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The effects of visual distraction following traumatic brain injury

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Abstract

Clinical assessments of individuals with traumatic brain injury (TBI) typically report attentional difficulties, with distractibility prominent among these complaints. However, laboratory-based measures have often failed to find disproportionate distraction among patients with TBI, as compared to control participants. In this experiment, we tested 21 patients hospitalized for rehabilitation following recent TBI and 21 demographically comparable control subjects on a visual reaction time go–no-go task in which the target was preceded or followed by a brightly colored moving visual stimulus, appearing above the target location. Early distractors actually served as warning stimuli, improving accuracy and speed for both participant groups. Distractors occurring at or shortly after the time of target presentation had no significant impact on accuracy or response bias in either group, but did produce slowing of RT that was significantly greater for patients than for controls. The distractor that produced maximal slowing occurred 100 ms after the presentation of the target or foil. Repeated testing sessions led to reduction in the impact of the distractor and loss of the group difference in RT impact. The degree of RT slowing induced by distraction was modestly related to injury severity, as measured by the current score on the Disability Rating Scale, and the time until the patient first followed verbal commands. There was also a trend of greater RT slowing among individuals with focal orbitofrontal lesions, as assessed on neuroimaging studies. These results document a greater susceptibility to extraneous visual distraction among patients with TBI in comparison to controls. The fact that this difference appears only in the RT domain, and is greatest when the distractor follows the target, suggests that the primary impact of visual distractors is on response preparation and execution rather than target detection. (*JINS*, 1998, *4*, 127–136).

Keywords: Attention, Arousal, Brain injury, Reaction time

INTRODUCTION

Difficulties with attention are widely reported by clinicians, patients, and family members after traumatic brain injury (TBI; Jacobs, 1988; McKinlay et al., 1981; Ponsford & Kinsella, 1992; van Zomeren, 1981, pp. 9–14). However, the precise nature of these difficulties remains controversial for several reasons. There is still no consensus on how to subdivide the multifaceted domain of attention, nor is there agreement on the operationalization of the subdivisions that have been identified. Differences in the severity and nature of TBI across studies further complicate matters.

One of the most troubling attentional problems after TBI is distractibility. In a clinical or naturalistic setting, distractibility generally refers to an individual's orienting to inappropriate or irrelevant stimuli. For example, a patient working with a physical therapist on a set of exercises may stop working when he or she hears footsteps in the hallway. Controlled simulations of this phenomenon, in which persons perform independent work in a distracting environment, have verified the fact that individuals with TBI are more likely than controls to look up from their tasks when distracting events occur, but that they are also more likely than controls to do so in the absence of overt distractions (Whyte

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et al., 1996). While substantiating the problem of distractibility in TBI, these data raise the question of whether the probability of becoming off-task in the presence of distraction is related to the degree of engagement in the task even in the absence of distraction.

In order to clarify the nature of distractibility following TBI, it would be useful to have a laboratory model of the phenomenon. However, attempts to study distractibility in controlled information processing tasks have met with mixed results. Different studies appear to have had different hypothetical constructs in mind when studying distraction and, hence, have operationalized the phenomenon in quite different ways. In addition, some studies have been limited by ceiling or floor effects during undistracted performance, thus limiting comparisons between patients and controls. Distractibility has sometimes been equated with a deficit in focused attention, with the assumption that a reduced ability to focus on a task-relevant stimulus would lead to an increased susceptibility to the effects of a distracting stimulus. However, it is also possible that one's ability to focus on something relevant and one's susceptibility to disruption by extraneous stimuli represent independent phenomena.

Many studies have used as distractions, stimuli which strongly elicit response tendencies that compete with those to the target stimuli. Stablum et al. (1994) studied a response conflict task in which subjects identified large capital letters which were composed of small capital letters that were either compatible or incompatible with the large letter. They found main effects for subject group and condition, but no Group × Condition interaction, indicating that patient participants were not disproportionately affected by the conflict condition. Similarly, van Zomeren (1981, pp. 80–86) taught participants to respond to lighted keys with a rapid key press, and then illuminated identical distractor keys simultaneously with the target keys, presumably eliciting conflict with respect to which key the motor response should be directed to. Van Zomeren found a significant Group × Condition interaction, as well as main effects for group and condition, but interpreted the interaction merely as evidence that patients, because of their generally slowed processing, required more time to deal with the response conflict. Studies of the Stroop task in this context have defined the color word stimulus as the distractor and the colored ink stimulus as the target, and have examined the degree to which response competition occurs. While most studies have found main effects for both subject group and condition (compatible *vs*. incompatible), there have been inconsistent findings with respect to a Group × Condition interaction (Chadwick et al., 1981; McLean et al., 1983; Ponsford & Kinsella, 1992; Vakil et al., 1995; van Zomeren & Brouwer, 1987).

