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Running title

Context and affective ToM in AD

Abstract

Affective theory of mind (ToM) is defined as the ability to deal with affective mental states. Attributing an affective mental state from a facial expression relies mainly on processes that allow information in the environment to be perceived and decoded. Reasoning processes are required when information is not directly available in the environment (e.g., when making an affective mental state attribution in a social situation where there is no visible facial expression of emotion). Although facial emotion decoding deficits have been reported in Alzheimer's disease (AD), few studies have assessed emotional reasoning processes. Long-term social knowledge may also contribute to mental state attribution, given its involvement in social situations, but the links between these two domains have not yet been properly explored. The aim of the present study was therefore to assess both decoding and reasoning processes in AD, as well as the effect of context on emotion attribution (i.e., whether prior presentation of a congruent vs. noncongruent social situation influences emotion recognition from faces). We also aimed to improve current understanding of the relationship between ToM processes and social knowledge. Participants were 20 patients with AD, 20 healthy older individuals, and 20 healthy young individuals. They performed three tasks testing ToM: a context task (emotion attribution in a social situation); a face task (facial emotion recognition); and a context-face task (determining whether the facial emotion was consistent with the emotion inferred from the social situation, e.g., an embarrassing situation followed by a proud face). All participants underwent a neuropsychological battery that included an assessment of social norm knowledge (e.g., determining whether it is socially acceptable to phone in a church). Results showed deficits in the patients with AD for decoding emotions from faces and for reasoning about emotions inferred from a social context. Patients were found to consider contextual information in such a way that congruency either helped or hindered the decoding of stimuli in the environment. As expected, we found that ToM abilities were linked to social norm knowledge. Overall, our findings suggest that patients with AD have difficulty attributing emotional mental states, and deficits in social norm knowledge and the presence of incongruent information may heighten this difficulty.

Keywords

Alzheimer's disease, emotion recognition, theory of mind, social knowledge, context

Highlights

- Contextual information affects facial emotion decoding in Alzheimer's disease (AD).
- Facial emotion decoding and reasoning about emotions in context are impaired in AD.
- Patients with AD correctly decode facial emotions in a congruent social situation.
- Patients with AD have difficulty detecting infringements of social norms.
- Impairment of social norm knowledge may contribute to theory of mind disturbances.

1. Introduction

Social cognition refers to a set of implicit and explicit processes encompassing several domains, including emotion recognition, empathy, theory of mind (ToM), moral judgment, and decision making (Baez, García, & Ibanez, 2016). These processes allow individuals to make sense of other people's behaviour, in order to adapt their own behaviour to their social world (Fiske & Taylor, 2013). Regarded as a key component of social cognition, *ToM* is defined as the ability to decode mental states such as intentions, beliefs, and emotions, and to reason about them (Frith, 2008). Researchers make a distinction between affective and cognitive ToM (Brothers & Ring, 1992). Whereas *cognitive ToM* concerns epistemic mental states, thoughts, beliefs and intentions, *affective ToM* refers to feelings, affects and emotions (Shamay-Tsoory, Aharon-Peretz, & Perry, 2009). There are thought to be at least two routes to attributing an emotional mental state: a direct route based on emotion recognition, and an indirect one based on the real-life situation and social knowledge (Samson, Apperly, & Humphreys, 2007). Whereas decoding processes are mainly automatic and based on the perception of information in the environment (Gallagher & Frith, 2003; Sabbagh, 2004), reasoning processes are mainly intentional and involve a high degree of processing to understand and predict behaviours (Sabbagh, 2004). More specifically, decoding processes rely on social information directly obtained from the environment, whereas reasoning processes rely on representations of the situation based on knowledge about the protagonists and the social world (Samson, 2007). Even if decoding and reasoning processes are theoretically distinct, they work together in social situations. Baron-Cohen et al. (1997) suggested that decoding and reasoning are both required to identify a social emotion. According to Happé, Cook, and Bird (2016), a variety of labels are currently used for overlapping concepts such as affective ToM and facial emotion recognition or affective ToM and cognitive empathy, but the literature clearly distinguishes between these different components of social cognition. Depending on the theoretical framework, emotion recognition and ToM are viewed either as two parts of a general ability (Phillips et al., 2002), or as two separate mechanisms (Shamay-Tsoory et al., 2007), while some authors regard emotion recognition as a precursor to ToM (Beer & Ochsner, 2006; Happé, Cook, & Bird, 2016; for a review, see Mitchell & Phillips, 2015).

One particular feature of affective mental states is that they are often directly detectable from faces (Baron-Cohen, Wheelwright, & Jolliffe, 1997). Although there has been some research on decoding or reasoning about affective ToM, the two are rarely studied together using the same material in normal individuals, let alone in patients with Alzheimer's disease (AD). Regarding decoding processes, studies in AD using photographs of faces expressing basic emotions have yielded inconsistent results (for a review, see Klein-Koerkamp et al., 2012), with some studies reporting a deficit (Kumfor et al., 2014; Laisney et al., 2013) and others not (Bucks & Radford, 2004; Fernandez-Duque et al., 2009). Links are frequently found between affective ToM and other cognitive functions, especially flexibility, working and/or episodic memory, and inhibition (Castelli et al., 2011; Fliss et al., 2016; Ramanan et al., 2017; Synn et al., 2018). As a result, the ToM impairments of patients with AD are often attributed to cognitive disorders, and commensurate with the severity of the disease, rather than to disturbed emotional processes (Dermody et al., 2016, Kumfor et al., 2014; Ramanan et al., 2017). Conversely, some studies have failed to find a link between ToM and executive functions in AD, and shown that ToM disturbances in AD are not fully explained by a general cognitive deterioration (Gregory et al., 2002; Laisney et al., 2013; Le Bouc et al., 2012).

