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Attention, response inhibition, and hoarding: A neuropsychological examination

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ABSTRACT

Background and aims: The prominent cognitive-behavioral model of hoarding posits that information processing deficits contribute to hoarding disorder. Although individuals with hoarding symptoms consistently self-report attentional and impulsivity difficulties, neuropsychological tests have inconsistently identified impairments. These mixed findings may be the result of using different neuropsychological tests, tests with poor psychometric properties, and/or testing individuals in a context that drastically differs from their own homes. *Methods:* One hundred twenty-three participants (hoarding = 63; control = 60) completed neuropsychological tests of sustained attention, focused attention, and response inhibition in cluttered and tidy environments in a counterbalanced order. *Results:* Hoarding participants demonstrated poorer sustained attention and response inhibition than the control group (CPT-3 Omission and VST scores) and poorer response inhibition in the cluttered environment than when in the tidy environment (VST scores). CPT-3 Detectability and Commission scores also indicated that hoarding participants had greater difficulty sustaining attention and inhibiting responses than the control group; however, these effect sizes were just below the lowest practically meaningful magnitude. Posthoc exploratory analyses demonstrated that fewer than one-third of hoarding participants demonstrated sustained attention and response inhibition difficulties and that these participants reported greater hoarding severity and greater distress in the cluttered room. *Discussion and conclusions:* Given these findings and other studies showing that attentional difficulties may be a transdiagnostic factor for psychopathology, future studies will want to explore whether greater sustained attention and response inhibition difficulties in real life contexts contribute to comorbidity and functional impairment in hoarding disorder.

KEYWORDS

hoarding disorder, attention, response inhibition, mental processes, executive function, cognitive dysfunction

INTRODUCTION

Hoarding disorder (HD) is characterized by a profound inability to discard possessions, and in most cases, the excessive acquisition of products (American Psychiatric Association, 2013; Frost, Tolin, Steketee, Fitch, & Selbo-Bruns, 2009). Hoarding problems emerge during adolescence, and by middle-to-late adulthood, clutter may prevent individuals from relaxing on their living room sofa, sleeping in their bed, cooking a meal in their kitchen, or bathing in their shower or bathtub (Dozier, Porter, & Ayers, 2016; Landau et al., 2011). Frost and colleagues' (Frost & Hartl, 1996; Steketee & Frost, 2003) cognitive-behavioral model of hoarding posits that information processing difficulties contribute to the etiology and maintenance of HD, as these difficulties make it hard to take in, store, and process

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information. For example, attentional problems may impair one's ability to balance the perceived value of a possession with the amount of space available, rendering organizing and disposal decisions challenging. Moreover, attentional difficulties may make it challenging for an individual to persist with sorting and organizing their possessions. In support of these assumptions, individuals who experience hoarding problems consistently self-report attention difficulties that are 1–3 standard deviations above the mean of healthy and clinical controls, with greater inattention being associated with greater hoarding severity (Diefenbach, DiMauro, Frost, Steketee, & Tolin, 2013; Fitch & Cougle, 2013; Frost, Steketee, & Tolin, 2011; Grisham, Brown, Savage, Steketee, & Barlow, 2007; Moshier et al., 2016; Sheppard et al., 2010; Tolin et al., 2018; Tolin & Villavicencio, 2011). Neuropsychological studies, however, suggest that attention difficulties may not be substantial or pervasive among people who hoard (Fitch & Cougle, 2013; Grisham et al., 2007; Mackin, Areán, Delucchi, & Mathews, 2011, 2016; Moshier et al., 2016; Sumner, Noack, Filoteo, Maddox, & Saxena, 2016; Tolin, Villavicencio, Umbach, & Kurtz, 2011; Woody, Lenkic, Neal, Bogod, 2021).

Fluctuating methodologies may be responsible for the mixed findings. First, different neuropsychological tests can produce seemingly conflicting results as many tests are complex in that they are influenced by and may measure more than one aspect of attention or executive function as well as draw upon other cognitive processes (Cohen, 2014; Friedman & Miyake, 2004; Sarter, Givens, & Bruno, 2001). For example, neuropsychological tests that measure or involve attention may also assess response inhibition, and be influenced by working memory, and speed of information processing (Cohen, 2014; Conners, 2000, 2014; Kane & Engle, 2003; Strauss, Sherman, & Spreen, 2006; Stroop, 1935; Woody, Lenkic, Jiang, Bogod, 2021). Second, different testing circumstances can lead to inconsistent findings as cognitive functioning is influenced by both internal factors and situational demands (Chaytor, Schmitter-Edgecombe, & Burr, 2006; Cohen, 2014). Importantly, testing situations that do not mimic the actual everyday environment of an individual may fail to predict everyday functioning (Chaytor et al., 2006). In the case of hoarding disorder, a tidy testing environment may place less demand on a person's attentional abilities than a cluttered environment. Third, unreliable and invalid findings can be produced when neuropsychological tests with poor psychometric properties are used (Strauss et al., 2006). Therefore, studies must use a battery of valid and reliable tests administered under everyday living conditions to fully understand the specific type of attentional difficulties that may contribute to hoarding problems, otherwise an incomplete or inaccurate understanding of attention may proliferate.

Continuous performance tests (CPTs), and the Connors CPT specifically, have been widely employed in hoarding research to measure attention. This computerised task requires participants over a 15 min period to view a series of letters and to press the spacebar each time a letter other than "X" appears. High omission errors, poor detection of targets (high detectability), and slow hit reaction times (HRT) suggest difficulty sustaining attention or maintaining vigilance (i.e., the ability to maintain a consistent response to a target during a continuous and repetitive activity over a long period of time; Cohen, 2014; Sohlberg & Mateer, 2001). High commission errors and fast HRT, on the other hand, indicate inhibitory control or response inhibition difficulties (i.e., an inability to inhibit responding to a particular stimulus; Conners, 2000, 2014). Two studies utilizing the Conners CPT II (Conners, 2000) reported small to medium effects when assessing highly educated adult participants who met diagnostic criteria for hoarding disorder. Hoarding participants were poorer at detecting targets than clinical and community control groups (Grisham et al., 2007) and age and education matched community controls without a current psychiatric disorder (Mackin et al., 2016). Hoarding participants also evidenced slower HRT scores and higher commission scores than clinical and community control groups (Grisham et al., 2007). Studies using the Conners CPT-3 (Conners, 2014) have found no (omission, detectability, HRT scores) to slight differences (HRT Inter-Stimulus Interval Change scores) between adults who met DSM-5 criteria for HD and adults who did not meet criteria for a mental health disorder (Woody, Lenkic, Jiang, et al., 2021; Woody, Lenkic, Neal, et al., 2021). One of these studies randomly assigned participants to complete testing within a standard or cluttered room and did not find that clutter altered performance (Woody, Lenkic, Jiang, et al., 2021).

