate their

acceptability by pressing either a green (acceptable) or red (not acceptable) key on the keyboard. Each sentence remained on the screen until one of the keys was pressed.

2.4. Data Analysis

We adopted three indexes of reading process as dependent variables: Gaze Duration (GD), probability of regression (go-back movements), and Total Fixation Duration (TFD)³. GD is defined as the sum of all fixations made on the target word before the eyes leave the region. This metrics is considered a measure of lexical access (Rayner et al., 2011), which, in the case of verbs, includes processing of the argument structure (Bock & Levelt, 1994). Probability of regression is, in our study, the probability to register a go-back movement starting from the verb and moving back towards the subject. Regression movements are associated with integration difficulties (Reichle et al., 1998), in our case, between the verb and its pre-verbal grammatical subject. TFD is the cumulative duration in milliseconds of all fixations on the target word, including any regression; this measure is generally considered to provide insight into any possible processing difficulties associated with the integration of the word meaning within the sentence (Rayner et al., 2006).

Differences in probability of regression in the two groups were tested with a 2-sample test for equality of proportions with continuity correction. Separate statistical models were run on each index of reading process as dependent variable, with (thematic) *Role*, *Condition*, and *Group* as categorical independent variables. Data on fixations (GD and TFD) were logarithmically transformed to reduce the skewness of distribution, thus obtaining a Gaussian-like distribution (Baayen, 2008). As each independent variable had two levels (Agent vs Theme, Correct vs With Violation, and Participants with SSD vs HCs, respectively), our study had a mixed 2x2x2 factorial design. Linear mixed-effects regression analyses (Baayen et al., 2008) and generalized linear mixed-effects models (Baayen et al., 2008) were conducted.

³ First Fixation Duration (FFD) and accuracy of responses were also collected. Analyses for these variables are reported in the Supplementary Materials.

Two-way and three-way interactions were included in the model. Random intercepts for items and participants were also included. All models were refitted after having identified and excluded atypical outliers using a 2.5 SD criterion over the model standardized residuals (model criticism: Baayen et al., 2008). Statistics of the refitted models are reported. Logistic mixed-effects regression analyses (Jaeger, 2008) were run on regression data, with participants and items as crossed random effects (Baayen et al., 2008). Pairwise post-hoc comparisons using R's multcomp package (Simultaneous Test for General Linear Hypothesis – glht) were run in case of significant three- or two-way interactions (Howell & Lacroix, 2012). Alpha level was set at .05. All the analyses were performed in R, v.3.6 (R CoreTeam, 2019).

3. Results

Data of interests were fixation duration on verbs (i.e. GD and TFD) and backwards eye-movement from the verb toward the grammatical subject (i.e., the probability of re-fixating the grammatical subject after having read the verb). The total number of valid data-points was 6,105 out of 6,480 (94.21%), equally distributed between groups (HC = 3,092; SSD = 3,013). Similarly, data were equally distributed across conditions in both groups (around one-fourth of the total number of valid fixations for each condition and each group). Table 4 summarizes the mean duration (in milliseconds) and standard error of the mean GD and TFD on target verbs, as well as probability of regression from target verbs, per conditions and in the two groups.

[Table 4 about here]

3.1. Gaze Duration

To explore whether the effects of *Role* (Agent or Theme) and *Condition* (congruent or incongruent animacy trait of the subject) interacted differently in GDs in the two *Groups*

(Participants with SSD and HC), we explored the results of a mixed-effect model, having GD as continuous dependent variable and the predictors of interest as categorical independent variables. Table 5 shows the estimated fixed and random parameters of the model, together with significance tests.

[Table 5 about here]

A significant three-level interaction ($t = 2.58$, $p = .010$) on GD indicates that the effects of *Condition* and *Role* interacted differently in the two experimental groups at this stage of the sentence processing. Results (Figure 1) show an opposite pattern in the two groups when reading verbs carrying a semantic violation of the Agent subject (e.g., “**Ogni sera il sonno telefona al nipotino*”/“*Every evening the sleep calls its nephew”) *vis-à-vis* verbs carrying a semantic violation of the Theme subject (e.g., “**A volte il sole cade dalle scale*”/“*Sometimes the sun falls from the stairs”).

[Figure 1 about here]

Post-hoc comparisons showed that HCs display significantly longer GDs when reading verbs that carry a semantic violation on their Agent subjects, *vis-à-vis* control sentences ($z = -7.16$, $p < .001$). However, HCs did not show such lengthening when reading verbs with a violation in which the incongruent subject was a Theme, *vis-à-vis* control sentences ($z = -2.54$, $p = .11$). In other words, the HC group was more sensitive to semantic violations when the affected subject was an Agent, compared to violations on the verb Theme.

On the contrary, GD in participants with SSD was significantly longer in case of verbs carrying a violation of the Theme subject *vis-à-vis* control sentences ($z = -3.306$, $p = .012$) and, conversely, GD in this group was not significantly longer when reading verbs carrying a violation of the Agent subject, *vis-à-vis* control sentences ($p = .07$). This finding suggests a different saliency of semantic violations for the two thematic roles in the two experimental

groups, and particularly that verbs carrying an animacy violation on the Agent grammatical subject are better tolerated in the SSD population.