Affective ToM had mainly been assessed with tasks featuring facial expressions of emotion that elicit decoding processes, such as the Reading the Mind in the Eyes (RME) test (Baron-Cohen et al., 2001; Baron-Cohen et al., 1997). The RME test is viewed either as a measure of ToM (Baron-Cohen et al., 2001) or as a measure of emotion recognition (Adolphs et al., 2002). Some studies have reported preserved performances (El Haj et al., 2015; Gregory et al., 2002), whereas others have found a deficit (Castelli et al., 2011; Laisney et al., 2013; for review, see Poletti, Enrici, & Adenzato, 2012). Differences in disease severity may contribute to discrepancies between studies. For example, patients with preserved RME performances in El Haj et al. (2015)'s study were in the very early stage of the disease (Mini-Mental State Examination (MMSE) mean score = 24/30), whereas the patients with impaired performances in Laisney et al. (2013)'s study had mild AD (MMSE mean score = 21/30). Methodological differences must also be considered, as impaired performances were found using the original procedure with four response options (Castelli et al., 2011), but not using a modified version with a binary answer choice (Gregory et al., 2002). Very few tasks assessing affective ToM have involved reasoning processes. Using a visual task that minimized the overall cognitive demand, a recent study highlighted a deficit in affective mental state attribution in patients with AD (Synn et al., 2018). Supplementary analyses taking into account scores on a vocabulary task showed that the patients' performances on the affective ToM question of the task improved to be then similar to controls.

Hence, most of the research investigating affective ToM has relied on isolated photographs of facial expressions, even though affective mental state decoding usually occurs within a context in everyday cognition. A broad definition of *context* (see Barrett et al., 2011; Barrett, Lindquist, & Gendron, 2007) encompasses both internal feedback (e.g., increased heart or respiratory rate, perspiration) and external information specific to the situation (e.g., body position and language, surrounding scene, vocal prosody, social knowledge associated with the situation). Of relevance here, recent studies have revealed that context substantially influences the perception of emotional facial expressions in healthy individuals (Aviezer et al., 2011; Stewart et al., 2018), as well as in patients with neurological disease (Kumfor et al., 2018).

Some studies have used tasks requiring emotions attribution from the presentation of a social situation. Zaitchik et al. (2006) failed to observe impaired performances on a 4-item inference story task in a group of patients. Similarly, when Goodkind *et al*. (2015) tested patients in the early stage of the disease, using 11 short sections of famous movies in which characters expressed facial emotions in congruent emotional contexts, they only observed emotion recognition difficulties for enthusiasm. By contrast, Shany-Ur et al. (2012) highlighted lower performances in patients with AD compared to controls using a movie task in which participants had to infer basic emotions from realistic dynamic situations in which the faces of the protagonists were not visible. The difference, however, failed to reach significance when the patients' overall cognitive deficit was taken into account in the analysis. Using a similar task, Torres et al. (2015) demonstrated decreased performances by patients with AD in a 6-month longitudinal study. Linear regressions revealed that the MMSE score was a significant predictor of emotion attribution performances (Torres et al., 2015).

Although some studies have focused on emotion recognition in context, it is only recently that context has become a subject of study in its own right. Affective targets (e.g., expressions of emotions) and contexts are not processed separately in healthy individuals. All the processes constituting social cognition, from basic emotion recognition processes to more complex ToM processes, are sensitive to the effects of context (Ibañez & Manes, 2012). In their social context network model (SCNM), Ibanez and Manes (2012) put forward the notion of *contextual frames* related to prototypical situations. These postulated frames combine the meanings of different social targets (emotional face, speech, behaviour, etc.) that usually appear in these specific situations and the relationships between them. The SCNM suggests that frontal, temporal and insular cortices are involved in the processing of contextual information, and we know that most of these regions are affected in AD (Villain et al., 2010). The model suggests that the appraisal of a context depends on representations stored in long-term memory, both episodic and semantic. In a similar way, Barrett et al. (2011) suggested that the effects of context are related to the reactivation of past personal emotional experiences by actions such as reading an emotional label. A recent study has suggested that the effects of context on the decoding of emotions from faces may also be the result of inferences about the emotional experiences of others in a social situation (Stewart et al., 2018).

Mental state attribution is also known to rely on semantic long-term ToM and social knowledge representations (Samson, 2009), but few studies have addressed social knowledge in AD. When they administered a social norm knowledge (SNK) questionnaire, Panchal et al. (2015) found that patients with frontotemporal dementia (FTD) scored lower than patients with AD. However, the absence of a comparison group without cognitive disorder prevented the authors from drawing any conclusions about the social knowledge profile of the patients with AD. Given the memory difficulties caused by AD, it is possible that stored personal representations of contextual clues are impaired in this disease.

Moreover, the meaning of a stimulus depends on the context in which it emerges. In some situations, the stimulus and its context are not congruent, and therefore this incongruence has to be resolved. Providing external contextual information that is incongruent negatively influences the recognition of facial expressions of emotions in healthy young individuals (Aviezer et al., 2011; de Gelder, 2006; Stewart et al., 2018). This effect is greater in healthy aging (Noh & Isaacowitz, 2013), but has never been studied in AD. In addition, eye fixation patterns have been found to vary according to whether the contextual information is congruent or noncongruent with the information conveyed by the faces (Aviezer et al., 2011). In healthy individuals, exposure to two successive emotions with the same or different valences significantly affects performances (Aviezer et al., 2011; Stewart et al., 2018). Interestingly, some studies have shown that patients with AD have difficulty understanding irony and sarcasm, which requires an incongruence between context and language to be resolved (Shany-Ur et al., 2012).

Attributing an affective mental state from a facial emotion mainly involves decoding processes, but when a facial expression is not available, reasoning processes are required. The presence or absence of a facial expression can therefore be manipulated in order to assess these two processes separately. Most of the time, they work together in everyday cognition, but sometimes result in conflicting representations. The first aim of the present study was thus to assess both decoding and reasoning processes in AD, as well as the effect of contextual congruency on emotion attribution. The second aim was to better understand the relationship between ToM processes and social knowledge representations. Based on Samson (2009)'s model, we hypothesized that reasoning about mental states is related to social knowledge.