Researchers have used other CPT variants, such as the University of Pennsylvania CPT (Kurtz, Ragland, Bilker, Gur, & Gur, 2001), Psychology Experiment Building Language CPT (PEBL; Mueller, 2008), and the NeuroTrax Go-No Go task (Dwolatzky et al., 2003). Using the University of Pennsylvania CPT, HD participants evidenced moderately slower HRT scores compared to OCD participants and much slower HRT scores than healthy controls, but no differences were found for commission scores (Tolin et al., 2011). In contrast, on the Neurotrax Go-No Go task, which is like a CPT but designed to chiefly measure response inhibition (Cohen, 2014), HD-only participants did not differ from OCD-only participants, or participants with both OCD and hoarding symptoms when examining omission and commission scores (Moshier et al., 2016). Negligible between-group differences were present when undergraduate university students with nonclinical hoarding symptoms were compared to student controls using the PEBL (commision, omission, and HRT scores; Fitch & Cougle, 2013). However, when examining a clinical sample, a PEBL general attention score was related to hoarding severity (Raines, Timpano, & Schmidt, 2014). This study randomized participants to complete testing within a cluttered or non-cluttered room and found that PEBL scores did not vary between conditions. The use of a between-subjects design in this study and the one mentioned above may have obscured the impact that clutter has on an individual's cognitive functioning, whereas the inconsistent CPT findings across studies may be due to using different comparison groups, different CPTs, and the inclusion of CPT scores with low test-retest stability (PEBL CPT omissions scores: $r = 0.10$; Piper, 2012; HRT from the Conners CPT II: $r = <0.59$; Strauss et al., 2006).

The Symbol Digit Modalities Test (SDMT; Smith, 2002), which calls for attentional focus, working memory, and rapid speed of information processing, also has been used in hoarding research (Cohen, 2014; Woody, Lenkic, Jiang, et al., 2021). The SDMT requires participants to read out different numbers as quickly as possible by pairing symbols with a number key shown at the top of a test form. Focused attention is needed because the task demands that an individual respond in a directed manner (Cohen, 2014; Strauss et al., 2006). Individuals with late life depression and compulsive hoarding obtained moderately worse (but not statistically different) scores compared to those with late life depression alone (Mackin et al., 2011). This finding was not replicated in two other studies when comparing middle-aged adult participants with a DSM-5 diagnosis of HD to community controls without a current psychiatric disorder (Mackin et al., 2016; Woody, Lenkic, Neal, et al., 2021). The small sample ($n = 7$) in the first study may have led to an unreliable finding (Mackin et al., 2011).

Although the Stroop test has been used by some hoarding researchers as a measure of attention (Moshier et al., 2016; Stolcis & McCown, 2018; Sumner et al., 2016; Tolin et al., 2011), it is a test of inhibitory control (Cohen, 2014; Kane & Engle, 2003; Strauss et al., 2006). The original version of the Stroop test consists of three cards and four timed trials. The first card and trial requires participants to read the name of colors (blue green, red, brown, purple) printed in black ink. The second card and trial requires participants to read the names of colors (blue green, red, brown, purple) while ignoring the different colors (blue, green, red, yellow) in which they are printed. The third card and trial requires participants to name colored squares (blue green, red, brown, purple). Finally, the fourth trial involves participants being given the second card again, but this time, participants must name the color in which the words are printed and disregard the verbal content (Strauss et al., 2006). As such, the Stroop test requires an individual to switch between tasks (i.e., cognitive flexibility) while selectively attending to competing stimuli to inhibit a habitual response in favor of a more effortful response (i.e., response inhibition; Cohen, 2014; Strauss et al., 2006; Stroop, 1935). When response speed slows due to inhibition of a habituation response an interference effect is evident (Cohen, 2014). Individual differences in working memory capacity (Kane & Engle, 2003), and other cognitive functions such as short-term memory, speed of information processing, semantic knowledge and conceptual abilities may also contribute to the Stroop interference score (Strauss et al., 2006).

There are several versions of the Stroop test which differ from the original in the number of cards (Delis, Kaplan, & Kramer, 2001), use of different stimuli (Delis et al., 2001; Dwolatzky et al., 2003; Regard, 1981), and the number of items contained on each card (Delis et al., 2001; Golden & Freshwater, 2002; Regard, 1981; Strauss et al., 2006). When using the Golden version of the Stroop Color Word Test (SCWT; Golden & Freshwater, 2002), HD participants evidenced a similar reading speed to community controls without a current psychiatric disorder and to OCD controls (Mackin et al., 2016; Tolin et al., 2011). Likewise, no differences were present between HD individuals and healthy controls when using the Delis-Kaplan Executive Function System Color Word Interference Test (Delis et al., 2001; Sumner et al., 2016; Woody, Lenkic, Neal, et al., 2021). Small differences, however, were found when comparing individuals with HD to individuals with OCD using the NeuroTrax Stroop Interference Test (Dwolatzky et al., 2003; Moshier et al., 2016) and moderate differences were found when comparing a sample of older individuals with comorbid hoarding and depression to individuals only experiencing late life depression using the SCWT (Mackin et al., 2011). Moreover, hoarding severity was moderately related to Stroop scores when using a computerized Stroop test (Keiser, 2006; Stolcis & McCown, 2018). These discrepant Stroop findings could be the result of using multiple methods of scoring, different comparison groups, and different versions of the Stroop task, which may examine different underlying processes, and/or which may lack normative data (Scarpina & Tagini, 2017; Strauss et al., 2006).

As can be seen, methodological differences across studies may have contributed to the mixed findings within the hoarding and attention literature. First, the use of different neuropsychological tests across studies and their inherent complexity may have led to discrepant findings. Additionally, the use of clinical control groups may have influenced outcomes as attentional difficulties seem to be a transdiagnostic factor that contributes to various psychopathologies (Abramovitch, Short, & Schweiger, 2021). Moreover, the reliance on between-subjects designs may have obscured the impact that everyday clutter has on a given individual's functioning.