3.2. *Probability of Regressions*

Probability of regression was rather high in both groups (>70%), with SSDs participants showing an overall higher ($M = 81.45\%$) probability than HCs ($M = 73.06\%$; $p < .001$) of regression from the verb in all conditions. We thus further explored the effects of *Condition* and *Role* in the two experimental groups on the probability to re-fix the grammatical subject after having read the target verb.

[Figure 2 about here]

A logistic mixed-effect model having the probability of regression as dependent variable (yes-no) and *Condition*, *Role*, and *Group* as predictors was run. Table 7 shows the estimated fixed and random parameters of the model, together with significance tests.

[Table 6 about here]

A significant three-level interaction ($z = 2.13$, $p = .033$) between the fixed effects of *Condition*, *Role*, and *Group* was found meaning that, similarly to what observed for GD, the effect of the independent variables *Role* and *Condition* acted differently on the probability of regression for the two experimental groups.

Post-hoc analyses indicated that the interaction between *Condition* and *Role* did not affect the probability of regression in HC. This group did not show a higher probability of re-reading the pre-verbal subject in sentences with a semantic violation than in control sentences, neither in the case of Agent subjects ($z = -2.38$, $p = .19$) nor in the case of Theme subjects ($z = 0.16$, $p = .99$). In other words, a violation did not affect the probability of re-reading the pre-verbal grammatical subject in HC, irrespective of its Thematic Role.

In the SSD group, the interaction between *Condition* and *Role* did not affect the probability of moving back from the verb to the subject in sentences with an Agent subject (z

= -2.79, $p = 0.07$). However, it significantly affected the probability of regression movements in sentences with a Theme subject ($z = -4.57$, $p < .001$). This means that a semantic violation on the Theme pre-verbal grammatical subject was salient for this group, as it significantly increased the probability of a regression movement, unlike what observed for a violation of the Agent. Again, this result speaks for a lack of sensitivity, at the local level, to violations on the Agent in the SSD group, as observed for GD.

3.3. *Total Fixation Duration*

To explore the cognitive mechanisms underlying later stage of sentence processing, we entered our variables of interests (*Condition*, *Role*, and *Group*) as categorical predictors in a mixed-effect model having TFD as continuous dependent variable. Table 6 shows the estimated fixed and random parameters of the model, together with significance tests.

[Table 7 about here]

No three-level interaction between the three fixed predictors was found, indicating that the effects of *Condition* and *Role* did not interact differently in the two groups on measures of later-stage processes. A two-level interaction between *Condition* and *Group* was found ($t = 3.22$, $p < .001$), indicating that the presence of a semantic anomaly on the subject (irrespective of its thematic role) might exert a different effect in the two groups (Figure 3). Post-hoc analyses (Figure 4) indicated that the interaction between *Condition* and *Group* significantly affected TFD both in HCs and in SSDs participants ($z = -3.43$, $p < .001$ and $z = -11.33$, $p < .001$, respectively). Estimated marginal means by Group showed an average increase in reading times for HCs (-.06 ms) and SSDs participants (-.21 ms). In other words, a semantic anomaly on the verb thematic grid determined an increased length of TFD, with participants with SSD showing a greater effect than HCs.

[Figure 3 about here]

[Figure 4 about here]

4. Discussion

The present study aimed to investigate the integrity of the cognitive representation of the thematic grids of verbs in people with SSD. Based on studies that identified an impaired verbal (action) fluency (Badcock et al., 2011; Kambanaros et al., 2010; Marvel et al., 2004; Smirnova et al., 2017; Woods et al., 2007) and an impaired sense of Self (Haug et al., 2012; Henriksen & Noordgard, 2014; Postmes et al., 2014; Nordgaard et al., 2018) possibly related with the linguistic knowledge of the “Agent” thematic role, we expected higher tolerability to a semantic violation on the Agent in people with SSD than in the healthy population. More specifically, we expected people with SSD to display no cognitive difficulty when processing sentences with animacy violations on the Agent subject, indicating the lack of an (implicit) anomaly detection process, along with the suboptimal integration abilities already observed in this clinical population (Kuperberg et al., 2006a).

To do so, we recruited a cohort of participants with and without SSD, matched for age, gender and education, and we collected eye-movement measures during a silent reading task. In half of the stimuli, grammatical subjects (either an Agent or a Theme) carried a violation of the animacy aspect, creating an unacceptable Thematic Grid for the sentence verb (e.g., “*Ogni sera il sonno telefona al nipotino”/ “**Every night the sleep calls its nephew*” - in this specific example, the thematic grid of the verb “telefonare”/ “*to call*” requires an animate Agent). A “lexicalist” approach to language processing, posing that the verb thematic grid is part of its lemma representation (Bock & Levelt, 1994), would predict an effect on the implicit measures of lexical access to the predicate components, i.e., gaze duration on the target verb. Moreover, based on previous evidence of syntactic-semantic integration anomalies (Kuperberg et al., 2006a) pointing to a suboptimal use of linguistic context to

process and produce speech, additional general-level effects could be expected in both measures of local and sentence integration, i.e., regression movements and TFD, respectively.