2. Materials and Methods

2.1. Participants

We enrolled 20 patients with probable AD in the moderate or mild stage of the disease (11 women; age range = 70-86 years, mean age = 79.4 ± 5.1), 20 age- and education-matched healthy older individuals (HOS; 15 women; age range = 70-87 years, mean age = 77.3 ± 5.9), and 20 young individuals (HYS; 12 women; age range = 20-31 years, mean age = 24.6 ± 2.3) (Table 1). We included the HYS group in order to better understand the data yielded by our AD group, taking the effect of ageing into account. All participants were French native speakers and had a minimum level of education equivalent to the French primary school certificate, obtained after 7 years of primary education. None of the participants had a history of alcoholism, head trauma, or neurological or psychiatric illness. The MMSE (Folstein, Folstein, & McHugh, 1975) score was lower for patients with AD (mean score = 21.9 ± 2.1, range = 19-25) than for HOS (mean score = 29 ± 1.1, range = 27-30). All patients were evaluated by a senior neurologist, a neuropsychologist and speech therapist, in French memory centres. They all met the criteria for AD established by the expert international workgroups convened by the Alzheimer's Association and the National Institute on Aging (McKhann et al., 2011). The patients' caregivers were enrolled in this study as control participants. All participants took part in this study on a voluntary basis, and gave their written consent after being provided with detailed information. The study was undertaken in accordance with the Declaration of Helsinki.

Table 1. Demographic characteristics of the patients with Alzheimer's disease and healthy subjects (HOS and HYS)

	AD patients	**HOS**	**HYS**	**F**	**Post hoc**
Male/female	9/11	5/15	8/12	1.86[a]	ns
Age (years)	79.4 (±5.1)	77.3 (±5.9)	24.6 (±2.3)	858.8	p = .35
Education (years)	10.2 (±3.6)	10.8 (±4.2)	14.3 (±2.2)	8.74	AD = HOS p = .82
MMSE score	21.9(±2.1)	29 (±1.1)	-	3.93	p <.0001

Note. Values are mean and standard deviation. Statistical significance was set at $P < 0.05$. ns = not significant. [a] Chi square value. AD= Alzheimer's disease; HOS = healthy older individuals; HYS = healthy young individuals.

2.2. Diagnostic neuropsychological assessment

All the patients underwent a standard neuropsychological diagnostic battery including episodic memory, working memory, language, executive function and visuospatial tests. Verbal and visual forms of long-term memory were assessed respectively with the Free and Cued Selective Reminding Test (FCSRT; Van der Linden & Adam, 2004) and 3-min delayed recall of the Rey-Osterrieth complex figure (Wallon, Mesmin, & Rey, 2009). Working memory was assessed with the forward and backward digit span tests of the Wechsler Memory Scale–Third Edition (Wechsler, 2001) and executive functions with the Trail-

Making Test (TMT; Godefroy & GREFEX, 2008) and Stroop test (Godefroy & GREFEX, 2008). Language was explored with 2-min categorical and phonemic verbal fluency tests (Godefroy & GREFEX 2008). Patients' performances were compared with French normative data taking age and education into account. The neuropsychological assessment highlighted deficits in the verbal component of episodic memory among most patients, and in the visual component among half of them (Table 2). Working memory performances were relatively preserved, but most of the patients exhibited at least one deficit in the executive tests. Finally, some patients had difficulty with categorical and phonemic fluency.

Table 2. Neuropsychological data of the Alzheimer's disease group

	Mean (*SD*)	μ *z* score	% patients impaired
FCSRT free recall (/48)	5.45 (± 4.26)	-4.65	95
FCSRT total recall (/48)	18.85 (± 10.91)	-4.63	100
FCSRT delayed total recall (/16)	6.05(± 3.70)	-	90
Rey-Osterrieth complex figure delayed recall (/36)	4.85 (± 4.33)	-1.66	50
Rey-Osterrieth complex figure copy (/36)	28.55 (± 8.89)	0.56	25
Digit span forward	7.35 (± 2.01)	0.17	0
Digit span backward	4.9 (± 2.20)	-1.05	15
TMT A time (s)	106.85 (± 85.36)	2.56	35
TMT B time (s)	270.05 (± 147.33)	1.96	45[a]
Stroop Interference Task errors	17 (± 12.56)	2.90	70
Categorical verbal fluency score	14.25 (± 6.46)	-1.76	60
Phonemic verbal fluency score	10.3 (± 7.37)	-1.50	45

Note. [a] Missing data for one patient. *SD* = standard deviation. Patients' scores were compared with published French normative data taking age and education in account.

2.3. Affective ToM assessment

The Peter and Mary emotion tasks battery

Affective ToM was assessed with a tailormade battery (Peter and Mary emotion tasks battery) including the following three 20-item tasks, presented on a computer screen in a fixed order: 1) context task, 2) face task, and 3) context-face task (Fig. 1). Four emotional mental states were featured: two basic emotions (anger and surprise), two self-consciousness emotions (embarrassment and pride), plus the neutral state. Each item could be viewed twice, if necessary.

The material consisted of short silent black-and-white videos featuring two characters, Peter and Mary. These characters were introduced as roommates living together for a short time. There were two types of videos: context videos (n = 40) and emotion expression videos (n = 40). In the context videos, the two characters interacted in social situations taking place in everyday places (dining and living rooms, entrance to a house, office, or public garden). The number of distracting elements in the background scene was intentionally limited, to ensure that participants' attention remained focused on the two protagonists. The context videos were designed to elicit an emotion (e.g., pride: Peter and Mary are playing darts and Mary hits all the bullseyes) or a neutral state (e.g., Peter and Mary are having lunch and Mary slices the bread) in one of the two characters, designated by a pink armband. Each video consisted of a full shot (8-9 s) giving an overview of the context, followed by a medium close-up shot (2 s) on a relevant element of the context that gave an insight into the emotion felt by the character with the pink armband. The context video ended just before the emotional reaction of the character with the pink armband, and none of the actors expressed an emotion in the course of the video. In the emotion expression videos, one of the two actors expressed one of the five mental states (i.e., embarrassment, pride, anger, surprise, or neutral expression) in front of the camera. These videos consisted of a medium close-up shot, including both the upper part of the body and the face of the actor.

The material was validated in a series of steps. First, 44 healthy individuals had to indicate the nature of the emotion induced by 210 verbal stories describing everyday social situations. Situations with the highest consensus (N = 152) were filmed in full (i.e., actors acted out the social situation and then expressed the emotion). Next, the videos were cut to create separate context videos and emotion expression videos, and 125 different healthy individuals were asked to assess whether the context and/or emotion expression videos properly conveyed the expected emotions when presented separately. The 152 situations were then shown in full (i.e. context followed by facial expression of emotion) to 22 different healthy individuals, who had to judge the congruence between the emotion felt in each context and the emotion expressed by each face. Based on these pretests, we selected the 60 situations with the highest congruence ratings (for more details, see Supplementary Material, Table 1).