To improve upon past methodology, we used a mixed design to examine differences between individuals who reported substantial discarding, acquiring, and clutter difficulties (hoarding group) to individuals who denied any discarding, acquiring, and clutter difficulties (control group) and across settings (tidy vs cluttered). To accommodate the within-subjects aspect of the design, we needed to use neuropsychological tests that have alternate forms with high-test retest reliability. We additionally utilized a battery of tests that gauged different abilities to obtain a thorough understanding of attentional difficulties within one study. We used the CPT-3 to assess sustained attention and response inhibition, the SDMT to assess focused attention, and the Victoria Stroop Test to measure response inhibition. It is important to note that attention and response inhibition are often captured together, not only on neuropsychological tests, but also on self-report measures in the form of impulsivity (e.g., Barkley & Murphy, 1998; Patton, Standford, & Barratt, 1995). Importantly, impulsivity is also presumed to be a risk factor for hoarding disorder (Frost & Hartl, 1996; Steketee & Frost, 2003).

We hypothesized that clutter would negatively impact hoarding participants' performance, such that participants in the hoarding group would perform worse on tests of attention and response inhibition in a cluttered environment compared to control participants and compared to being in a tidy environment.

METHODS

Participants

Individuals aged 18 and older, who found it easy or difficult to throw away items they no longer needed, were recruited through flyers, social media advertisements, and SONA (research and participant pool management software) to participate in a study examining if attention impacts emotional attachment to possessions. Interested individuals completed an online screener, consisting of the Savings Inventory Revised (SI-R; Frost, Steketee, & Grisham, 2004), demographic questions, and one reading validity item. Participants were eligible for the study if they answered the reading validity item correctly and if they could be allocated to the hoarding or control group. To be assigned to the hoarding group, participants must have had an SI-R total score greater than or equal to 43, a discarding subscale score of 15 or above, an excessive acquisition subscale score of 11 or above, and a clutter subscale score of 17 or above on the of the SI-R (Frost et al., 2004). These clinical cut-offs were chosen as they have high sensitivity and specificity for a diagnosis of HD in individuals under 40 years of age (Kellman-McFarlane et al., 2019). Participants were allocated to the control group if they scored within 1/2 SD of the non-clinical total SI-R mean (30 or less) and within 1/2 SD of the non-clinical means for all the SI-R subscales (12 or less on the SI-R discarding subscale, 9 or less for the acquisition subscale and 12 or lower on the clutter subscale; Kellman-McFarlane et al., 2019). Individuals who were color-blind were excluded from this study.

Measures

Demographics. We assessed age, sex, education level, and ethnicity.

Hoarding severity. The Savings Inventory Revised (SI-R; Frost et al., 2004) is a 23-item self-report questionnaire that assesses excessive acquisition, difficulty discarding, and problems with clutter. The SI-R has demonstrated good test-retest reliability ($r = 0.86$) and strong (total score: $\alpha = 0.92 - 0.94$) to acceptable levels of internal consistency (subscale scores: α range = 0.73 – 0.93; Frost et al., 2004). Internal consistency was excellent in the current sample for the total score ($\alpha = 0.98$) and the acquiring ($\alpha = 0.92$), difficulty discarding ($\alpha = 0.93$) and clutter subscales ($\alpha = 0.95$).

Acute distress. Six negative emotions (embarrassed, disgusted, sad, guilty, anxious, stressed) were measured using a self-reported Visual Analogue Scale (VAS) anchored from 0 (*not at all*) to 100 (*very*) in each room before initiating neuropsychological testing. Scores within each room were averaged to obtain a negative emotions score. VAS have demonstrated good reliability and validity in both clinical (Folstein & Luria, 1973) and non-clinical populations (Ahearn, 1997). In the current sample, internal consistency was good for both administrations (α range = 0.81 – 0.88).

Clinician-administered neuropsychological tests. The Test of Premorbid Functioning (TOPF; Pearson Clinical, 2009) requires individuals to read out loud 70 atypically pronounced words of increasing difficulty and was administered to obtain an estimate of participants' intellectual functioning. We had intended to use TOPF scores as a covariate in our hypothesis testing, but later abandoned their use. A large proportion of participants in this study unexpectedly reported being from culturally and linguistically diverse backgrounds with a primary language other than English, and TOPF scores likely would have underestimated their premorbid intellectual functioning (Carstairs, Myors, Shores, & Fogarty, 2006; Holdnack, Schoenberg, Lange, & Iverson, 2013).

The Conners Continuous Performance Test 3rd edition (CPT3; Conners, 2014) is a 14 min, 360 trial computerized test shown to be sensitive to sustained attention and response inhibition (Cohen, 2014; Conners, 2014; Strauss et al., 2006). Participants view a series of letters and press the spacebar each time a letter other than "X" appears. CPT scores are age and gender standardized T-scores, in which the mean is equal to 50 and the standard deviation is equal to 10. Higher T-scores reflect a worse ("*elevated*" to "*very elevated*") performance, apart from HRT scores, in which higher scores reflect a "*slow*" to "*atypically slow*" performance and lower scores reflect "*a little fast*" to an "*atypically fast*" performance (Conners, 2014). Atypical scores are higher than 60 (lower than 45 and higher than 60 for HRT).

This study only examined CPT3 indices that have evidenced good test-retest reliability. Good test-retest reliability within an interval of one to five weeks has been reported for CPT detectability scores [how well a participant discriminates between non-targets ("X") and all other letters (targets), $r = 0.74$], omission scores (how often a participant fails to respond to all letters except "X", $r = 0.83$), HRT scores (reaction time to the nearest millisecond for correct responses to all non "X" letters, $r = 0.89$), and commission scores (incorrect responses to the letter "X", $r = 0.85$; Conners, 2014; Strauss et al., 2006). Omission and detectability scores are used to index inattentiveness/sustained attention, and depending on HRT scores, sustained attention (high scores/slow response) or response inhibition (low scores/fast response). Commission scores can index either inattentiveness or impulsivity/response inhibition.