In contrast, Stuss et al. (1989) studied a paradigm in which no inherent response conflict was produced. In this task, one condition (the *multiple choice redundant* condition) required the participant to respond to targets with three simultaneous attributes—shape, color, and orientation—but the attributes were perfectly correlated such that the task could be performed perfectly while attending to any one of the three dimensions. The presence of these unnecessary attributes disproportionately slowed performance for patients *versus* controls, suggesting that patients were processing irrelevant information in the task. However, although the subjects were told of the task constraints, it may be that patients were merely less able to translate the constraints into an efficient task strategy, particularly since this condition was intermixed with conditions where all three attributes were relevant. A similar study by Miller and Cruzat (1981) required participants to sort packs of cards into those with an "A" *versus* those with a "B" on them. In one condition the letter "A" or "B" appeared alone, while in other conditions, various numbers of additional letters, functioning as irrelevant distractors, were also present on the card. The authors report significant main effects of group and number of letters, but again, no significant Group × Condition interaction. This particular finding, however, is difficult to interpret in view of their use of a logarithmic scale. While the additional letters led to comparable increases in performance time for both groups on a logarithmic scale, the amount of slowing was considerably greater for patients than controls when measured untransformed in seconds.

Several studies have examined the impact of extraneous auditory stimuli on performance. An early study by Denker and Lofving (1958) involved reading stories to subjects with TBI and their uninjured identical twins. Background conversations were played during one of the stories. Unfortunately, little can be concluded from this study because the TBI subjects had mild injuries as long as 10 years prior to the study and no negative impact of the auditory distraction was seen in either participant group, suggesting a ceiling effect in the task. Ceiling effects also confounded a study by Gronwall and Sampson (1974) in which participants were asked to shadow a message delivered to one ear while ignoring a simultaneous message delivered to the other. There were no intrusions from the irrelevant message in either group. In a study by Kewman et al. (1988), differences between patients and controls in error rates in the absence of distraction were very large. In this study, participants answered comprehension questions after hearing stories read with or without another story presented simultaneously in another voice. When the TBI participants with the highest undistracted error rates were eliminated, and the data were analyzed with analysis of covariance (with undistracted errors as the covariate), no significant Group × Condition interaction was noted. However, the sample at this point consisted of 14 controls and 12 patients, and it is not clear that the analysis had sufficient power to detect such an interaction.

In summary, research attempting to examine the phenomenon of distractibility in TBI has suffered from several problems. First, investigators have differed in what they mean by distraction; focused attention, suppression of response conflict, ignoring of unnecessary information, or the ability to select a relevant stimulus from background noise. Studies in which the distractions are both unambiguously irrelevant and physically easy to distinguish from targets (as is the case in the clinical example discussed above) have generally not been conducted. Second, interpreting differences in distractibility between groups is complicated by the presence of differences in scores in the absence of distraction. Such baseline differences require one to look for a disproportionate impact of the distractors on patients *versus* controls, but the meaning of disproportionate is highly dependent on the scale (e.g., raw *vs*. logarithmic), and the method of analysis (e.g., the linear assumption of ANCOVA).

Because of these problems, we chose to study distractibility in a way that we hoped was more analogous to the inappropriate orienting to irrelevant stimuli that occurs in clinical and naturalistic settings. Using a visual reaction time go–no-go task with which our participants were very familiar from prior testing, we added a salient, colorful, moving visual distractor that was unfamiliar. Thus, although participants might orient to this stimulus, it should not be because it elicited specific response tendencies associated with the target stimuli. Moreover, since the distractor stimulus was located above the location of the target stimuli, it might induce participants to orient away from the target location. Finally, we attempted to equate initial accuracy levels between groups, to facilitate a direct comparison of distractor impact. Since we anticipated baseline RT differences between groups, over which we would have no control, we planned a careful analysis of the relationship between baseline RT and distractor influences.

METHODS

Research Participants

Twenty-one individuals with recent nonpenetrating traumatic brain injury were recruited from the inpatient population of the Drucker Brain Injury Center of MossRehab Hospital. Patients had sustained their injuries in motor vehicle accidents ($N = 15$), as pedestrians ($N = 2$), in falls ($N = 2$), in work-related injuries ($N = 1$), or in interpersonal conflicts ($N = 1$). They were excluded if they were older than 65, had a prior brain injury with loss of consciousness, prior central nervous system pathology or major mental illness. Those taking psychoactive medications (other than carbamazepine) were also excluded. Patients were tested at variable times postinjury when they were cognitively able to perform the tasks and were free of excluded drugs. The mean time postinjury was 110 days (range: 15–277). All patients were out of posttraumatic amnesia at the time of testing. However, they continued to demonstrate considerable disability, ranging from the need for assistance with basic activities of daily living, to the need for supervision in managing a complex daily routine. The rationale for testing at nonstandard times has been discussed previously (Whyte et al., 1995).