The **context task** featured 20 context videos (four videos for each of the five mental states). The female actor (Mary) was the target of the reasoning (i.e., wearing the pink armband) in half the videos. Participants had to answer two questions for each item. The first question concerned the emotional state of the character wearing the pink armband and took the form of a five-alternative (anger, surprise, embarrassment, pride, or neutral) forced choice. The second question assessed the comprehension and recall of the relevant contextual information needed to properly attribute the mental state (e.g., who hits all the bullseyes?). We computed an emotion reasoning score (total number of correct answers divided by 20) and a control score (max. 20).

The **face task** featured 20 emotion expression videos (four videos for each of the five mental states), half with Peter and half with Mary. Participants had to recognize the emotion expressed by the character by responding to a five-alternative (anger, surprise, embarrassment, pride, or neutral) forced-choice question. We computed an emotion decoding score (number of correct answers divided by 20).

The **context-face task** featured 20 context videos followed by 20 emotion expression videos. This task did not include videos associated with neutral mental states, and there were therefore five videos for each of the four emotional mental states. Both the context and the emotion expression videos differed from those used in the previous tasks. Each item included a context video immediately followed by an emotion video. The actor with the pink armband was systematically the one expressing the emotion at the end. Eight of these expressions were congruent with the context, and 12 were noncongruent (e.g., Peter shows how he builds his biceps doing exercises and then expresses anger). For each item, participants had to answer three distinct questions. The first was a yes-no question about the congruency of the emotional expression with the situation (e.g., "Does the emotion expressed by the character match the context?"). The second was related to the emotional expression and had a four-alternative (anger, surprise, embarrassment, or pride) forced choice (e.g., "What is the emotion expressed by the character?)". The third question assessed the comprehension and recall of the relevant contextual information (e.g., "Who is showing his muscles?"). Matching and emotion attribution scores were computed for the whole task (number of correct answers divided by 20) and for each condition: congruent (number of correct answers divided by 8) and noncongruent (number of correct answers divided by 12). Incorrect emotion attributions in the noncongruent condition were further classified as *context response errors* if the answer corresponded to the emotion associated with the situation (one of the three distractors) or as *random errors* (two of the three distractors). When the context video showed Pierre building his biceps and the emotion expression video showed him expressing anger, the emotion inferred from the context (pride) and the expressed emotion (anger) were noncongruent. The correct and expected answer for emotional expression was *anger*, and *pride* was the context response error, while surprise and embarrassment were not related to the situation (see Fig. 1). Finally, we computed a control score for the comprehension/recall question (i.e., sum of correct responses).

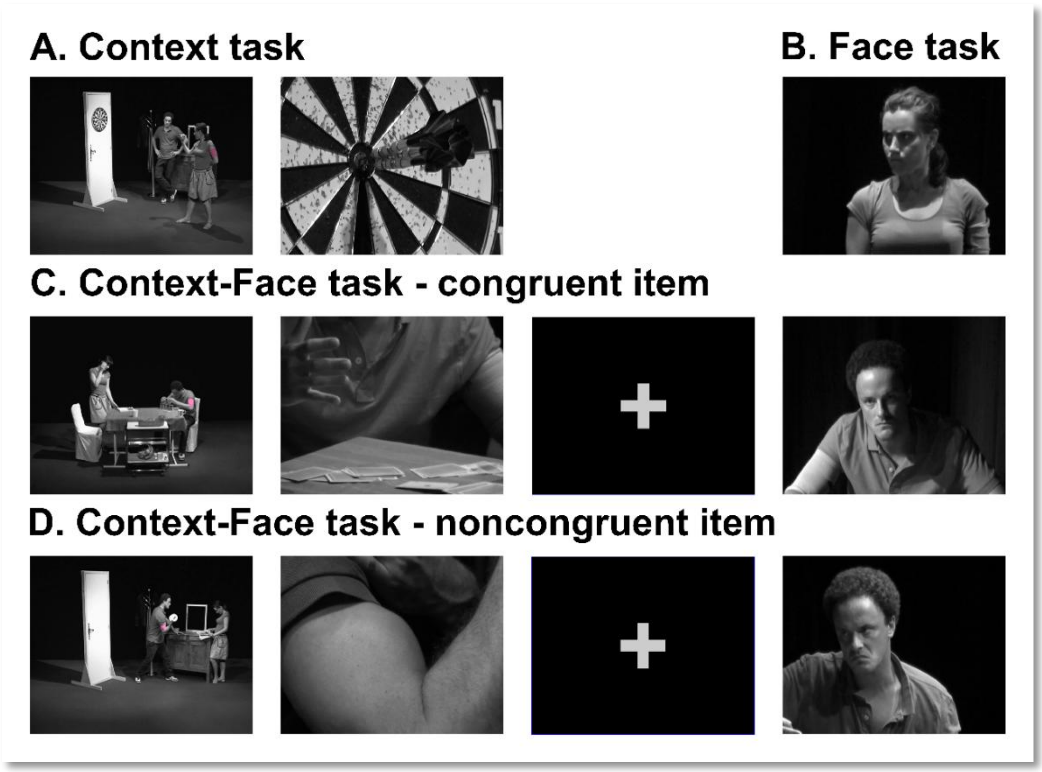

Figure 1. Examples of stimuli for the three tasks taken from the Peter and Mary emotion tasks battery: A) context task, B) face task, and C & D) context-face task. For a description of the situations, see Materials and Methods.

Before administering the Peter and Mary emotion tasks battery, we used a questionnaire to check the participants' knowledge of the four different emotions (anger, surprise, embarrassment and pride). Participants had to provide a synonym for each emotion and describe a situation in which it was possible to feel it. They then had to choose which of four words was closest to the emotion and which of four situations could induce this emotion. There was no significant difference between the groups (all *p*s > .6).

The Interpersonal Reactivity Index

All the patients completed the perspective-taking (PT) and the empathic concern (EC) subscales of the Interpersonal Reactivity Index (IRI; Davis, 1983). Both subscales were made up of seven items rated on a 5-point Likert scale ranging from 1 (*Does not describe me well*) to 5 (*Describes me very well*). The PT subscale, which has been used as a measure of affective ToM, probes the cognitive aspect of empathy, measuring the ability to spontaneously adopt the mental point of view of others, while the EC subscale refers to the emotional aspect of empathy, considering the ability to feel warmth, compassion and concern for others (Davies, 1983).