As for the GD measure, our results indicate that the effects of our variables of interests, *Condition* and *Role*, interacted differently in the two groups. Sentences carrying a violation of the animacy feature of the Agent appeared to be more tolerated by people with SSD than by HPs, insomuch as this combination of variables did not affect GDs on the target verb: in other words, people with SSDs did not increase the processing time for the verb, visually processing the anomalous stimulus as if it was correct. We interpret these results as an indication of a disrupted lexical representation of the verb thematic grid in the SSD population, which seem to hinder the ability of people with SSD to evaluate the appropriateness of the Agent animacy features. These results further support and extend studies on SSD that employed word-monitoring tasks (Kuperberg et al., 1998), which highlighted an insensitivity to linguistic violations by schizophrenic participants, as well as analyses on electrophysiological responses (Kuperberg et al., 2006b) on critical verbs, suggestive of abnormalities in combining semantic and syntactic information online to build up propositional meaning. The present results provide further evidence in this respect, showing the impact of different thematic roles. According to Levelt's theory of lexical access (Bock & Levelt, 1994; Levelt et al., 1999), a speaker selects a lemma (i.e., the cognitive representation of a word) from the mental lexicon and, in doing so, the active lexical concept spreads some of its activation to "its" lemma node: in the case of verbs, these are specified by the verb argument structure and its thematic grid. Upon the selection of a lemma, its syntax becomes available to create the appropriate syntactic environment for further grammatical encoding. We suggest that in people with SSD this top-down linguistic processing could be linked to the disrupted sense of agency observed in this clinical population. Albeit a univocal characterization of the Agent thematic role of a verb cannot be given, the group of HCs

appear to share an overall agreement that certain subjects (animate nouns) are likely to “act”, while others (inanimate nouns) are not. In other words, linguistically speaking, the Thematic Grid Knowledge appears coherently shared in HCs and, as a result, the conceptual representation of agency is consistently translated into lexicalized items. Such shared representations in the lexical store are then used to process the subject-verb relationship during reading. On the contrary, in people with SSD such knowledge appears to be impaired, allowing for anomalous subjects to fill the role of Agent. We suggest that the disrupted representation of agency as observed in SSD might be implied in the integration processes between subjects and verbs. Although our results cannot allow any conclusions on the directionality of this effect, a primary linguistic misrepresentation of the thematic grid knowledge may affect the ability to properly attribute agency (Crow, 2008; Hinzen & Rossello, 2015). However, the reverse direction of the effect is also possible and indeed further sustained by neurological evidence (Lindner et al., 2005; Synofzik et al., 2010) whereby a primary bottom-up misrepresentation of one own’s action may cause an impaired lexical representation of the thematic grid knowledge (for first-person actions) and possibly extending to actions performed by others.

As for the probability of regression from the verb, our group of participants with SSD showed a higher probability of regression in all conditions than the group of healthy controls, coherently with previous literature indicating a significant effect of integration load on neurophysiological measures of reading in people with SSD (Kuperberg et al., 2006b). To the best of our knowledge, this is the first study to extend such observation to eye-tracking measures in reading. In normal condition, the identification of a semantic anomaly would prompt the reader to go back to the element that could presumably help to disambiguate the conceptual conflict (in this case, the pre-verbal subject). However, we found that participants with SSD were likely to re-read the subject of a sentence containing a semantic violation on

the Theme grammatical subject but, conversely, the presence of the same type of semantic violation did not affect the probability of regression when the element carrying the semantic violation was an Agent subject. As go-back movements during reading have been linked to integration difficulties (Reichle et al., 1998), we interpret this result as indicative of an impaired ability to identify online semantic anomalies involving an Agent as grammatical subject, leading to a reduced sensitivity to violations on this linguistic structure. These results are indeed in line with our findings on GD measures and demonstrate both the psychological reality of Thematic Roles and a disrupted lexical representation of verb Thematic Grid in SSD individuals.

At the end-of-sentence stage, we observed an interaction between the effects of the main variables *Group* and *Condition* on TFD, a measure of cognitive processing previously linked to integration difficulties of the word meaning within the sentence (Rayner et al., 2006). Specifically, post-hoc comparison highlighted significantly longer TFDs when reading sentences with a violation, for both HCs and participants with SSD. This finding may reflect late integration and re-analysis processes of structural and lexical-semantic information at the sentence level in conjunction with a semantic violation. A greater magnitude of the effect was observed for the SSD sample, in line with the model proposed by Kuperberg and colleagues (2010) about a specific integration difficulty between syntactic and semantic information in sentence comprehension in people with SSD.