Twenty-one control participants were selected for their demographic comparability to the patients in terms of age, sex, ethnicity, and years of education. They were recruited from hospital staff and through community advertising. Exclusion criteria were identical to those for patients, with the additional restriction that they had never had a brain injury with loss of consciousness. Perhaps the ideal control group for TBI patients is composed of friends or siblings with precise sociodemographic matching. This was not possible in our studies because the many hours of control testing required were generally more than visiting friends and family members could consent to.

As in our prior research, patients and controls were not excluded for histories of substance abuse, because of uncertain reliability of such histories and difficulties of generalizing to the larger population of patients with TBI, in whom such histories are common. The demographic and injury characteristics of patient and control participants are listed in Table 1.

Measures of brain injury severity were recorded from referral charts, including the Glasgow Coma Score (GCS; Teasdale & Jennett, 1974) and the estimated time (in days) until verbal commands were first followed. In addition, disability level at the time of testing was scored using the Disabil-

Table 1. Participant characteristics

Variable	Patients	Controls	Probability
Sex			
Female	7	6	$\chi^2 = .11, p = .74$
Male	14	15	
Ethnicity			
Non-White	5	7	$\chi^2 = .47, p = .50$
White	16	14	
Age (*M*, range)	29.6 (17–53)	29.5 (13–54)	Mann-Whitney $U(21,21) = 208, p = .75$
Education (*M*, range)	12.0 (10–14)	12.6 (8–16)	Mann-Whitney $U(21,21) = 255, p = .22$
Glasgow Coma score (*M*, range, number missing)	6.67 (3–14) 6	—	—
Time until commands were followed in days (*M*, range, number missing)	18.26 (0–45) 2	—	—
Disability Rating Scale score (*M*, range, number missing)	4.71 (1–8) 0	—	—

ity Rating Scale (DRS; Rappaport et al., 1982) All patients were examined by a behavioral neurologist (H.B.C.) using a standardized neurologic examination designed to localize areas of neuropathology on the basis of clinical findings. CT or MRI scans obtained for clinical purposes were also reviewed and coded for the presence or absence of focal pathology in a variety of brain regions, as described previously (Whyte et al., 1995).

Cigarette smokers were interviewed about their smoking patterns and a standardized smoking schedule was instituted during the protocol that allowed them a fixed number of cigarettes in the hours prior to testing and none within 1 hr of testing. Patients and controls were asked to refrain from caffeine for several days prior and throughout the experimental protocol. Daily interviews and medication record checks were conducted to assess compliance with these restrictions. All of the subjects were also participants in a study of sustained attention published previously (Whyte et al., 1995) and many of them also participated in other research on phasic arousal (Whyte et al., 1997) and behavioral inattention (Whyte et al., 1996).

Procedure

The experimental design was adapted from that used previously in the study of sustained attention and phasic arousal in this subject population. The rationale for the design of the stimuli has been discussed previously (Whyte et al., 1995). Testing was conducted in a sound-damped laboratory adjacent to the hospital. In this experiment, participants performed a go–no-go reaction time task on three occasions at the same time of day. These sessions were conducted on successive days when possible, but were sometimes separated by gaps of a few days.

The participant sat with his or her chin on a chin rest approximately 50 cm away from the color monitor of a PC. The dominant index finger rested on a response key that was in the center of a slanted surface below the monitor. The arm was held in place by a sling to prevent fatigue. Stimuli consisted of pairs of vertical lines presented in the center of the screen, subtending 5.8° of visual angle in the vertical direction and .4° in the horizontal direction. Participants were taught that a pair of identical lines constituted a target, whereas a pair of grossly unequal lines constituted a foil (one line was the same length as the target and the other was 50% shorter), and to press the response key as quickly as possible in response to targets only. Participants were explicitly informed that targets would constitute half of the stimuli. Responses occurring more than 3 s after the stimulus were excluded. The center area of the screen was covered by a random pattern mask with a central blue fixation cross except when a stimulus was presented, to prevent phosphor after-glow and retinal after-image. Subjects wore headphones that played white noise throughout the experiment. Once the experimenter started the experiment, he or she withdrew from the participant's view.

Participants were presented with 12 blocks of 16 stimuli (8 targets and 8 foils). The visual distractor in this research consisted of a horizontal bar approximately 3.8 cm (4.3° of visual angle) in length, which was composed of a string of 10 characters corresponding to ASCII Code 14 (similar to the "@" sign). This bar appeared in the midline, above the location of stimulus presentation, and moved rapidly up and down over an excursion of 5 cm (5.7° of visual angle), with a duration of 500 ms. This distractor appeared on every trial, but its onset time varied. Distractor–stimulus intervals were -750, -500, -250, -100, 0, $+100$, $+200$, and $+300$ ms, with the negative intervals indicating that the distractors preceded stimulus presentation, zero that distractor and stimulus onset were simultaneous, and positive intervals indicating that the distractor followed stimulus presentation. One target and one foil at each distractor interval (DI) were delivered in each block of 16 trials in random order. Blocks with randomized DIs were chosen to encourage the participants to attempt to resist distractions throughout the interval. The participant was given a 1–2 min break between blocks to minimize fatigue effects. The interstimulus interval ranged randomly from 4 to 8 s, with a mean of 6 s. The entire session of 192 trials lasted about 35–40 min.