2.4.Social norm knowledge assessment

All participants underwent a task assessing SNK previously used in a single-case study in AD (Duclos et al., 2017). The task features 44 colour drawings depicting two characters involved in 22 different daily life activities (e.g., using a cellphone, reading a newspaper). Each activity takes place in two different contexts: a context in which the behaviour complies with social rules (e.g., phoning in a train station) versus a context in which the behaviour transgresses social rules (e.g., phoning in a church). For each drawing, participants had to 1) detect items with an infringement, 2) identify the character committing the infringement, and 3) justify their response by describing the broken rule. An SNK score (max. 22) was computed from the number of correct detections where the character committing the infringement was correctly identified and the response was correctly justified.

2.5. Statistical analysis

Statistical analyses were performed using Statistica Version 10 software (StatSoft, Tulsa, OK, USA). The reported values are means and standard deviations. Partial eta-squared and Cohen's *d* effect sizes are reported. For all these analyses, the statistical level of significance was set at $\alpha = .05$. All the analyses described here were also performed with nonparametric tests, which yielded the same results.

Regarding the control scores of the context and context-face tasks, between-group comparisons (HYS vs. HOS vs. AD) were performed using an analysis of variance (ANOVA).

For the context task, the emotion reasoning scores were submitted to an analysis of covariance (ANCOVA) with group (HYS vs. HOS vs. AD) as a between factor and the control score as a covariate.

For the face task, the emotion decoding scores of the three groups were compared using an ANOVA, with group (HYS vs. HOS vs. AD) as a between factor.

For the context-face task, the matching and emotion attribution scores were analysed separately with ANCOVAs, with group as a between factor and the control score (comprehension score) as a covariate. In addition, Pearson's chi-square goodness-of-fit tests were used to compare the AD and HOS groups on the distribution of types of emotion attribution errors in the noncongruent condition. These analyses were repeated in the AD and HOS groups to compare the distribution of errors with chance level. The HYS group made a total of 11 errors and was therefore not included in the latter analysis. For each ANCOVA and ANOVA, homogeneity of the regression slope was checked via the interaction between the control score and the independent variable. Interactions were not significant. ANCOVAs and ANOVAs were followed by post hoc comparisons between the AD and HOS groups and between the HOS and HYS groups (Tukey's honestly significant difference test).

Regarding SNK, we compared the HYS, HOS, and AD groups using an ANOVA with group as a between factor. Finally, partial correlations were computed for patients with AD between the four total affective ToM scores and the SNK score, holding disease severity (as assessed with the MMSE score) constant. As we had formulated a hypothesis, the level of significance for these analyses was set at $p = .01$. To explore the links between cognitive functions and ToM, we performed correlation analyses between the four total affective ToM scores and 1) memory scores and 2) executive function scores. As these analyses were exploratory, we performed multiple comparison corrections with a threshold set at $p = .001$, to guard against false positive findings. Finally, we performed correlation analyses between the decoding and reasoning scores of the battery and the score on the PT subscale of the IRI measuring affective ToM.

3. Results

3.1. Affective ToM

The performances of all the participants on the context task, face task, and the control questions (comprehensions questions) of the context and context-face tasks are set out in Table 3.

ANOVAs indicated a significant group effect for both scores, context and context-face **control** questions, $F_{(2, 57)} = 19.47$, $p < .0001$, $\eta^2 = 0.41$, and $F_{(2, 57)} = 14.56$, $p < .0001$, $\eta^2 = 0.34$. Patients with AD scored lower than HOS ($p < .0001$). Scores did not differ between HYS and HOS participants ($p = .79$).

Table 3. Performances of the HYS group, HOS group and AD group on the context task, face task and control questions (comprehensions questions) of the context and context-face tasks.

		Mean (*SD*)		*F*
	HYS	HOS	AD	
Context task emotion reasoning score	0.96 (± 0.05)	0.87 (± 0.12) †	0.68 (± 0.16) ‡	9.93
Face task emotion decoding score	0.98 (± 0.04)	0.89 (± 0.09) †	0.71 (± 0.14) ‡	38.11
Context task control question	1.00 (± 0.00)	0.99 (± 0.02) †	0.89 (± 0.10) ‡	19.47
Context-Face task control question	0.97 (± 0.03)	0.92 (± 0.06) †	0.86 (± 0.08) ‡	14.56

Note. ‡ A post hoc test (Tukey) indicated a significant difference between HOS and patients with AD at p < .0001, † A post hoc test (Tukey) indicated a significant difference between HYS and HOS at p < .0001.

Regarding the **context task**, the ANCOVA on the emotion reasoning score with the control score (comprehension question) as a covariate indicated a significant group effect, $F_{(2, 57)} = 9.93$, $p < .0002$, $\eta^2 = 0.26$. Patients with AD scored lower than HOS participants ($p < .0001$), who scored lower than HYS participants ($p < .01$).

Regarding the **face task**, the ANOVA on the emotion decoding score indicated a significant group effect, $F_{(2, 57)} = 38.11$, $p < .0001$, $\eta^2 = 0.57$. Patients with AD scored lower than HOS participants ($p < .0001$), who scored lower than HYS participants ($p < .01$).

Regarding the **context-face task**, the ANCOVA on the matching score (question about the congruency between context and emotion) with the control score (comprehension question) as a covariate indicated a significant main group effect, $F_{(2, 113)} = 5.24$, $p < .006$, $\eta^2 = 0.08$, a significant main congruence effect, $F_{(2, 113)} = 33.87$, $p < .0001$, $\eta^2 = 0.23$, and a significant Group x Congruence interaction effect, $F_{(2, 113)} = 13.49$, $p < .0001$, $\eta^2 = 0.19$ (Fig. 2). Post hoc analyses showed no between-group differences for the congruent condition, but a significant difference between groups for the noncongruent condition, with lower performances in the AD group than in the HOS group ($p < .001$), but no difference between the two groups of healthy individuals ($p = .44$). There was a significant difference between performances in the two conditions, with lower performances in the noncongruent condition for AD ($p < .001$), but not for HOS ($p = .49$) or HYS ($p = .98$).