One may argue that these results are linked, at least in part, to the fact that constructs implying syntactic movement (unaccusative verbs with pre-verbal Theme as grammatical subject) pose an additional cognitive load to the reader. The task employed in the present study requires the subject to store and integrate syntactic (pre-verbal movement of the subject), morphological (argument structure), as well as semantic information (animacy of the thematic roles) in the working memory store. In such a frame, the impaired working memory

and executive functions in people with SSD (Gold et al., 2002) may have negatively affected the performance of these individuals. However, in this case, we should have found, irrespective of violations, longer GDs for the allegedly cognitively heaviest sentences (those with a Theme subject), compared to sentences with an Agent subject. This was not the case, ruling out such alternative, syntax-centered, explanation. From a more pragmatically centered point of view, one may claim that, when reading sentences with unaccusative verbs depicting changes of states, it is more difficult to exclude the implausibility of inanimate grammatical subjects. In other words, it could be that sentences such as “*The sun falls from the sky*” are more acceptable than sentences such as “*The sleep gives a call*”. However, if this were the case, we would have found the same effect for both groups, i.e., the semantic anomaly on the Theme subject would have been difficult to recognize both by HPs and participants with SSD, and this would have led to significantly longer GDs for sentences with an anomalous Theme subject in both groups. On the contrary, we observed a double dissociation for group and thematic role: while HPs take significantly longer to process an anomalous Agent as such, they can easily spot a correct Agent. Previous studies found that Agents provide more information about event structure than do Themes, and therefore facilitate event processing in healthy participants (Cohn et al., 2017). The reverse pattern emerged in our experimental group: for participants with SSD it was significantly easier to process an anomalous Theme than a correct one, but we observed no difference when this group of participants processed an anomalous Agent compared to an appropriate one.

It must be noted that a fundamental aspect of the present study is lexical access. This process entails linking the written symbol (the word) and its corresponding representation from long-term memory. One factor associated with prolonged lexical access time is the presentation of a word in an incongruous context. From a neurophysiological perspective, the Evoked-Related Potential (ERP) that best mirrors this process is the so-called N400. Studies

investigating the effect of semantic violations through selection restrictions (i.e., anomalies derived from failing to comply with requirements posed by the verb on nouns that can take part to a certain action) consistently elicited a monophasic increase in N400 amplitude (Osterhout & Mobley, 1995; Osterhout & Nicol, 1999; De Vincenzi et al., 2003), a negative peak in ERP that appears around 400ms after the onset of the anomalous stimulus. From a theoretical, as well as time-related, point of view, it appears likely that our GD measure reflects the N400 component found in ERP studies. In this frame, GDs seem to mirror the semantic integration processes of words with its preceding context and indicate that such integration is strongly influenced by the congruency of grammatical subjects with the thematic role assigned by the verb. Our findings support the assumption that syntactic-semantic incoherence is processed at the local level, with animacy playing a role in influencing the computation of thematic relationships between a verb and its argument(s) during online sentence comprehension in healthy participants (Kuperberg et al., 2007) but less so in people with SSD. Later stages of linguistic processing, when structural and lexical-semantic representations of the sentence are integrated, have been identified to be related to the P600 component (Friederici, 2002), a positive ERP component that appears about 600ms after the onset of the critical stimulus. If there are problems with the integration of the syntactic and semantic representation of a sentence, the P600 indicates the process of sentence re-adjustment or re-analysis (when possible). Similarly, in our study, such late stage of sentence processing appears to be mirrored in the TFD measure and appears to be active both in HCs and in participants with SSD.

Therefore, our results are consistent with previous modular models of language comprehension in healthy subjects (Frazier & Rayner, 1982, 1987) as well as in people with SSD (Kuperberg et al., 2006a; Ruchow et al., 2003). Along these lines, we propose a

possible model of anomalous sentence processing in SSD, developing, temporally speaking, along two stages:

- (1) Early access to an impaired lexical representation of the verb (indexed by GD). As soon as the sentence main verb is accessed, syntactic and semantic information stored in the Thematic Grid of the verb argument structure is retrieved from the mental lexicon. In the case of participants with SSD, the disrupted lexical representation of the verb thematic grid, reflecting an altered mental representation of agency, leads to a different saliency of semantic violations on the animacy trait of an Agent-subject, and in turn an increased tolerance of this kind of violations. It follows that no regression movement from the verb to the pre-verbal grammatical subject, needed to disambiguate the semantic anomaly at the local level, is triggered. In other words, at this first stage, participants with SSD overlook the semantic anomaly in the case of Agent pre-verbal subject, while displaying a distinguished sensitivity for a violation on the Theme.
- (2) A later resolution of the semantic anomaly by integrating syntactic and semantic information at the sentence level (mirrored by TFD). At the end of the sentence, both HCs and participants with SSD show an effect of the semantic violation, with longer TFD when reading sentences with a violation of the subject (regardless of its Thematic Role). However, the magnitude of the effect seems to be particularly evident in the SSD group. This result speaks for a general-level integration difficulty in participants with SSD in front of a semantic violation.

5. Conclusions

This study shows the specific contribution of a disrupted lexical representation involving the thematic grid structure to the reading performance in individuals with SSD. Our

results support the hypothesis of an impaired lexical representation of verbs requiring an animated Agent as the grammatical subject in this clinical population. A disrupted representation, which we link to the presence of a “disordered self”, affects the implicit processing of sentences, as captured by GDs and probability of regression in reading.