Before beginning the experiment, participants participated in individual training and stimulus calibration sessions (generally two sessions) to ensure that they understood the task, and to identify a stimulus duration that eliminated ceiling and floor effects with respect to accuracy. Stimulus durations for patients ranged from 33.33 to 166.67 ms ($M = 91.27$) and for controls ranged from 16.67 to 83.33 ms [$M = 48.41$; Mann-Whitney $U(21,21) = 61$, $p < .001$], with patients requiring longer stimulus exposure to achieve comparable accuracy.

Data Analysis

Patients and controls were compared demographically using the chi-square test for nominal variables and the Mann-Whitney *U* test, for continuous variables. The effects of distractors were examined in relationship to three dimensions of performance. Impact on accuracy was measured with D', an index of perceptual discrimination ability which is derived from the proportions of hits, false alarms, misses, and correct rejections. Impact of the distractors on speed was assessed with respect to median reaction time for hits. Impact on response bias was measured with respect to *yes rate*, the overall proportion of button presses, irrespective of accuracy.

Because the effects of distractors might be most powerful in the initial session, and then might habituate over time, the initial session data were analyzed separately. This experiment included no nondistractor condition, but rather varied the timing of the distractors that were presented on every trial. Thus, in order to evaluate the overall impact of the distractors, we compared performance to each participant's initial performance in the sustained attention experiment, performed a few days previously, in which neither warnings nor distractors were introduced. For graphic analysis, each participant's score for the three performance domains (accuracy, reaction time, response bias) in the initial block of the sustained attention experiment was subtracted from his or her score in the same domain at each distractor interval, providing an estimate of the impact of the distractor relative to undistracted performance for that individual. The median of these corrected values was then plotted across DIs to examine the impact of distractors on each participant group.

The Wilcoxon signed ranks test was used to compare performance within participants between distraction and baseline conditions. Differences between groups in the impact of distractors were analyzed by analysis of covariance (ANCOVA). Our prior research has shown that the impact of experimental variables is often dependent on baseline performance (Whyte et al., 1997). Thus, for statistical analysis, three ANCOVAs were performed (one for each performance domain), in which the score at DI = +100 was the dependent variable, participant group was the independent variable, and baseline score (from the sustained attention experiment) was the covariate. Performance at DI = +100 was chosen for this analysis based on preliminary graphic and statistical analysis because both groups demonstrated their worst performance at approximately this distractor interval. Alpha was set at .017, with a Bonferroni correction for the 3 ANCOVAs that were conducted.

The relationship between measures of injury severity and distractibility was assessed with Spearman's rank-order correlations, using the distraction decrement score (distracted performance − baseline performance). The influence of focal frontal lobe lesions on distractibility was examined *via* Mann-Whitney *U* tests on the distraction decrement scores, comparing patients with and without the specific lesion of interest.

RESULTS

Graphs of the group medians for Session 1 data for each performance domain *prior to correction for baseline performance*, demonstrate that in each domain, performance is worst in the region where distractors appear nearly simultaneously with target stimuli (see Figure 1A, B, C). However, as noted previously, these graphs do not reveal the absolute impact of distractors at each DI. In Figure 2, these same data are re-graphed after subtracting each participant's baseline performance score. Interestingly, these corrected graphs demonstrate that early distractors (e.g., DIs of −750 and −500) actually *benefit* performance. Accuracy levels at these distractor intervals are above baseline and reaction times below baseline for both groups. The pattern for response bias is more complex, in that early distractors appear to have little effect on control participants, whereas they raise response rates for patients. However, this is consistent with our prior research suggesting that the effects of warnings (which these early distractors appear to be) on yes rate are dependent on the baseline level of yes