The Symbol Digit Modalities Test oral version (SDMT; Smith, 2002) is a motor free test of information processing speed, in which participants focus on reading out as quickly as possible different numbers that are paired with symbols in a key at the top of a test form. The number correct within 90 s is recorded out of a maximum score of 110. A lower score on the SDMT (a slower speed of information processing) reflects poorer attentional focus. For this study, two alternate forms of the SDMT (B and C), developed by Hinton-Bayre, Geffen, and McFarland (1997) were used. These alternate forms demonstrate excellent alternate form comparability (*ICC* range = 0.88–0.99) and reasonable test-retest reliability with intervals of 1–2 weeks (A. D. Hinton-Bayre et al., 1997; *r* range = 0.72–0.74; A. Hinton-Bayre & Geffen, 2005). The SDMT has been shown to be sensitive to information processing speed impairment and its scores are strongly correlated with other tests of information processing speed (A. Hinton-Bayre & Geffen, 2005; Strauss et al., 2006).

The Victoria Stroop Test (VST; Regard, 1981) is a brief version of the Stroop task, measuring cognitive flexibility and response inhibition (Cohen, 2014; Regard, 1981; Strauss et al., 2006). The VST consists of three timed trials, each of 24 items, administered successively that require individuals to name the color of dots, the color in which neutral words are printed, and colored words printed in incongruent colors (Troyer, Leach, & Strauss, 2006). A difference (interference) score was generated from the ratio of time to name colored words printed in incongruent colors/time to name colored dots. An interference effect is demonstrated when a participant's naming speed slows down due to inhibiting an automatic response (reading words) for a more effortful response (naming colors; Strauss et al., 2006). Lower scores (a faster response time) indicate better response inhibition. The VST has excellent test-retest reliability for time taken to name the color of dots ($r = 0.90$), neutral words ($r = 0.83$) and color words printed in contrasting colors ($r = 0.91$; Strauss et al., 2006). Low to moderate correlations among VST trials suggest they are associated but not identical abilities (Pineda & Merchan, 2003). Because the VST is a briefer test and participants have less time to improve from practice, it has been shown to be relatively independent of cognitive speed, and preferable to other Stroop variations (Strauss et al., 2006). As a result, the VST may be more sensitive in identifying difficulties with response inhibition than other Stroop tests (Troyer et al., 2006).

Experimental rooms. This study utilized two experimental conditions, the first was a cluttered living room intended to mimic hoarding participants' home environment, and the second was a tidy office designed to mimic a neuropsychologist's office. The tidy office condition was devoid of clutter. In contrast, the living room was covered with commonly hoarded items (magazines, books, clothing, toys, videos, DVDs) and required clinical attention, representing a level 4 on the CIR scale (Frost, Steketee, Tolin, & Renaud, 2008). Only one cushion on the sofa was left clear for the participant to use. A small circular end table sat in front of the participant, and they had to clear it of items if they wished to use it in the study. Otherwise, participants could place study materials (e.g., laptop and forms) on their lap using a portable cushion desk. The researcher was required to sit on a very small segment of the chaise that was free of objects (See Fig. 1).

Procedure

Participants provided informed consent in the waiting room upon arrival to the laboratory. Following this, participants' room allocation order was determined by a counterbalanced randomization schedule produced by a random number generator to eliminate order effects. If assigned to the uncluttered environment first, the researcher said nothing as they led the participant to the room. If the participant was assigned to the cluttered environment first, the researcher told the participant that the room was being used for another study and that they would move into the intended room for current study once it became available.

Once inside the first testing environment, the experimenter administered the TOPF, SDMT, CPT-3 and VST to participants in a randomized order determined by a random number generator. After completing this neuropsychological battery, participants had a five-minute break while the researcher set up the testing the next room. After the break, the researcher informed participants that they would change rooms. If moving from the cluttered environment to the uncluttered environment, participants were told their room

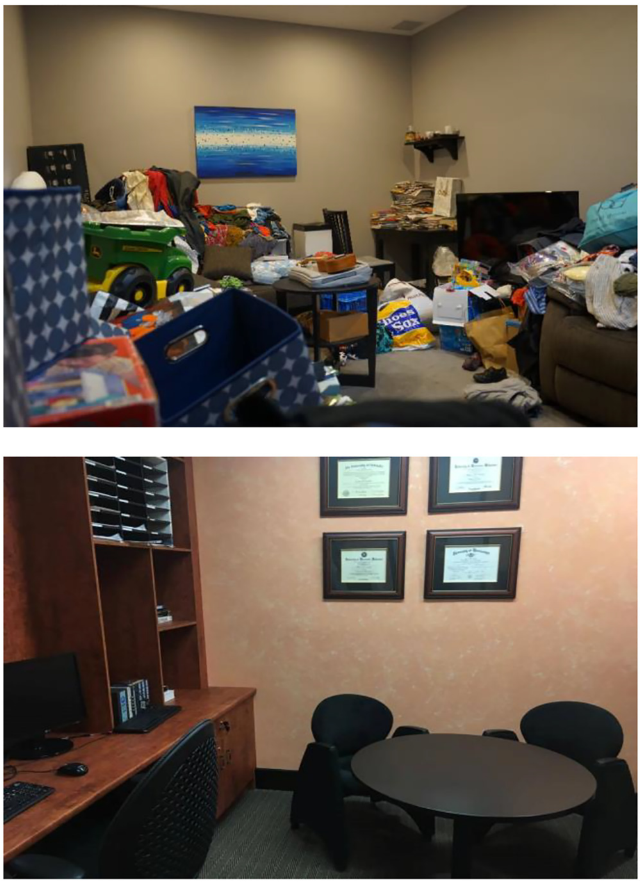

Fig. 1. Pictures of the cluttered room (top) and uncluttered room (bottom)

had become available. If moving from the uncluttered environment to the cluttered environment, participants were told that they had been unable to book their room for the duration of the study and needed to move. After moving into the cluttered room, participants were instructed that the room was meant for another study.

In the second testing environment, participants again completed the VST, CPT-3 and the alternate form of the SDMT in a randomized order. Upon completion of the study, participants were debriefed and compensated with either $40 or course credit for their participation.

Statistical analysis

When interpreting p-values, alpha was set at 0.05 and effect sizes were considered. We followed the recommendations of Ferguson (2009) and used $d = 0.41$ as the lowest practically significant effect size. We did not adjust the alpha level of each test because each test provided only one opportunity to make a Type I error (Rubin, 2021). In other words, each test was interpreted based on the specific facet of attention studied rather than as an overall indication of attentional problems or lack thereof. Group (hoarding vs. controls) demographic and clinical characteristics were compared by using chi-square and independent samples t-tests.