To our knowledge, the present study is the first attempt to address eye-movement signatures in an anomaly detection task using sentences containing semantic violations of different Thematic Roles in a group of individuals with SSD, which was compared to a matched group of healthy participants. This study identifies an overall difficulty in processing the concept of “agentivity”, and further research investigating language disturbances in people with SSD could help to shed light on the specific (dis)ability showed by the SSD population in the recognition of non-agentivity of inanimate objects, thus contributing to the explanation of some clinical aspects of their impairment as delusions of persecution (e.g., being intentionally followed by the wind). The present study also contributes to the understanding of the connection between language and schizophrenia: the so-called schizophrenic “word salad” could be partially explained by this anomalous lexical representation of verbs, which eventually yields the characteristic “incoherent speech”, made of bizarre and sometimes nonsensical word associations.

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Declaration of interest statement

We have no conflict of interests to disclose.

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Table list

Table 1 - *Socio-demographic and clinical data of participants at recruitment.*

Variables	SSD		HC		Full sample		p-value
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	
Age, years	47.5	9.8	47.7	10.6	47.7	10.1	.99
Education, years	10.8	3.6	12.4	3.8	11.6	3.8	.1
Illness duration, years (N = 29)	23.6	11.6	-	-	-	-	-
Antipsychotic treatment, number	2.6	1.6	-	-	-	-	-

Note. N = 60 (n = 30 for each group). HC = Healthy Controls; SSD = Schizophrenia Spectrum

Disorder. M = mean; SD = standard deviation

Table 2 - Experimental stimuli.

Condition	Example	N. of stimuli
Agent – correct	Ogni sera Bianca <u>telefona</u> al nipotino (<i>Every evening Bianca calls her nephew</i>)	28
Agent – with violation	* Ogni sera il sonno <u>telefona</u> al nipotino (<i>Every evening the sleep calls its nephew</i>)	28
Theme – correct	A volte il bambino <u>cade</u> dalle scale (<i>Sometimes the child falls from the stairs</i>)	28
Theme – with violation	* A volte il sole <u>cade</u> dalle scale (<i>Sometimes the sun falls from the stairs</i>)	28

Note. Conditions, examples, and numbers of experimental stimuli. Target verbs are underlined. The grammatical subject can be either coherent or incoherent. A literal translation is reported in brackets

Table 3 - Quantitative description of target items (verbs).

Verb variables	Correct sentences		With violations		p-value
	M	SD	M	SD	
Length	7.50	1.93	7.48	1.96	0.96 ^a
Log frequency	4.48	5.10	4.48	5.10	0.25 ^b

Note. a = Student's t-test. b = χ^2 test. M = mean; SD = standard deviation.

Table 4 - Gaze Duration, Total Fixation Duration, and probability of regression: descriptive statistics.

		SSD		HC					
		Agent		Theme		Agent		Theme	
		M	SEM	M	SEM	M	SEM	M	SEM
GD	Correct	519.02	16.11	484.17	12.40	362.81	7.12	382.22	7.88
	With violation	545.40	16.08	527.72	13.05	420.78	9.35	421.18	9.96
TFD	Correct	1197.90	48.01	1118.41	42.85	602.62	14.84	597.64	14.38
	With violation	1379.39	52.42	1470.16	54.04	620.27	14.49	635.11	16.35
Probability of regression	Correct	80%		76%		71%		73%	
	With violation	84%		84%		75%		73%	

Note. Mean durations and standard error of the mean (in milliseconds) of GD and TFD on target verbs, and probability of regression from target verbs backwards, per conditions, in the two groups. GD = Gaze Duration; HC = Healthy Controls, M = Mean; SEM = Standard Error of the Mean; SSD = Schizophrenia Spectrum Disorder; TFD = Total Fixation Duration.

Table 5 - Estimated fixed and random parameters for GD.

Random effects	Variance	SD				
Subject (intercept)	.0779	.2790				
Item (intercept)	.0201	.1420				
Residual	.1412	.3758				
Fixed effects	Estimate	SE	df	t-value	p	Sign
(Intercept)	5.79	.06	93.41	97.86	< .001	***
Condition (violated)	.14	.02	5829.22	7.16	< .001	***
Role (Theme)	.06	.04	72.20	1.31	.194	
Group (SSD)	.25	.07	64.47	3.36	.001	**
Condition * Role	-.09	.03	5839.91	-3.23	.001	**
Condition * Group	-.08	.03	5807.75	-3.06	.002	**
Role * Group	-.07	.03	5807.72	-2.70	.007	**
Condition * Role * Group	.1	.04	5807.64	2.58	.010	**

Note. Df = Degree of freedom; SD = Standard Deviation. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant

Table 6 - Estimated fixed and random effect for the probability of eye-movement regression from the verb.