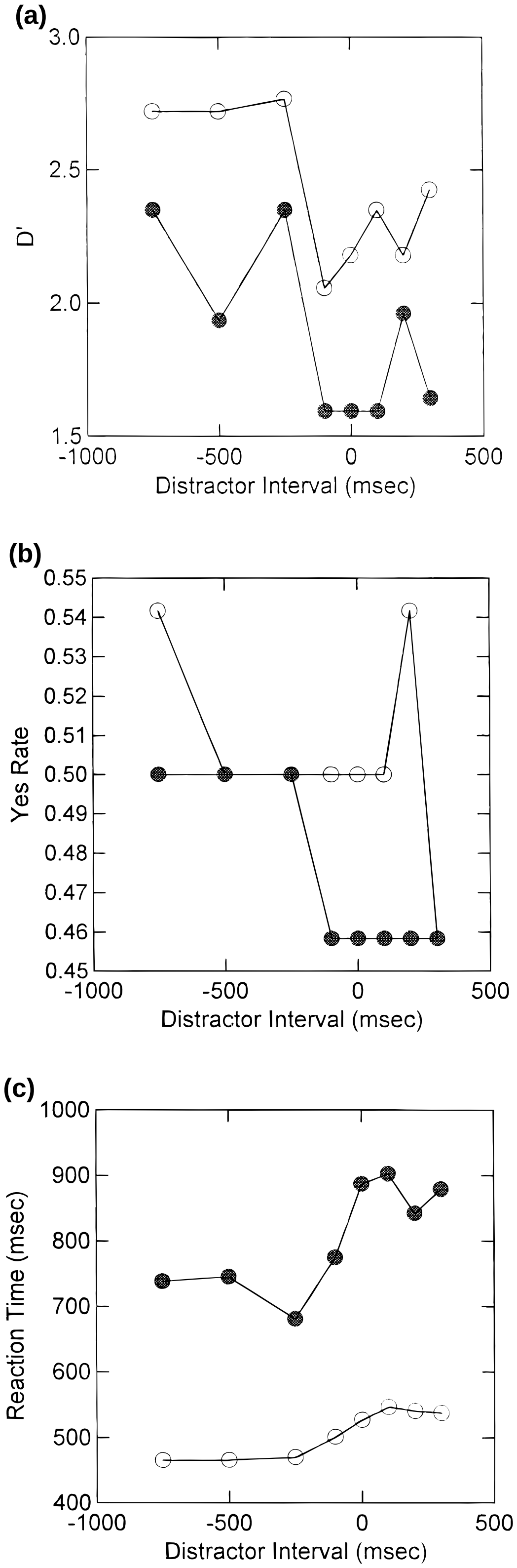

Fig. 1. Figure 1 shows the median performance of each participant group (patients' symbols are filled, controls' are unfilled) with respect to *D′* (1A), yes rate (1B), and reaction time (1C). In each graph, the performance score is represented on the *y*-axis and the distractor interval on the *x*-axis.

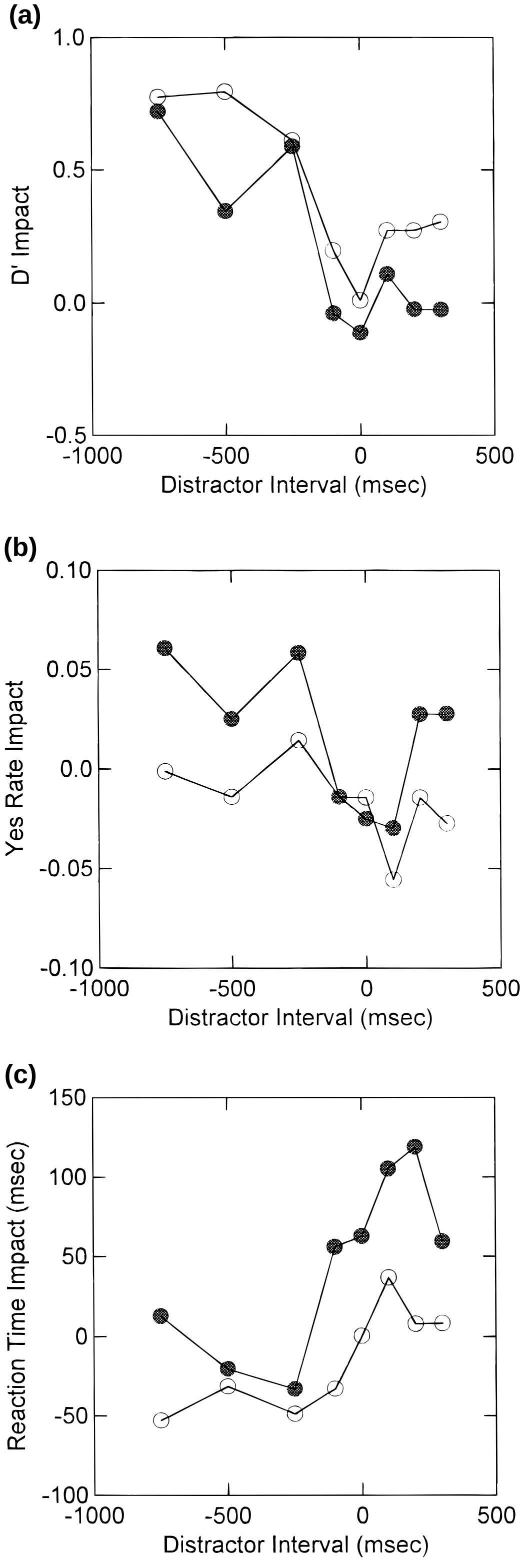

Fig. 2. Figure 2 shows the median performance of each participant group (patients' symbols are filled, controls' are unfilled) with respect to D' (2A), yes rate (2B), and reaction time (2C). In these figures, each individual's baseline score has been subtracted from all distractor scores before calculation of the group median, such that a score of zero indicates no distractor impact. In each graph, the performance score is represented on the y-axis and the distractor interval on the x-axis.

rate, with warnings tending to raise patients' initially lower response rates (Whyte et al., 1997).