The ANCOVA on the emotion attribution score, with the control score (comprehension question) as a covariate, showed a significant main group effect, $F_{(2, 113)} = 6.56$, $p < .002$, $\eta^2 = 0.10$, a significant main congruence effect, $F_{(2, 113)} = 46.96$, $p < .001$, $\eta^2 = 0.29$, and a significant Group x Congruence interaction effect, $F_{(2, 113)} = 8.83$, $p < .0002$, $\eta^2 = 0.14$ (Fig.

2). Post hoc analyses did not reveal any significant differences between the groups in the congruent condition. There was, however, a significant difference in the noncongruent condition, with lower performances by the AD group compared with the HOS group ($p < .01$). Performances by the HOS group were lower than those of the HYS group in this condition ($p < .0001$). For both the AD and HOS groups, there was a significant difference in performances between the two conditions, with lower scores in the noncongruent condition (both $p < .001$).There was no such difference in the HYS group ($p = .99$).

The distribution of errors (106 errors for patients with AD and 37 for HOS) in the noncongruent condition for emotion attribution (context-response errors vs. random errors) differed between the AD (28% vs. 72%) and HOS (49% vs. 51%) groups, $X^2(2) = 6.31$, $p < .02$. In the AD group, there was no significant difference, $X^2(2) = 0.49$, $p = .48$, between the ratio of error types and chance level (33% vs. 67%). By contrast, HOS participants made almost as many context-response errors as random errors, and the distribution of their errors tended to be significantly different from chance level, $X^2(2) = 2.80$, $p = .09$.

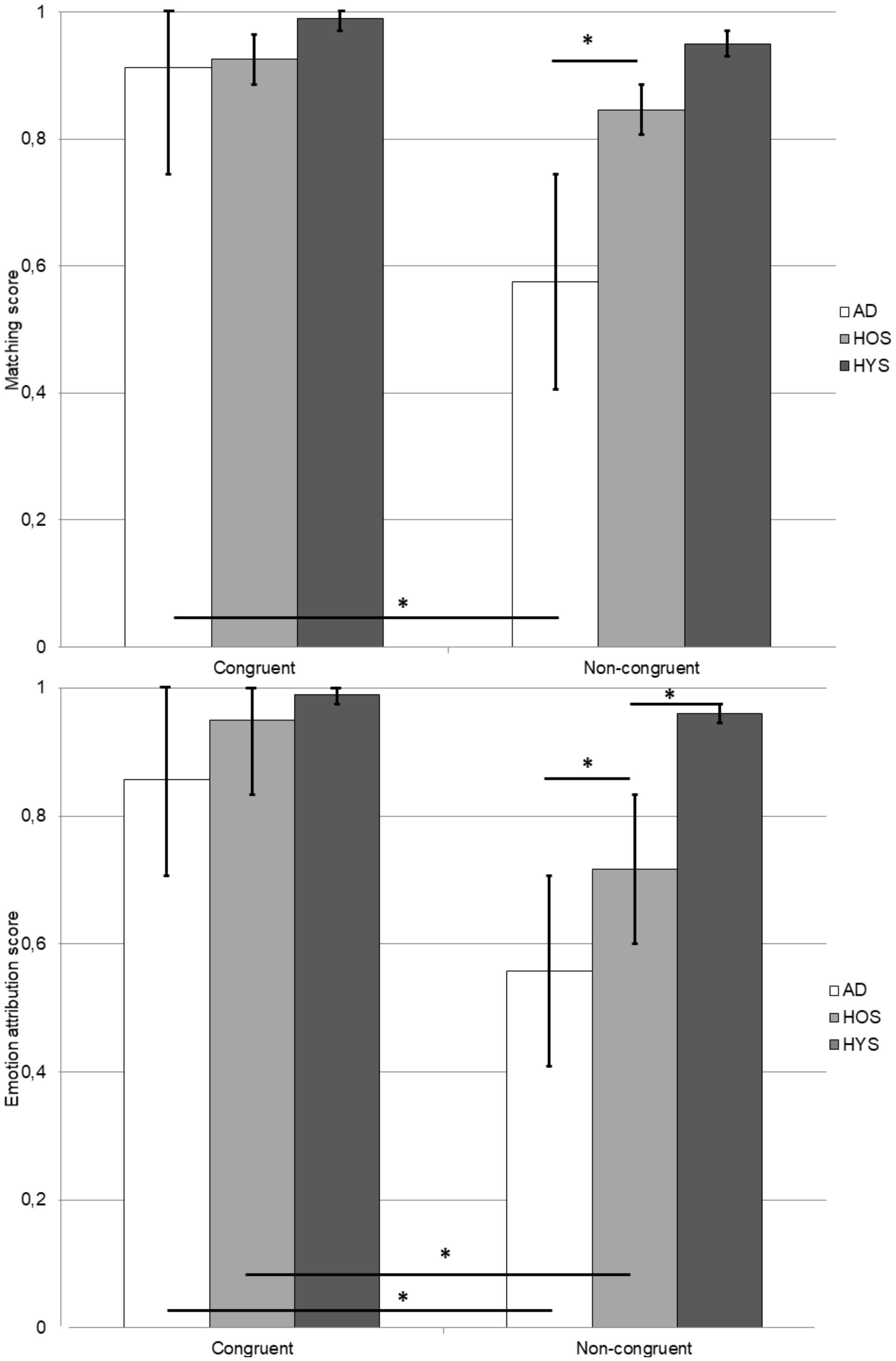

Figure 2. Matching scores (context-face task) and emotion attribution scores (context-face task) of patients with Alzheimer's disease (AD), healthy older participants (HOS) and healthy young participants (HYS). * p < .05 for Tukey's post hoc analyses

3.2. Social norm knowledge task

Regarding the SNK task, the ANOVA on the SNK score indicated a significant group effect, $F_{(2, 57)} = 12.08$, $p < .0001$, $\eta^2 = 0.29$. Patients with AD performed more poorly than HOS ($p < .0002$). Performances did not differ between HOS and HYS ($p = .83$).