Random effects	Variance	SD			
Subject (intercept)	1.3583	1.1654			
Item (intercept)	.3298	.5743			
Fixed effects	Estimate	SD	Z value	p	Sign
Intercept	1.12	.26	4.39	< .001	***
Condition	.30	.13	2.38	.017	*
Role	.16	.20	.80	.426	
Group	.68	.33	2.05	.041	*
Condition * Role	-.32	.18	-1.79	.074	
Condition * Group	.11	.19	.59	.558	
Role * Group	-.43	.19	-2.30	.022	*
Condition * Role * Group	.58	.27	2.13	.033	*

Note. Df = Degree of freedom; SD = Standard Deviation. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant.

Table 7 - Estimated fixed and random parameters for TFD.

Random effects	Variance	SD				
Subject (intercept)	.1906	.4366				
Item (intercept)	.0318	.1783				
Residual	.2541	.5041				
Fixed effects	Estimate	SE	df	t	p	sign
Intercept	6.21	.09	82.43	70.23	< .001	***
Condition	.07	.03	5898.00	2.85	.004	**
Role	-.01	.05	80.55	-.11	.911	
Group	.48	.12	62.68	4.13	< .001	***
Condition * Role	-.02	.04	5910.00	-.59	.558	
Condition * Group	.12	.04	5876.00	3.22	.001	**
Role * Group	-.04	.04	5876.00	-.99	.323	
Condition * Role * Group	.06	.05	5876.00	1.23	.219	

Note. Df = Degree of freedom; SD = Standard Deviation. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant

Figure 1 - Mean GD by Group, Role, and Condition (bars indicate the standard error of the mean).

Note. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant.

Figure 2 - Probability of regression from the target verb backwards, by Group, Role, and Condition.

Note. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant.

Figure 3 - Mean TFD for Group, Role, and Condition (bars indicate the standard error of the mean).

Note. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant.

Figure 4 - Two-way interaction plot on TFD by Group and Condition.

Note. HC = Healthy Controls. SSD = Schizophrenia Spectrum Disorders.

**Sleeping Stones and Other Implausible Agents: Agency of Subjects and Eye
Movements in Schizophrenia Spectrum Disorders
- Supplemental Materials –**

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Table S.1*Target stimuli*

AGENT - correct	AGENT – with violation	THEME - correct	THEME – with violation
In estate la luce brilla attraverso le ante	Nel cantiere l'architetto solleva la cisterna	Al mattino le stelle tramontano dietro alla collina	In paese le fontane cambiano a ogni generazione
Alla luce i diamanti luccicano nell'astuccio	In inverno la neve riposa nella grotta	In paese gli abitanti cambiano a ogni generazione	Davanti al camino la zia rimane calda
Ogni sera Bianca telefona al nipotino	Ogni sera il sonno telefona al nipotino	A volte il bambino cade dalle scale	A volte il sole cade dalle scale
Sulla roccia il leone ruggisce con fierezza	Sulla roccia l'arbusto ruggisce con fierezza	In estate il maestro parte per la montagna	In estate la tana parte per la montagna
Alla festa gli uomini ridono di gusto	Alla festa i bicchieri ridono di gusto	All'improvviso il ragazzo sviene per la paura	All'improvviso l'oro sviene per la paura
In cucina i gatti dormono al sole	In cucina le bucce dormono al sole	Tutti i giovedì il professore arriva in ritardo	Tutti i giovedì il cielo arriva in ritardo
In estate i calciatori giocano all'aperto	In estate le panchine giocano all'aperto	Ogni giorno molti soldati muoiono nel mondo	Ogni giorno molte scarpe muoiono nel mondo
Nella favola la regina abdica al trono	Nella favola la colonna abdica al trono	A mezzogiorno i pensionati vanno in banca	A mezzogiorno i negozi vanno in banca
A pranzo il papà sbuccia l'arancia	A pranzo il porto sbuccia l'arancia	Grazie alla pedana l'elefantino scende dal camion	Grazie alla pedana il cruscotto scende dal camion
Sul marciapiede il ciclista gonfia la ruota	Sul marciapiede il parchimetro gonfia la ruota	Alle sei gli operai tornano a casa	Alle sei i ristoranti tornano a casa
La mattina i postini consegnano le lettere	La mattina i cereali consegnano le lettere	Ogni giorno molti neonati nascono in ospedale	Ogni giorno molti treni nascono in ospedale
Nel fine settimana i cuochi cucinano le torte	Nel fine settimana i parchi cucinano le torte	A mezzanotte i fuochi scoppiano nel cielo	A mezzanotte gli innamorati scoppiano nel cielo
Tutti i giorni la mamma legge il giornale	Tutti i giorni il muro legge il giornale	All'aeroporto gli aerei decollano a ogni ora	In primavera la gallina sboccia nel campo
In autostrada il camionista guida con prudenza	In autostrada l'asfalto guida con prudenza	In primavera il fiore sboccia nel campo	Questa settimana l'avvocato tramonta al mattino
Ogni sera sua moglie regola la sveglia	Ogni sera la notizia regola la sveglia	Con la convalescenza i malati guariscono dalla malattia	Con la convalescenza gli ospedali guariscono dalla malattia
D'estate le onde bagnano la riva del mare	D'estate le tasse bagnano la riva del mare	Dopo le feste molte persone ingrassano di qualche chilo	Dopo le feste molti piatti ingrassano di qualche chilo
A pranzo gli atleti mangiano i maccheroni	A pranzo i gomiti mangiano i maccheroni	All'improvviso le rovine franano rumorosamente	All'improvviso le lavoratrici franano rumorosamente
Di giorno i cani abbaiano alle automobili	Di giorno le rose abbaiano alle automobili	Sul balcone le fragole spuntano nei vasi	Sul balcone le insegnanti spuntano nei vasi
La sera i pesci abboccano con facilità	La sera i dischi abboccano con facilità	Sul monte gli alberi fioriscono a primavera	Sul monte gli studenti fioriscono a primavera
Nel castello la spada scintilla accanto al camino	Nel castello lo stalliere scintilla accanto al camino	La sera i fulmini lampeggiano sulla montagna	La sera i cervi lampeggiano sulla montagna
A mezzogiorno le campane risuonano nella valle	A mezzogiorno le ballerine risuonano nella valle	Col caldo l'acqua evapora dalla pozzanghera	Col caldo il dottore evapora dalla pozzanghera
All'occorrenza i pompieri corrono in aiuto	Quando occorre i papaveri corrono in aiuto	Dopo la sconfitta il nemico fugge sulle montagne	Col maltempo il caffè rimane al porto
Nel cantiere la gru solleva la cisterna	Nel cielo il gufo brilla a primavera	Col maltempo la nave rimane al porto	Dopo un terremoto le macerie intervengono con tempestività
In ufficio i telefoni squillano senza sosta	In ufficio le mosche squillano senza sosta	Dopo un terremoto i pompieri intervengono con tempestività	Alle quattro i telefoni escono dall'ufficio
A Natale il nonno regala qualche caramella	Alla luce gli attori luccicano nell'astuccio	Alle quattro gli impiegati escono dall'ufficio	Il mercoledì il cane costa di meno