The timing of worst performance was very similar for patients and controls and across performance domains. In general, lowest corrected scores occurred at DIs of 0 or +100 for D' and yes rate, and at +100 for RT. Since there were no significant differences in scores between DIs of 0 and +100 in D' or yes rate, a DI of +100 was chosen for further analysis for both groups and all three performance domains.

Effects of Distraction on Accuracy (D')

As shown in Figure 2, the impact of the most potent distractors (at DI = +100) was negligible for both groups in Session 1. Patient accuracy was a median of .11 D' units above baseline while control accuracy was .27 units above. Neither group's performance was significantly worse than their baseline D' score (Wilcoxon signed ranks test, Z-score approximation for patients and controls were .052 and −.921, respectively, $P = .96$ and .36). Indeed, the number of patients who performed more poorly than at baseline was 11, where 10.5 patients would be expected to perform more poorly by chance. Similarly, 13 controls performed more poorly than at baseline at this distraction interval. The ANCOVA showed no significant main effect of group [$F(1,38) = 1.11$, $p = .40$], nor any Group × Baseline interaction [$F(1,38) = .53$, $p = .47$], indicating that accuracy levels were comparable for patients and controls, and that, when adjusted for individual baseline performance, there were no group differences in the impact of the distractor. Thus, there was no persuasive evidence that distraction significantly impaired accuracy in either group, or that distractors at DI = +100 had any differential effect on patients *versus* controls.

Effects of Distraction on Response Bias (Yes Rate)

Both groups showed slightly lower yes rates in the initial session at DI = +100 than at baseline. Patients' yes rates were a median of 3% lower than baseline (Z approximation = .904, $p = .37$). For controls the difference was 6% ($Z = 1.86$, $p = .06$). Thirteen patients and 16 controls' yes rates were lower than baseline at this distractor interval (again, with 10.5 in each group expected by chance). For yes rate, the ANCOVA revealed no main effect of participant group [$F(1,38) = .05$, $p = .82$], nor any Group × Baseline interaction [$F(1,38) = .12$, $p = .73$]. Thus, like accuracy, there was little evidence that maximal distraction affected response bias at all, or that it differentially affected patients and controls.

Effects of Distraction on Speed (RT)

Unlike accuracy and response bias, speed appeared to be dramatically affected by distraction, particularly in patients. Patients were a median of 105 ms slower than baseline at a DI of +100 (Wilcoxon signed ranks test, Z-score approximation $= -2.659$, $p = .008$), whereas for controls the difference was only 37 ms ($Z = -.504$, $p = .61$). Seventeen patients and 13 controls were slower than at baseline at this DI (where 10.5 would be expected to be slower by chance). The ANCOVA comparing the impact of maximal distraction on patients' and controls' RTs showed no significant main effect of baseline RT [$F(1,38) = 2.63$, $p = .11$], a marginally significant main effect of participant group [$F(1,38) = 3.53$, $p = .068$], and a highly significant Baseline × Group interaction [$F(1,38) = 9.05$, $p = .005$]. This indicates that patients tended to be slower than controls throughout, but that those patients with slower baseline RTs (and hence, presumably greater impairment) were significantly more slowed by distractions than controls. Rerunning this analysis with removal of outliers did not alter the results.

In view of the fact that our control subjects were not recruited from patients' social circles, we were concerned that subtle socioeconomic biases might have distorted our results. However, the correlation between education and degree of distractor impact on RT among controls was negligible ($r_s = .04$), suggesting that at least this aspect of socioeconomic status was not a serious confound.

Habituation to Distraction

In all three performance domains, early distractors appeared to aid performance, perhaps by summoning attention to the location of an upcoming target stimulus. However, only response speed was adversely affected by distractors, and this effect was significantly larger in the slower patients than in controls. Although this differential impact of distraction was evident in the initial session, it was of interest to assess whether this difference remained across all three testing sessions in which the same distractor was used.

Figure 3 shows the impact of the distractor on corrected reaction time at DI = +100 in each group over the three sessions. It can be seen that the adverse effect of the distractor was initially larger in patients than in controls and, while it appeared to diminish over sessions somewhat in both groups, this reduction was more dramatic in patients than in controls such that the two groups differed less in the third session than in the first. An ANCOVA, calculated on Session 3 data alone, confirms this trend, in that the Group × Baseline interaction, which signifies differential distractor impact, was no longer significant [$F(1,37) = 1.58$, $p = .217$].