Generalized estimating equations (GEE) assessed performance differences between a cluttered and tidy environment, accounting for the correlation among repeated measurements. We specified a normal distribution with the identity link function. Data either appeared normal, or in the case of CPT Omission and CPT Commission scores, parameter estimates were assumed to be normal by the central limit theorem (Lumley, Diehr, Emerson, & Chen, 2002).

As it is common for healthy individuals to demonstrate variability in test performance, related to affect, education, sex, and IQ, rather than an underlying difference (Brooks, Strauss, Sherman, Iverson, & Slick, 2009; Cohen, 2014; Holdnack et al., 2017), our hypothesis testing took this into account. Gender, age, education, and negative emotions served as covariates when examining VST and SDMT raw scores, but only education and negative emotions served as covariates when examining CPT T-scores because CPT standardized scores are age and gender adjusted. Pairwise comparisons, which considered covariates, were conducted with least square means contrasts from the GEE models, to test whether hoarding participants performed worse on tests of attention in a cluttered environment compared to a tidy environment and whether hoarding participants performed worse in a cluttered environment compared to controls without hoarding problems. When room by group interactions were non-significant in a GEE model, they were removed, and the main effects of room and group were explored.

Before testing study hypotheses, we examined whether random assignment to first room impacted neuropsychological performance using a series of GEE models. The first room in which people were assigned did not impact performance ($p > 0.41$ in all models), and therefore, room order was not included as a covariate in later models.

Ethics

The study procedures were carried out in accordance with the Declaration of Helsinki. This study was approved by the Human Research Ethics Committee at Macquarie University. All participants provided informed consent before taking part in the study.

RESULTS

Sample characteristics

One hundred thirty-one participants agreed to participate. CPT data were not available for 8 participants, either due to computer malfunction or the CPT-3 determining responses were invalid. Thus, 123 (60 control; 63 hoarding) participants were included in analyses.[1]

Table 1 presents sample characteristics. Participants in the hoarding group were more likely to be recruited from the community than the control group but did not significantly differ from the control group on age, education, gender distribution, or ethnicity distribution. By design, the hoarding group reported more severe hoarding problems. Hoarding participants reported having discarding difficulties for an average of 10 years.

When exposed to the tidy environment, hoarding participants reported slightly more distress than control participants, but this trend was not seen for the cluttered environment. In both rooms, distress was low for both groups (e.g., VAS negative emotions score of 15 or less on a 100-point scale).

CPT-3 detectability and omission scores: inattentiveness/sustained attention

There was an interaction between room and group for CPT-3 omission error scores, $\widehat{\beta} = 3.41, SE = 1.65, p = 0.04$ (See Fig. 2). Pairwise comparisons showed that although the hoarding group evidenced similar attentiveness in the cluttered and tidy environments, $\chi^2(1, N = 123) = 2.66, p = 0.10,\ d = 0.20\ (-0.04 - 0.45)$, that they more often failed to respond to all letters except "X" in the cluttered environment than the control group, $\chi^2(1, N = 123) = 6.12, p = 0.01, d = 0.45\ (0.09 - 0.80)$.

There was not a statistically significant interaction for CPT-3 detectability scores, $\widehat{\beta} = 1.43, SE = 1.10, p = 0.20$, or a main effect of room, $\widehat{\beta} = -0.21,\ SE = 0.63,\ p = 0.74, d = 0.02\ (-0.15 - 0.20)$. There was a statistically significant main effect for group, $\widehat{\beta} = -4.29,\ SE = 1.93,\ p = 0.03, d = 0.40\ (0.05 - 0.76)$. Hoarding participants showed greater inattentiveness in that they had more difficulty discriminating between non-target letters ("X") and target letters than did control participants. However, the effect size difference between groups was just below the

[1]Models that included gender as a covariate involved 122 participants as one transgender individual could not be included in the analysis due to statistical limitations.

Table 1. Sample characteristics

Variable	Control (N = 60) M (SD)/n (%)	Hoarding (N = 63) M (SD)/n (%)	Group difference
Age	24.42 (9.88)	27.95 (11.84)	t (121) = −1.79
Recruitment Pathway			
SONA	41 (68%)	6 (10%)	
Community	19 (32%)	57 (89%)	χ^2 (1) = 45.02***
Years of Education	14.15 (2.71)	14.91 (2.33)	t (121) = −1.64
Gender			
Male	21 (35%)	16 (25%)	
Female	39 (65%)	46 (73%)	
Transgender/Intersex[a]	0 (0%)	1 (2%)	χ^2 (1) = 1.22
Ethnicity			
Anglo-Australian	18 (30%)	13 (21%)	
Asian	27 (45%)	33 (52%)	
European	5 (8%)	8 (13%)	
Other	10 (17%)	9 (14%)	χ^2 (3) = 2.08
Saving Inventory-Revised			
Total	16.30 (6.61)	58.24 (9.20)	t (121) = −29.60***
Acquiring	5.53 (2.25)	17.65 (3.95)	t (99.38) = −20.04***
Discarding	5.50 (3.02)	19.33 (3.15)	t (121) = −24.84***
Clutter	5.27 (3.02)	22.27 (4.19)	t (112.84) = −25.93***
Activities of Daily Living-Hoarding	1.24 (0.31)	1.95 (0.71)	t (86.09) = −7.19***
Years of Discarding Difficulties	–	10.37 (8.43)	
VAS Negative Affect			
Tidy	4.27 (5.79)	9.94 (12.31)	t (91.73) = −3.29**
Clutter	9.48 (12.69)	15.11 (18.63)	t (109.73) = −1.97

Note. VAS = Visual Analog Scale. [a]As cells had less than 5 counts, this response was excluded from analysis. **p < 0.01, ***p < 0.001.