3.3. Correlation analyses

Results of the partial correlation analyses in the AD group, controlling for disease severity, are reported in Table 4. We observed significant positive correlations between the SNK score and each of the four total ToM scores of the Peter and Mary emotion tasks battery ($r > 0.53$, $p < .01$). No significant correlations were found between the SNK score and the control scores (comprehension) of the Peter and Mary emotion tasks battery. No significant associations between ToM scores and other cognitive functions were significant at the chosen threshold ($p = 0.001$).

Table 4. Correlation coefficients (*p* values) between the total ToM scores of the Peter and Mary battery and the SNK score.

	Emotion reasoning score (context task)	Emotion decoding score (face task)	Matching score (context-face task)	Emotion attribution score (context-face task)
SNK score	0.53 ($p < .01$)	0.67 ($p < .001$)	0.57 ($p < .006$)	0.60 ($p < .004$)

Note. SNK: Social norm knowledge.

The score on the PT subscale of the IRI was significantly and positively correlated with the emotion decoding ($p < .02$) and emotion reasoning ($p < .05$) scores of the Peter and Mary emotion tasks battery, whereas the EC subscore was not significantly correlated with either score ($p = .77$ and $p = .25$).

4. Discussion

To our knowledge, this is the first study to have investigated both separately and jointly the decoding and reasoning abilities of patients with AD for affective ToM. We found that patients with mild-to-moderate AD had a deficit in their ability to decode emotions from faces and to reason about emotions in a social context. Surprisingly, when the context fitted the emotion expressed by the character, patients performed similarly as age-matched healthy participants on congruency judgment and attribution of facial emotions. By contrast, their performances were impaired when the context was not congruent with the emotion expressed by the character. Finally, as expected, we observed relationships in AD between ToM abilities and social knowledge, regardless of disease severity. Overall, our findings suggest that patients with AD have difficulty reasoning about emotional mental states in context, and highlight the relationships between ToM and SNK.

In our study, patients with AD exhibited impaired decoding of emotional mental states from facial expressions. Despite considerable variations in emotion processing reported across AD studies (see Section 1. Introduction), our findings fit with results showing a deficit in AD for emotion labelling and the matching of emotional expressions (Bucks & Radford, 2004; Cadieux & Greve, 1997; Kumfor et al., 2014).

A major finding of our study is that patients with AD have impaired attribute of emotional mental states from a context in the absence of facial expressions of emotion. The context task required social reasoning processes, as mental states could not be directly decoded from the stimuli that were presented. Our results are in line with several studies that have assessed reasoning processes in AD (Narme et al., 2013; Shany-Ur et al., 2012).

Our results for the IRI are in line with the recent literature, where impairment is only reported for the PT subscale (Dermody et al., 2016; Rankin et al., 2006; Seeley et al., 2007). We found a significant positive correlation between the PT subscore and the ToM assessment in AD, in line with previous reports in patients with FTD or traumatic brain injury (Ibanez et al., 2013; Shamay-Tsoory & Aharon-Peretz, 2007). The correlation between the objective measure of affective ToM and the subjective measure of cognitive empathy suggests an impaired ability to adopt another person's perspective, which is involved in the cognitive dimension of empathy and in ToM.

Various studies of ToM in AD have reported deficits for complex ToM tasks involving reasoning processes (e.g., false-belief tasks) and less impaired performances for tasks involving the decoding of immediately available information (e.g., emotion recognition tasks) (Bora et al., 2016). Although we failed to find any associations between ToM and general cognitive functioning, relationships between ToM deficits and cognitive functioning are often reported (Dermody et al., 2016; Ramanan et al., 2017; Synn et al., 2018). These different results suggest that ToM deficits reflect the general cognitive impairment of patients with AD. However, depending on the ToM task and the methodology employed, different cognitive processes may be involved (e.g., self-perspective inhibition, flexibility, working memory, maintaining and shifting attention). For example, a recent study found that the impaired performance of patients with AD on the faux-pas task are related to deficits in episodic memory and executive functions (Ramanan et al., 2017). Performance on the faux-pas task is known to have several cognitive determinants, such as language, verbal working memory, SNK, and knowledge about emotions. Interestingly, it seems that patients have greater difficulty with cognitive ToM tasks than with affective ToM tasks (Laisney et al., 2013). Goodkind et al. (2015) showed that patients with AD are able to recognize emotions from watching short movie sequences. Patients also perform poorly on cognitively undemanding ToM tasks like the preference judgment task (Laisney et al., 2013), which requires elementary ToM processes. These discrepant results in AD may reflect variations in the tasks' cognitive processing demands. We found that impaired reasoning about mental states persisted even when the comprehension score was taken into account in the analyses, so comprehension disorders alone cannot explain patients' ToM performances. Only 3/20 patients in our study had working memory disorders, compared with half who displayed deficits in the context task. Finally, despite a significant difference between healthy participants and patients with AD, the latter performed well on the comprehension/memory questions (more than 87% correct responses on average), indicating that they properly understood the situations and retained the elements needed to reason about mental states.

When corrected for multiple correlations, our results did not indicate any relationship between ToM performance and either episodic memory or working memory scores. Other authors, however, have shown a link between cognitive ToM and episodic memory in patients with AD (Castelli et al., 2011; Cuerva et al., 2001; El Haj et al., 2015; Le Bouc et al., 2012; Moreau et al., 2013; Synn et al., 2018). It has already been suggested that memory influences ToM, insofar as reasoning about mental states may involve inductive reasoning based on memories of personal interactions that have gradually been constructed across social experiences (Gopnik & Meltzoff, 1997; Gopnik & Wellman, 1992). Memories of past social experiences are presumably useful for understanding social scenarios (Frith & Corcoran, 1996; Moreau et al., 2013), but are not a prerequisite for ToM decoding processes. In addition, building the representations needed for episodic memory recollection and ToM may partly rely on the same cognitive processes that are impaired in AD (Buckner & Carroll, 2006). Our results could be explained by the fact that we used a measure of the anterograde component of memory. Future studies featuring measures of the retrograde component of memory could help to settle this issue.

