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Effects of traumatic brain injury on a virtual reality social problem solving task and relations to cortical thickness in adolescence

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ABSTRACT

Social problem solving was assessed in 28 youth ages 12–19 years (15 with moderate to severe traumatic brain injury (TBI), 13 uninjured) using a naturalistic, computerized virtual reality (VR) version of the Interpersonal Negotiations Strategy interview (Yeates, Schultz, & Selman, 1991). In each scenario, processing load condition was varied in terms of number of characters and amount of information. Adolescents viewed animated scenarios depicting social conflict in a virtual microworld environment from an avatar's viewpoint, and were questioned on four problem solving steps: defining the problem, generating solutions, selecting solutions, and evaluating the likely outcome. Scoring was based on a developmental scale in which responses were judged as impulsive, unilateral, reciprocal, or collaborative, in order of increasing score. Adolescents with TBI were significantly impaired on the summary VR-Social Problem Solving (VR-SPS) score in Condition A (2 speakers, no irrelevant information), $p = 0.005$; in Condition B (2 speakers + irrelevant information), $p = 0.035$; and Condition C (4 speakers + irrelevant information), $p = 0.008$. Effect sizes (Cohen's D) were large ($A = 1.40$, $B = 0.96$, $C = 1.23$). Significant group differences were strongest and most consistent for defining the problems and evaluating outcomes. The relation of task performance to cortical thickness of specific brain regions was also explored, with significant relations found with orbitofrontal regions, the frontal pole, the cuneus, and the temporal pole. Results are discussed in the context of specific cognitive and neural mechanisms underlying social problem solving deficits after childhood TBI.

1. Introduction

Individuals who have sustained traumatic brain injury may show dysfunction in several domains of functioning, including both cognitive and social domains. Children and adolescents who have sustained traumatic brain injury (TBI) demonstrate difficulties in social functioning (Hanten et al., 2008; Turkstra, McDonald, & DePompei, 2001; Yeates et al., 2004). After a TBI, children and adolescents are reported to be lonely and dissatisfied with their social situations, have fewer friends, and to rely on family for social needs more than uninjured peers (Yeates et al., 2007). Studies with adolescents have revealed specific aspects of social processing that are impaired in youth with TBI as compared to their typically-developing peers, including identifying emotions and rating conversational skills from video tapes (Turkstra et al., 2001). Another study (Turkstra, Dixon, & Baker, 2004) with adolescents reported differences between youth with TBI and typically-developing peers in judgments of equality of the conversational burden between two people, judgments of appropriateness of language level, and second order Theory of Mind judgments. In this study, there were no differences in the groups on identifying good listeners in a conversation, or on first order Theory of Mind judgments although small sample size may have been an issue. These studies suggest that social outcome in adolescents is affected by TBI, but more empirical data are needed.

Several studies have sought to identify mechanisms underlying negative social outcome and have documented skills that appear to be impaired after TBI. Among the impaired skills is the ability to engage in age-appropriate social problem solving. Yeates et al. (2004) used the Interpersonal Negotiations Strategy Test (INS; Yeates, Schultz, & Selman, 1991) to study social problem solving in 109 children who had sustained moderate to severe TBI.

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The INS involves the narrative presentation of conflict scenarios between two people, after which the subject is queried for a solution to the conflict based on problem-solving steps. Scoring reflects a social-developmental model in which responses are rated on the maturational level of the proposed solutions (i.e., how well the solution proposed preserves the relationship between the two people depicted). Yeates et al. (2004) discovered that the children with TBI used less socially mature strategies to resolve conflicts than did a group of 80 age-matched children with orthopedic injuries. Using the INS to assess social problem solving in children after TBI and in children with orthopedic injury, Hanten et al. (2008) replicated and extended the findings of Yeates et al. (2004) that children with TBI were significantly impaired on INS performance relative to children with orthopedic injury, and displayed a notable lack of recovery. In addition, Hanten et al. (2008) found that poorer performance on the INS was related to poorer performance on tasks of memory and language. This is intuitively plausible when taken in the context of well-documented deficits on neuropsychological tests of language and memory after pediatric TBI, and given that the INS is administered in spoken narrative form that must be maintained in memory, with scoring based on spoken language responses.

Although the presence of cognitive and social deficits after TBI has been established, there is recurring criticism regarding the ecological validity of the tests used to assess outcome. For example, in real life a person is seldom required to perform discrete cognitive operations in the activities of daily living. Recent advances in virtual reality gaming (VR) technology have provided an opportunity to marry the specificity of neuropsychological tests with a realism that more closely mimics activities of daily living to achieve a more ecologically valid assessment of cognitive and social skills. The social-cognitive research community is beginning to take advantage of this opportunity to create more realistic and dynamic measurement tools.