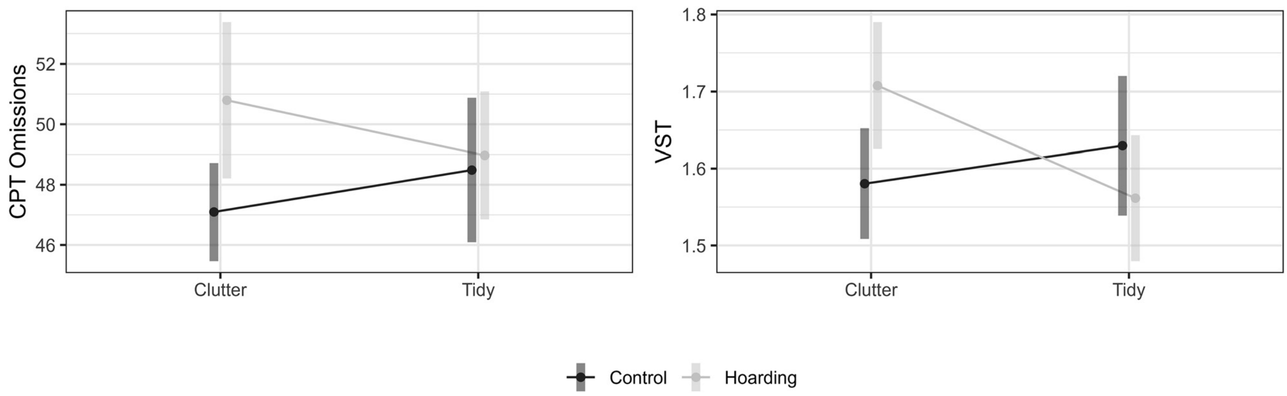

Fig. 2. Interaction plots for CPT omission scores and VST scores. For all CPT scores, differences between clusters were statistically significant

lowest practically significant magnitude, which suggests this difference may not be clinically meaningful.

CPT-3 commission scores: inhibitory control/response inhibition

There was not a statistically significant interaction for CPT-3 commission error scores, $\widehat{\beta} = 0.62, SE = 0.97, p = 0.52,$ or a main effect of room, $\widehat{\beta} = -0.91,\ SE = 0.67,\ p = 0.17,$ $d = 0.12\ (-0.05 - 0.30)$. However, there was a main effect for group, $\widehat{\beta} = -4.34, SE = 2.05,\ p = 0.03,\ d = 0.38$ $(0.29 - 0.74)$. Hoarding participants responded incorrectly to more non-target letters (“X”) than did control participants; however, given the effect size was slightly below the lowest practically important value, this difference may not be clinically meaningful.

CPT-3 HRT: sustained attention or response inhibition

There was not a statistically significant interaction for CPT-3 HRT scores, $\widehat{\beta} = -0.29, SE = 0.71, p = 0.69,$ or a main effect of room, $\widehat{\beta} = -0.48,\ SE = 0.39, p = 0.22,\ d = 0.11$ $(-0.07 - 0.29)$, or a main effect of group, $\widehat{\beta} = -0.79,$ $SE = 1.37, p = 0.56, d = 0.10\ (-0.25 - 0.46)$. See Table 2 for least square means and standard errors by group and condition.

Table 2. Least square means and standard errors for attentional measures by group and room

Variable	Control (N = 60) Tidy M (SE)	Control (N = 60) Clutter M (SE)	Hoarding (N = 63) Tidy M (SE)	Hoarding (N = 63) Clutter M (SE)
VST	1.62 (0.05)	1.57 (0.04)	1.55 (0.04)	1.70 (0.04)
SDMT	66.07 (1.09)	65.14 (1.37)	63.13 (1.26)	63.63 (1.23)
CPT-3 Detectability	48.62 (1.45)	48.08 (1.31)	52.20 (1.38)	53.09 (1.48)
CPT-3 Omissions	48.56 (1.24)	47.04 (0.84)	48.90 (1.07)	50.79 (1.29)
CPT-3 Commissions	49.55 (1.48)	50.14 (1.38)	53.58 (1.50)	54.80 (1.53)
CPT-3 HRT	46.34 (0.84)	46.96 (0.89)	47.27 (1.15)	47.61 (1.11)

Note. VST = Victoria Stroop Test. SDMT = Symbol Digit Modalities Test. CPT-3 = Conners Continuous Performance Test 3rd edition. HRT = Hit Reaction Time.

VST: response inhibition

There was an interaction between room and group for VST scores, $\widehat{\beta} = 0.19, SE = 0.06, p = 0.002$ (See Fig. 2). Pairwise comparisons showed that within the cluttered environment, hoarding participants had greater difficulty inhibiting their automatic reading response, $\chi^2(1, N = 122) = 5.59$, $p = 0.02, d = 0.42$ $(0.07 - 0.78)$ and that the hoarding group demonstrated greater susceptibility to interference when in the cluttered environment than when in the tidy environment, $\chi^2(1, N = 122) = 11.05$, $p<0.001, d = 0.42$ $(0.17 - 0.67)$. See Table 2 for least square means and standard errors by group and condition.

SDMT: attentional focus

There was no interaction between room and group for SDMT speed of information processing scores (attentional focus), $\widehat{\beta} = 1.43, SE = 1.68, p = 0.39$. Likewise, there was no effect of room, $\widehat{\beta} = 0.19, SE = 0.87$, $p = 0.82$, $d = -0.02$ $(-0.20 - 0.16)$, or group, $\widehat{\beta} = 2.22$, $SE = 1.43$, $p = 0.12$, $d = -0.28$ $(-0.63 - 0.07)$.

Posthoc exploratory analyses

Examining participants as a whole may be misleading. Some individuals do not seem to mind the clutter within their homes (Frost, Tolin, & Maltby, 2010); therefore, clutter may only impact some people's performance. To explore this posthoc hypothesis, we conducted a combination of hierarchical and k-means cluster analysis, using z-scores from the neuropsychological tests completed in the cluttered room, to identify if attentional performance clustered in meaningful ways among hoarding participants. First, hierarchical cluster analysis using the average linkage clustering