In order to examine the question of habituation more directly, a *habituation index* was calculated by subtracting each participant's RT at DI = +100 in Session 3 from that in Session 1. As expected, this index was larger for patients ($M = 54$ ms, median = 34) than controls ($M = 15$ ms, median = 19), although the group difference was not statistically significant [Mann-Whitney $U(21,20^1) = 170$, $p = .30$; effect size = .53]. Together these data suggest that the initially large adverse impact of distractors on patient RT waned with repeated exposure such that patient and control responses to the distractors become more similar.

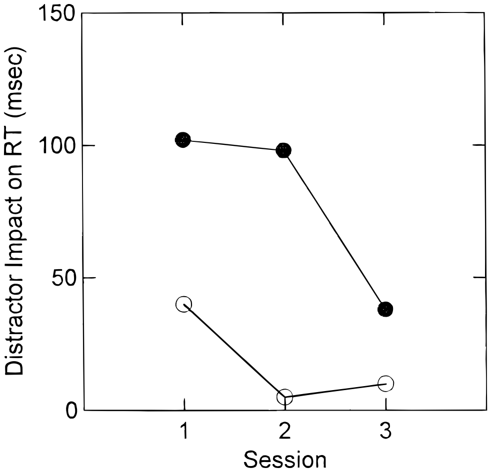

Fig. 3. Distractor-induced slowing is shown for patients (filled circles) and controls (open circles) across the three testing sessions. The impact of the distractor presented 100 ms after the target or foil is calculated by subtracting each participant's baseline RT and then calculating the group median for each session.

Timing of Distractor Effects

As noted above, the distractors that appeared to disrupt RT maximally occurred about 100 ms after the presentation of the target or foil. Since it is somewhat surprising that distractors occurring *after* target presentation should have the greatest impact, the time of maximal distraction was analyzed more specifically. In Session 1, each participant's slowest RT was located and the corresponding DI was noted. The median DI at which both groups exhibited their slowest performance was +100 ms. The individual participants' DIs were compared to a hypothetical DI of zero (simultaneous presentation) *via* the Wilcoxon signed ranks test, to determine whether maximal distraction occurred significantly later than zero. This verified that both groups' point of maximal distraction was significantly later than a DI of zero (Z approximations of 2.50 for controls and 2.18 for patients, $p = .012$ and .029, respectively).

Neurologic Correlates

Because only patients' RT performance was disproportionately affected by distractors, we selected the RT decrement (i.e., RT at DI = +100 ms minus the baseline RT) in Session 1 as the dependent variable. This variable was modestly correlated with the patients' Disability Rating Scale score measured at the time of testing ($r_s = .45$, $N = 21$, $p = .041$), and with the time until the patients began to follow verbal commands ($r_s = .41$, $N = 19$, $p = .083$). The corre-

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[1] One patient did not complete the third session, leaving an N of 20 patients for this analysis.

lation with the initial Glasgow Coma Score was negligible, but in the expected direction ($r_s = -.16$, $N = 15$, $p = .66$). Correlations between severity measures and baseline RT were negligible, indicating that the correlations above were specific to the impact of distraction and not merely correlates of generalized RT slowing. For many of our TBI participants, measures of injury severity were either missing or of uncertain validity. This was of particular concern for GCS. Thus, it is possible that prospectively gathered measures of severity would show a more consistent relationship to the distractibility we measured.

The impact of focal cortical lesions in the dorsolateral prefrontal, orbitofrontal, and medial frontal cortex (as coded from neuroimaging studies) on the RT decrement was examined *via* the Mann-Whitney *U* statistic. No individual lesion location was associated with a significant difference in distraction decrement. However, the sample of patients with any given lesion was quite small. The lesion locations that showed the greatest trend in this regard were orbitofrontal lesions. Median RT decrement among those with bilateral orbitofrontal lesions was 253 ms ($N = 4$); for those with left orbitofrontal lesions it was 206 ms ($N = 5$); for those with right orbitofrontal lesions it was 124 ms ($N = 7$); and for those with no orbitofrontal lesions, it was 90 ms ($N = 14$; total number of subjects with scans = 18). Focal neurologic abnormalities as coded from the standardized neurologic examination were not associated with the degree of impact of distractors.

DISCUSSION

Previous studies of distractibility following TBI have conceptualized the phenomenon as a deficit in focused attention, a difficulty in managing response conflict, or slowed and/or inefficient processing of redundant information (Miller & Cruzat, 1981; Ponsford & Kinsella, 1992; Stuss et al., 1989; van Zomeren, 1981). In the present study we attempted to operationalize distractibility in a manner more analogous to the phenomena observed by clinicians treating patients with TBI: inappropriate orienting to stimuli that are irrelevant to the task at hand. To this end, we studied the impact of a visually salient distractor on speed, accuracy, and response rate during a visual go–no-go reaction time task. Because the participants were already familiar with responding to targets and not responding to foils, but had no prior exposure to the distractors, we presumed that any adverse impact of the distractor on performance would not be due to response conflict based on stimulus similarity. Rather, it should be based on the tendency of a novel, salient stimulus to summon attention.