1.1. Virtual environments and social cognition

In social cognitive research, simulating the social environment has become an important objective in the need to balance experimental control with ecological validity. Measures that have components of mundane realism increase the subject's experience of being part of the interaction (Blascovich et al., 2002). Mundane realism is exemplified by tasks in which the experimental demands match the real-world situation to which the task results will be applied, thus the tasks are more likely to elicit responses similar to those in everyday life contexts. Less virtual measures (i.e., paper tests, picture displays) may be experimentally more rigorous, as they allow more controlled experimental responses to independent variable manipulations. However, these types of measures create a sterile environment, in which the measurement reliability of social cognitive processes can take precedence over the validity of those processes in a comparable, real-world situation. With emerging technologies, the trade-off between realism and experimental control can be lessened, as virtual technology can be modified and controlled without compromising measurement (Blascovich et al., 2002; Loomis, Blascovich, & Beall, 1999).

Virtual reality (VR) tasks use dynamic graphically displayed interactions between participants, which more aptly capture the mechanisms by which real-life social situations are mediated. As such, it is not surprising to find that virtual environments (VEs) are increasingly being used to study social cognition. For example, neuroimaging research has demonstrated that the medial prefrontal cortex is activated both when observing social communication of virtual others through their facial expressions, as well as when perceiving personal involvement in a virtual situation through direct eye contact with virtual characters (Schilbach et al., 2006). Riva et al. (2007) used college-age participants (19–25 yrs old), to determine the effectiveness of VEs in inducing specific emotional responses by manipulating VR environments that subjects visited (i.e., an "anxious" park, a "relaxed" park, and a "neutral" park). The study confirmed the efficacy of VR environments in eliciting the target emotion. Another study on social paranoia – the first of its kind with regard to its methodology – subjected participants to a VE train ride filled with neutral characters. Although participants were pre-screened for severe mental illness, a significant minority of the participants reported paranoid concerns about the virtual train environment when questioned afterward (Freeman et al., 2008). The validity of VR methodology in social cognition research has also been confirmed for studies with VR characters of social prejudice (Dotsch & Wigboldus, 2008).

Evidence of the realness of virtual reality tasks – whether provoking emotional reactions similar to that experienced in actual circumstances (Moore, Wiederhold, Wiederhold, & Riva, 2002), or promoting the suggestion that an individual is a participant in a particular situation (Biocca, Harms, & Burgoon, 2003; Heeter, 1992) – has provided validation of a novel method for observing social functioning in clinical and normal populations (Cobb & Sharkey, 2007).

1.2. Clinical application

VR technology has been used in diverse populations, including clinical, to study social processing. Several studies have explored autism and social functioning, and concluded that VEs are an effective medium for both observing and teaching social skills in autistic populations (Mitchell, Parsons, & Leonard, 2007; Parsons, Leonard, & Mitchell, 2006; Parsons & Mitchell, 2002; Parsons, Mitchell, & Leonard, 2004). Beyond the autistic population, VR characters have also proven more effective than the current paper–pencil techniques in teaching acceptable social skills of a particular culture (e.g., South Indian) to participants from a fundamentally different culture (e.g., non-Asian). Interactions with the virtual characters produced a significantly better understanding of the cultural practices being learned (Babu, Suma, Barnes, & Hodges, 2007).

The ever-increasing complexity and integrity of virtual environment programming (LaViola, Prabhat, Forsberg, Laidlaw, & van Dam, 2008; Livatino & Koffel, 2007; Trenholme & Smith, 2008), as well as its popularity with patients and research participants of all ages (Parsons et al., 2006; Reinkensmeyer & Housman, 2007; Virvou & Katsionis, 2008), makes it an excellent medium for research in domains ranging from skill transference in children with learning disabilities (Cromby, Standen, Newman, & Tasker, 1996), to constructional processes in children with developmental disorders (Jacoby et al., 2006) and social rule violation behavior in patients with prefrontal neurosurgical lesions (Morris, Pullen, Kerr, Bullock, & Selaway, 2006).

1.3. Virtual reality and investigations of traumatic brain injury

Limited studies of traumatic brain injury (TBI) have used virtual reality technology to assess or treat TBI. Matheis et al. (2007) found that a VR task was sensitive to memory impairments in adult TBI patients 7 years post injury. In younger TBI patients, research is scarce, but emerging. Lloyd, Powell, Smith, and Persaud (2006) found route learning performance in a virtual town environment to be highly correlated with real-world performance, and subsequently used this "town" to examine route memory in patients with acquired brain injury. Slobounov, Slobounov, and Newell (2006) demonstrated the long-lasting effects of visual destabilization after mild TBI in student athletes by developing virtual tasks, which proved sensitive to post concussive symptoms up to 30 days after the injury. Very few, if any, studies utilizing VR technology have examined the social outcome of children and adolescents with TBI.