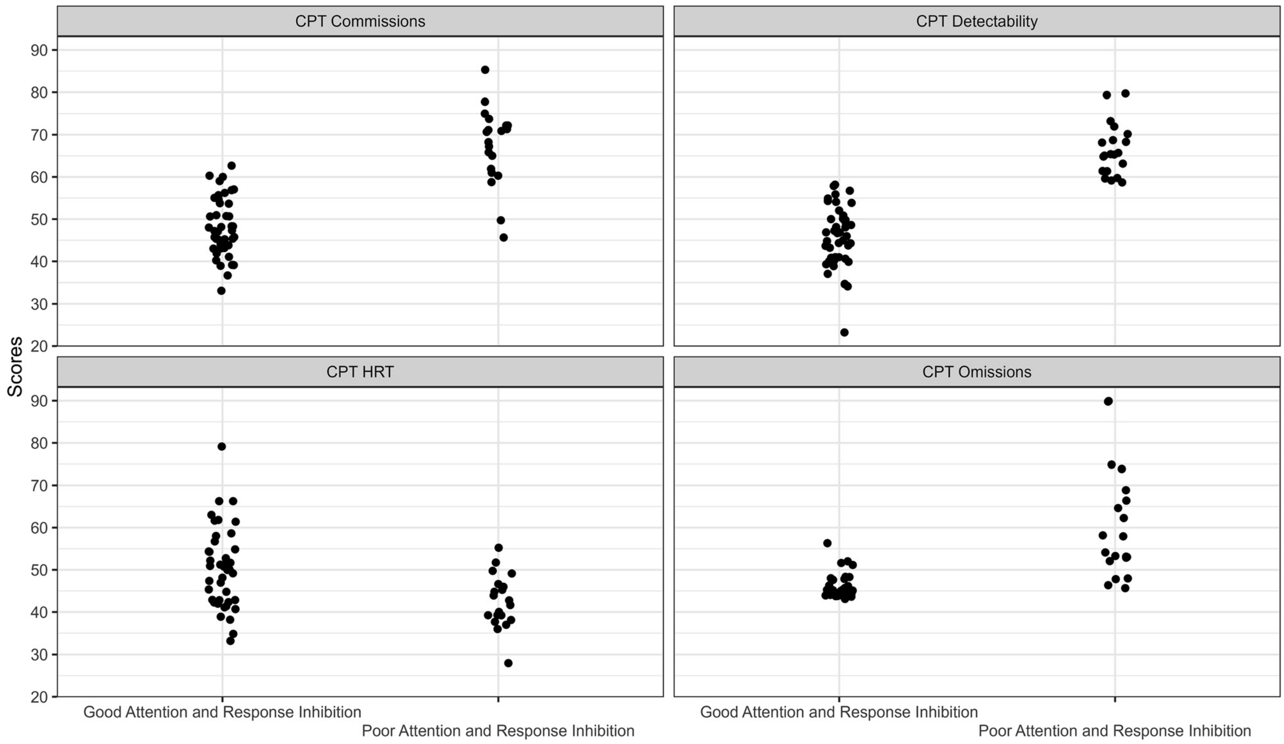

Fig. 3. Mean CPT scores for a two-cluster model. For all CPT scores, differences between clusters were statistically significant

Table 3. Saving inventory-revised scores for cluster groups

Variable	Poor Attention and Response Inhibition Group (N = 18) M (SD)/N (%)	Good Attention and Response Inhibition Group (N = 45) M (SD)/N (%)	$t(df)/\chi^2$ (df)	Cohen's d/φ
SI-R Total	64.50 (11.33)	57.13 (7.34)	t (22.94) = 2.55**	0.85
SI-R Acquiring	19.44 (4.05)	16.93 (3.71)	t (61) = 2.36*	0.66
SI-R Discarding	20.50 (3.82)	18.87 (2.75)	t (61) = 1.90*,a	0.53
SI-R Clutter	24.56 (5.07)	21.36 (3.43)	t (61) = 2.90**	0.81
VAS NA Tidy	15.07 (15.94)	7.88 (10.01)	t (22.56) = 1.78*	0.60
VAS NA Clutter	13.93 (17.94)	15.58 (19.08)	t (61) = −0.32	−0.09
Age	23.17 (5.25)	29.87 (13.18)	t (60.99) = −2.89**,a	−0.58
Education	14.92 (3.03)	14.92 (2.02)	t (61) = 0.008	0.002
Gender			$\chi^2 = 0.16$	0.05
Male	5 (29.4%)	11 (24.4%)		
Female	12 (70.6%)	34 (75.6%)		

Note. SI-R = Saving Inventory – Revised. VAS = Visual Analog Scale. NA = Negative Affect. SI-R Discarding (U = 306, p = 0.13) and age (U = 509, p = 0.11) were not found to significantly differ when potential cluster differences were examined with Mann-Whitney tests.
* = $p < 0.05$; ** = $p < 0.01$.

method and squared Euclidean distance as the similarity measure suggested retaining two or three clusters. We then explored retaining two to three clusters using k-means cluster analysis. SDMT and VST scores were shown not to contribute to clustering, so these scores were removed and the analyses were reran. Using only CPT scores, hierarchical cluster analysis again suggested retaining two or three clusters. Based on interpretability and the silhouette results, we settled on a k-means two cluster solution (Good Attention and Response Inhibition, n = 45; Poor Attention and Response Inhibition, n = 18). The Poor Attention and Response Inhibition cluster had moderately to substantially worse CPT scores than the Good Attention and Response Inhibition cluster (d range = −1.10 – 2.83; See Fig. 3). The Poor Attention and Response Inhibition cluster reported greater negative affect in the tidy room and higher SI-R scores than the Good Attention and Response Inhibition cluster (See Table 3).[2]

DISCUSSION

This study sought to examine the effects of clutter on sustained attention, response inhibition and focused attention using psychometrically strong standardized neuropsychological tests. We hypothesized that clutter would negatively impact hoarding participants' performance, such that hoarding participants would evidence poorer performance on neuropsychological tests in a cluttered environment compared to a tidy environment, and that they would perform worse in a cluttered environment than would control participants without hoarding problems. In support of study hypotheses, hoarding participants demonstrated poorer sustained attention in the cluttered environment than did the control group, when they failed to respond to all letters except "X" to a greater degree (CPT omission scores). Hoarding participants also exhibited poorer response inhibition in the cluttered environment than when in the tidy environment as evidenced by higher VST scores in this context. In addition to these findings, the hoarding group demonstrated slightly poorer overall sustained attention (CPT detectability scores) and slightly poorer response inhibition (CPT commission scores and VST scores) than the control group, although some of these differences may not be clinically meaningful given the magnitude of effect. No differences were found for sustained attention or response inhibition when examining CPT HRT scores or in focused attention based on SDMT scores. An overview of study findings is presented in Fig. 4.