Sulla montagna il vento soffia indisturbato	Sulla montagna il falco soffia indisturbato	Il mercoledì il cinema costa di meno	In Niger le madri scarseggiano durante la carestia
Sul banco la cartella contiene i libri	Durante l'intervista il microfono regala una copia del film	In Niger le risorse scarseggiano durante la siccità	Grazie alle dighe i manichini sopravvivono all'inverno
In città i grattacieli luccicano sotto il sole	Sotto al tavolo la mattonella solleva una briciola	Grazie alle dighe i castori sopravvivono all'inverno	In estate il macellaio scade dopo pochi giorni
Nel cielo il sole brilla a primavera	D'estate il sasso riposa sotto l'albero	In America i mandati presidenziali scadono dopo quattro anni	Quando piove i lombrichi decollano con fatica

Table S.2*Filler sentences*

Subject-verb agreement (number)	Determiner-NP (gender and number)	Verb and clitic
Proto-Theme	Gender	Gender
<p>Nel bosco le volpi *scappa dal cacciatore</p> <p>In cucina la torta *lievitano nel forno</p> <p>Nella lavatrice la centrifuga *girano con grande rumore</p> <p>In inverno la neve *cadono in montagna</p>	<p>Nel mare *le pesci nuotano liberi</p> <p>In cucina *i pentole borbottano fumanti</p> <p>Sugli spalti *le tifosi incitano la squadra</p> <p>In laboratorio *gli operaie smontano la macchina</p>	<p>Il cane insegue il gatto e *la rincorre fin sotto il tavolo</p> <p>Finito il libro, Sandro *la appoggia sulla libreria</p> <p>Mario accende la radio e *lo sintonizza sul giornale locale</p> <p>Il nonno raccoglie le patate e *li porta in cucina</p>
Proto-Agent	Number	Number
<p>In casa il pittore *dipingono le pareti</p> <p>In estate le zanzare *punge le caviglie</p> <p>Oggi la mamma *vanno al mercato</p> <p>Di sabato i turisti *affolla il centro città</p>	<p>Al pomeriggio *il professori correggono i compiti degli alunni</p> <p>Tutti i giorni *il ballerini si allenano per quattro ore</p> <p>Oggi *la tartarughe nuotano libere nell'oceano</p> <p>Nel pollaio *la galline depongono le uova al mattino</p>	<p>L'automobile sbanda e il camion *le urta</p> <p>L'impiegata ritarda e il capoufficio *le chiama al telefono</p> <p>Il vaso vacilla e Giovanni *li prende al volo</p> <p>L'ape si avvicina e il turista *le scaccia</p>

Data analyses on First Fixation Duration and Accuracy of responses

First Fixation Duration

First Fixation Duration (FFD) is the duration in milliseconds of the first fixation on the target item and is considered as a proxy of early word processing (Liversedge et al., 1998)⁴.

Table S.3 and Figure S.1 summarize the mean durations (in milliseconds) of FFD on target verbs, by conditions, in the two groups. Table S.4 reports the estimated fixed parameters of the model, together with significance tests for the analysis on FFD.