In addition to poor episodic memory performances, we found a social knowledge impairment in the patients with AD. Although there is currently a debate as to the nature of the relationship between social knowledge and semantic memory, both require intact temporal poles (Panchal et al., 2015; Pobric et al., 2016; Zahn et al., 2007, 2009). Temporal pole damage is known to occur in AD (Galton et al., 2001) as are disturbances in general semantic knowledge (Adlam et al., 2006; Laisney et al., 2009) and knowledge about famous people (Joubert et al., 2008). Interestingly, for the first time, we reported a correlation (taking the degree of cognitive deterioration into account) between social knowledge and the ability to reason about emotion in context in AD, as suggested by Samson's model (2009). Interestingly, we did not find any link between the comprehension question and the SNK task, suggesting that activation of social knowledge only occurs in relevant social situations (Low & Perner, 2012) and should not be regarded as a general mechanism.

We also observed a significant correlation between SNK and the emotion decoding score. This result is in line with Baron-Cohen et al. (1997)'s suggestion that reasoning is required in addition to decoding to infer a social emotion from a face. Furthermore, we used both basic and social emotions, which could explain the correlation with SNK. Social emotions are more meaningful in context, and so by their very nature involve social knowledge. Finally, the videos for the face task featured medium close-up shots that framed the character's head and bust, thus showing not only facial expressions but also upper-body postures. Body posture is an important element when humans make judgments about emotions (de Gelder et al., 2006), and social information can be conveyed by body posture (e.g., a straight back evokes pride).

Interestingly, in the context-face task, when the context and emotion were congruent, patients performed similarly to healthy controls on both matching and emotion attribution. For matching, patients' success could be explained by the binary yes-no form of the answers and a tendency to answer "yes" (i.e., in favour of congruent responses). However, as shown by the post hoc tests for the emotion attribution score, patients not only correctly identified matches, but also correctly attributed emotions. In line with our results, Freedman et al.

(2013) failed to observe impaired performances in patients with AD who had to attribute emotions associated with emotional scenes.

According to Samson (2009)'s theoretical framework, recognizing emotions from faces (as in the face task) mainly relies on bottom-up decoding processes, whereas top-down processing, mostly involving reasoning, is required to attribute mental states (as in the context task). We suggest that patients with AD have difficulty forming complete representations when they only have either the contextual information or the facial expression of emotion to go on. This difficulty is alleviated when the two are congruent. Even if patients' representations are less precise than those of healthy individuals, emotion reasoning in context favours emotion decoding which, in turn, helps to validate the established emotion. Patients may also still have an implicit understanding of the emotions associated with particular situations that allows them to infer an emotion from a situation. This implicit understanding of situations has already been studied in young children (see Low & Perner, 2012, for a review). Thus, there appear to be two distinct systems allowing for a mental state to be understood: an early developing implicit system that is cognitively efficient but inflexible for tracking mental states, and a later developing explicit system that is abstract and conscious (Apperly & Butterfill; 2009; Low, 2010). By contrast, patients failed when the emotion that might be expected given the context was not congruent with the emotion that was subsequently expressed. This result was to be expected, as patients exhibited difficulty in the other two conditions (identification of emotions from faces and according to the context). It is noteworthy that even though HOS had higher matching scores than patients, they performed more poorly than HYS. This suggests that healthy aging is associated with difficulty attributing an emotion in a noncongruent situation.

Emotions were significantly better attributed for congruent items than for noncongruent items by both patients and HOS. However, the error analysis revealed distinct error profiles.

In HOS, half the errors concerned context-response errors (answer reflecting the emotion associated with the context). This response pattern may reflect age-related context adherence (Aviezer et al., 2011; Kret & de Gelder, 2010) linked to impaired inhibition or updating of mental representations. For older individuals, contextual information may be more salient than facial expressions (Noh & Isaacowitz, 2013), but further research is needed to explain why this might be the case.

Overall, our results suggest that patients with AD take account of contextual information in a way that may either help (if congruent) or hinder (if incongruent) the decoding of stimuli within the environment. A context effect has already been highlighted in patients with FTD, who appear to have difficulty gauging how context influences the meaning of stimuli (Baez et al., 2016; Mesulam, 2009). For these patients, behaviours seem to be driven by superficial environmental information, suggesting that they are unresponsive to the congruency between an action and its context. However a recent study showed that the presentation of congruent contextual information improves emotion recognition in FTD (Kumfor et al., 2018). Studies specifically comparing these two pathologies are therefore needed to establish their respective profiles.

Our novel exploration of ToM processes in context enabled us to highlight the different mechanisms involved in emotional mental state attribution in AD. While our results contribute to a better understanding of ToM decoding and reasoning processes, there are other distinctions that can be made in ToM. These distinctions deserve to be assessed in AD, as our results suggest that implicit processes allow patients to recognize emotions and, by extension, to adapt their social behaviour. Nevertheless, the present study had several limitations, starting with the small sample of patients. In addition, the small number of items in each ToM task condition prevented us from comparing the different types of emotion. Further research is therefore needed to establish the precise profile of patients with AD for the attribution of basic and social emotions according to the context, as it is crucial to identify the different processes at play. Furthermore, correlation analyses between ToM and cognitive functioning failed to reveal clear relationships. To better understand the contribution of cognitive functions and ToM processes in social dysfunction, studies on ToM need to minimize the task's cognitive demand. Future studies that combine similar tasks with a more extensive neuropsychological assessment should provide insights into the impairment of patients with AD. In particular, the link between the retrograde component of episodic memory and context deserves exploration.

5. Conclusion

Patients with AD exhibited disturbed affective ToM, at least in the mild-to-moderate stage of the disease, concerning both the decoding of facial emotions and reasoning about these emotions in context. The way they consider contextual information influences the decoding of stimuli in the environment. For the first time, we reported deficits for the SNK task in AD, and showed that this impairment contributes to ToM disturbances. Patients displayed deficits in multiple affective ToM processes, but these difficulties were alleviated by the presentation of congruent information. Ambiguous situations frequently occur in daily life, and patients with AD may have difficulty understanding them. Caregivers therefore need to ensure that patients are given congruent information, in order to minimize the possible confusions that can generate behavioural disorders or anxiety. Our results suggest that tasks involving real-life social scenarios are sufficiently sensitive to be used for clinical assessment in AD. Context is an essential part of social cognition, and future studies will need to take it into account in order to better understand patients' social cognition profiles. Further research is needed to pinpoint the links between the different ToM processes, the effect of context, and the neural bases underlying these processes.

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