Confidence intervals were very wide for all differences, other than for VST scores for the hoarding group in the two contexts, and encouraged us to explore the existence of different clusters within our hoarding group. Posthoc exploratory cluster analysis using test results from the cluttered environment demonstrated the presence of two hoarding subgroups, a larger one that had overall good attention and response inhibition and a smaller one that experienced attention and response inhibition difficulties. The poor attention and response inhibition subgroup had atypically fast CPT-3 HRT scores and elevated CPT-3 omission, detectability, and commission scores. Specifically, these participants emphasized speed over accuracy, had difficulty discriminating between target and non-target letters, more often failed to respond to target letters, and more often incorrectly responded to non-target letters. These findings indicate that these participants were responding with a degree of impulsivity and failing to inhibit their response. This response style was associated with greater hoarding severity as well as greater distress when in the tidy environment. More specifically, the good attention group

[2]Although the t-test (results shown in Table 2) is robust to violations of normality, differences between clusters were also explored using Mann-Whitney tests. Similar results were found, except for SI-R Discarding subscales scores (U = 306, p = 0.13) and age (U = 509, p = 0.11).

NEUROPSYCHOLOGICAL FINDINGS

DOMAIN	TEST	FINDING
Sustained Attention	CPT-3 Ommissions	Hoarding group performed worse than control group in the cluttered environment*
	CPT-3 Detectability	Hoarding group performed worse than control group overall*
	CPT-3 Hit Reaction Time (high scores)	No group or room differences
Response Inhibition / Inhibitory Control	CPT-3 Hit Reaction Time (low scores)	No group or room differences, but poor attention group atypically fast
	CPT-3 Comissions	Hoarding group performed worse than control participants*
	VST	Hoarding group performed worse in the cluttered environment than in the tidy environment, and when in the cluttered environment, performed worse than control group
Focused Attention	SDMT	No group or room differences

*Findings might have been driven by a subset of participants (n=18 of 63)

Fig. 4. Study findings presented by test and domain

reported a slight increase in distress from the tidy to the cluttered environment, whereas the poor attention group reported slightly elevated distress scores in both environments. These results could mean that emotionally salient contexts or feeling chronically stressed contributes to attentional difficulties. Alternatively, these findings could indicate that the poor attentional group has difficulties with self-regulation (Gagne, Liew, & Nwadinobi, 2021).

Except for our HRT data, these findings are in line with past studies that have found differences between hoarding and non-hoarding groups. They also suggest that when past studies have not found between group differences that it may have been a consequence of where participants were tested and who was tested. First, this study's findings indicate that research studies must use within-group designs, rather than between-group designs, to study the impact of clutter. Second, this study's findings indicate that not all hoarding participants may experience information processing deficits, at least not in the realm of attention and response inhibition. Given this study's unique HRT findings, the size of our impaired attention and response inhibition cluster, and prior research on comorbidity (Frost et al., 2011), it may be that only participants who also meet criteria for attention deficit hyperactivity disorder (ADHD) may experience these deficits and that they may be particularly prone to experience cognitive difficulties when confronted by clutter. At this time, this is only conjecture as this study did not assess for the presence of ADHD. Future studies may want to assess for ADHD and compare to an ADHD only group. Regardless of whether ADHD can be diagnosed in the impaired group, our results suggest that these sustained attention and response inhibition difficulties are associated with greater hoarding severity. Thus, cognitive-behavioral treatment for this cluster of individuals may need to include frequent repetition of information, use of written/visual/electronic memory aids, regular reflections on what has been learnt, and increased support with setting and completion of homework tasks.

Study findings must be interpreted considering study design and methodology limitations. First, recent research on the CPT with ADHD samples has shown that the CPT lacks clinical and possibly ecological utility. In a study examining 201 adult ADHD patients, the CPT correctly classified only 52% as likely to meet diagnostic criteria for ADHD and was particularly poor at identifying the inattentive subtype (Baggio, Hasler, Giacomini, et al., 2020). These classification errors may be from the CPT being unable to simulate everyday life and real-life distractors (Baggio, Hasler, Giacomini, et al., 2020). We attempted to circumvent this limitation by exposing participants to a cluttered living environment, but as shown by this study's VAS scores, other people's clutter may not produce the distress caused by a real-life clutter within one's home. Therefore, future studies may need to test participants' cognitive abilities when they are at home attempting to declutter. Moreover, future studies may want to employ a larger test battery to examine the task impurity problem, in which a number of cognitive processes are involved in complex cognitive tasks (Friedman & Miyake, 2004).

Second, similar to prior studies (Grisham et al., 2007; Mackin et al., 2011, 2016; Moshier et al., 2016; Sumner et al., 2016; Woody, Lenkic, Neal, et al., 2021), this study examined attention and response inhibition among highly educated individuals who experience hoarding symptoms. High IQ may be a protective factor as individuals with ADHD and an IQ above 110 have obtained better CPT scores than those with a lower IQ (Baggio, Hasler, Deiber, et al., 2020). Although we adjusted for education (and affect, age and sex) which is moderately correlated with IQ (Holdnack et al., 2013), we were unable to examine if IQ was related to attentional performance as many of our participants may have been educated in non-Western schools where English is not taught or spoken, rendering TOPF scores invalid. Future studies will need to explore whether attentional differences are more frequent among those with lower IQ.

Lastly, the diagnostic status of the hoarding and control groups were not ascertained. Rather we relied upon established psychometric cut-offs to form our groups (Kellman-McFarlane et al., 2019). Thus, future studies will want to utilize the same battery of tests used in this study (except for the SDMT which has now repeatedly been shown not to differ across groups), while also incorporating diagnostic assessments and various clinical groups. Based on comorbidity rates, ADHD, OCD, and depression clinical comparison groups would be helpful. A recent systematic review examining cognitive dyfunction across psychiatric disorders found small effect sizes differences for OCD and medium effects for ADHD and depression when comparing attentional performance to non-psychiatric control samples (Abramovitch et al., 2021). Perhaps greater attentional impairments, or broad self-regulation difficulties as noted above, may contribute to hoarding's comorbidity with other psychopathology.

Overall, the results of this study demonstrate that some individuals who report hoarding symptoms may have problems with sustained attention and response inhibition, and these troubles may be exacerbated by clutter. As not all individuals in this study who reported hoarding symptoms evidenced objective attentional and response inhibition difficulties on the neuropsychological tests used in this study, future studies may want to concentrate on identifying subgroups of individuals who experience objective cognitive difficulties and exploring how these difficulties influence hoarding behaviors. Likewise, future research will want to explore what leads to hoarding in the absence of cognitive difficulties, or at least in the absence of cognitive difficulties identified by neuropsychological tests of attention and response inhibition.

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