Table S.3

Mean duration in (ms) of FFD on target verbs

	HCs				SSD			
	Agent		Theme		Agent		Theme	
	M	SEM	M	SEM	M	SEM	M	SEM
Correct	261.93	3.36	266.88	3.69	310.79	5.29	313.18	4.92
With violation	274.72	3.75	268.63	3.74	319.50	5.72	314.63	5.18

Note. M = mean; SEM = Standard error of the mean

Figure S.1

Mean durations (in milliseconds) of FFD on target verbs, by conditions, in the two groups

Note. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant.

⁴ Liversedge, S. P., Paterson, K. B., & Pickering, M. J. (1998). Eye movements and measures of reading time. In *Eye guidance in reading and scene perception* (pp. 55-75). Elsevier Science Ltd.

Table S.4*Fixed and random effect on FFD*

Random effects	Variance	SD				
Subject (intercept)	.0201	.1417				
Item (intercept)	.0003	.0183				
Residual	.1015	.3186				
Fixed effects	Estimate	SD	df	t	p	Sign
Intercept	5.53	.03	77.72	193.53	< .001	***
Condition (violated)	.03	.02	5893.00	1.95	.051	
Role (Theme)	.01	.02	510.40	.49	.622	
Group (SSD)	.15	.04	76.29	3.67	< .001	***
Condition * Role	-.04	.02	5871.00	-1.80	.073	
Condition * Group	-.03	.02	5849.00	-1.08	.279	
Role * Group	-.01	.02	5848.00	-.38	.707	
Condition * Role * Group	.02	.03	5847.00	.76	.450	

Note. Df = Degree of freedom; SD = Standard Deviation. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant.

Of the three main effects considered, only that of *Group* ($p < .001$) was found to significantly affect FFD, suggesting that, irrespective of *Condition* and *Role*, participants with SSD show longer FFDs than HCs. Neither a two- nor a three-level interaction was found. Results can be explained bearing in mind that variables that may have affected FFDs, i.e. length and frequency of target verbs, had been controlled in the experimental material. For this reason, the significantly longer FFD for the SSD group cannot be imputed to this variable but perhaps rather to the general psychomotor delay generally observed in this group.

Accuracy

A score for Accuracy in the detection of violations was also computed as the percentage of correct responses. A response was considered correct if in agreement with the expected categorization (i.e., “acceptable” or “not acceptable”). As summarized in Table S.5, there were four possible answers participants could produce:

- (i) they could categorize as acceptable sentences in the correct condition (i.e., with no violation of the animacy trait of the subject, either a Theme or an Agent);

- (ii) they could categorize as acceptable sentences with a semantic violation of the subject;
- (iii) they could categorize as non-acceptable sentences in the correct condition; or
- (iv) they could categorize as non-acceptable sentences with a semantic violation of the subject (i.e., the Agent or the Theme are not coherent with the verb).

In this study, we considered accurate only responses that fulfilled conditions (i) and (iv).

Table S.5

Codification of possible answer

Participant responses	Expected categorization	
	Acceptable	Not acceptable
Acceptable	i. Correct	ii. Not correct
Not acceptable	iii. Not correct	iv. Correct

Table S.6 and Figure S.2 report the accuracy by *Condition* and *Role* in the two groups. Table S.7 summarizes the estimated fixed parameters of the model for Accuracy, together with significance tests.

Table S.6

Accuracy by Condition and Role in the two groups

	HC		SSD	
	Agent	Theme	Agent	Theme
Correct	92%	88%	87%	87%
With violation	97%	98%	87%	86%

Figure S.2

Accuracy by Group and Role

Note. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant.

Table S.7

Fixed and random effect on accuracy

Random effects	Variance	SD
Subject (intercept)	.7162	.8463
Item (intercept)	.3956	.6289

Fixed effects	Estimate	SD	Z value	p	Sign
Intercept	2.79	.24	11.50	< .001	***
Condition	1.12	.25	4.57	< .001	***
Role	-.40	.25	-1.62	.106	
Group	-.52	.29	-1.80	.072	
Condition * Role	1.01	.39	2.62	.009	**
Condition * Group	-1.04	.29	-3.56	< .001	***
Role * Group	.41	.24	1.70	.089	
Condition * Role * Group	-1.22	.45	-2.72	.006	**

Note. Df = Degree of freedom; SD = Standard Deviation. * = significant at $\alpha = .05$; ** significant at $\alpha = .01$; *** significant at $\alpha = .001$; n.s. = non-significant.

A three-level interaction between fixed predictors was significant ($z = -2.72$, $p < .01$) with respect to accuracy scores. This result shows that *Condition* and *Role* acted differently in the two groups concerning explicit judgments.

Post-hoc comparisons indicate that HCs were significantly more accurate in categorizing sentences containing a violation than correct sentences, both concerning Agent ($z = -4.57, p < .001$) and Theme subjects ($z = -7.09, p < .001$).

On the contrary, the accuracy of responses of participants with SSD did not significantly differ between *Conditions*, neither on the Agent subject ($z = -0.48, p = 1$), nor on the Theme subject ($z = 0.77, p = .992$). This significant three-way interaction suggests an advantage for Theme-violation compared to Agent-violation sentences for HCs.