Using this paradigm, we determined that distractors at many intervals preceding the targets and foils actually improved performance for both patients and controls. In retrospect, it seems plausible that the very summoning of attention that might be disruptive under some circumstances, may actually have attracted the participants' attention to the general vicinity of the target and foil, as well as modestly reducing the temporal uncertainty associated with stimulus arrival. The similar ability of patients and controls to benefit from these warning stimuli is in agreement with prior research suggesting that auditory warnings are processed relatively normally by individuals with TBI (Ponsford & Kinsella, 1992; Whyte et al., 1997). Interestingly, this positive effect of distractors occurred even at DIs of −500 (where distractor termination coincided with target appearance) and −250 ms (where the distractor overlapped the target). Thus, it appears that it is primarily the timing of the distractor *onset* that determines its influence as a facilitating or disruptive stimulus.

An adverse impact of distraction was seen only within a narrow range of distractors, when they were presented shortly before to shortly after targets or foils. Even this effect was seen to a significant extent only for reaction time, but not for D' or yes rate. The failure to find an adverse effect of distractors on D' in either group suggests that the effect of the distractors was to cause participants to miss targets and foils altogether, and/or to process them more slowly, but not to increase the difficulty in distinguishing between them. Distractors near simultaneity tended to produce a slightly (but not significantly) more conservative response bias (i.e., lower yes rate), supporting the notion that subjects were more likely to miss the stimuli altogether when distractors were present. Because D' is relatively independent of response bias, a distractor impact mainly on response bias would not necessarily be detected in D'.

Distractors, however, tended to produce slower responding in both participant groups, but this effect was significantly greater in patients. It is not possible to determine with certainty from our design precisely where in the stream of information processing this disruption occurred; indeed, it is possible that the disruptive influences of distractors occurred at multiple steps from stimulus evaluation to response execution, or at different points for different individuals. However, at the distractor interval of greatest RT disruption, +100 ms, participants had already had access to the target or foil for 100 ms before they were even exposed to the distractor. Thus, this effect of the distractor could not arise from inducing the subject to attend elsewhere *when the target or foil arrived*. Rather, the incoming salient stimulus must have served to slow the processing of the target or foil that was already under way. Because this later presentation of a distractor interfered with performance *more than* simultaneous presentation, these results suggest that distraction may interfere the most by disrupting response planning and preparation rather than by preventing stimulus registration. These findings would be difficult to reconcile with van Zomeren's notion (1981) that patients with TBI respond normally to distraction but take longer to reorient to the relevant stimulus, since such a model predicts that distractors would be maximally disruptive when presented prior to or simultaneously with targets. Other literature, attempting to characterize the source of slow RTs in TBI (but not addressing the issue of distraction), has produced conflicting results, with different studies documenting slowing at various stages of information processing depending on injury severity, acuity, and other factors (Schmitter-Edgecombe et al., 1992). However, there is strong consensus that TBI-induced slowing does occur in the response selection phases of performance (Gronwall & Sampson, 1974; Miller, 1970; Schmitter-Edgecombe et al., 1992).

In our research, distractor-induced slowing was more evident in the slowest participants with TBI, suggesting that the effect is most pronounced in those with the most severe injuries. The fact that the degree of distractor-induced slowing was related to other measures of injury severity, taken at the time of testing, provides further support for this point. There was also evidence suggestive of a role of orbitofrontal lesions in the production of this deficit. Together, these findings may suggest a role of prefrontal cortex in inhibiting distractibility, with either focal orbitofrontal lesions, or diffuse axonal injury leading to impaired operation of the relevant prefrontal systems.

If patients are more disrupted by distractors than controls on initial testing, why should this effect diminish over time? One possibility is that the deficit in individuals with TBI is in effortfully inhibiting orienting to a highly salient stimulus, whereas habituation to recurring stimuli may be preserved. By this account, we would expect an initial group difference, since controls would be able to consciously suppress their tendency to orient to the distractors while patients would not. As habituation proceeds with both groups, however, the need to perform this effortful inhibition, perhaps mediated by orbitofrontal systems, diminishes, and the group difference fades.

Several limitations in this research need to be kept in mind. First, in order to characterize the disruptive effects of distractors, we referenced performance to a baseline score derived from a previous experiment, rather than using a no-distraction condition in this experiment. However, although this may have added more “noise” to our data, it would not be expected to bias the comparison between patients and controls, whose data were handled similarly. Furthermore, we performed the same calculations using a baseline score from a third experiment, and using an average of the two available baselines, with identical results, suggesting that these baseline scores were fairly stable from day to day and experiment to experiment.

Secondly, the finding of greater distractor-induced slowing among the slowest patients raises the concern that this might be, in some way, an artifact of their more general problem of slowed responding. However, there was no relation between the degree of distractor-induced slowing and baseline RT among control participants, nor was there a main effect of baseline RT on distraction in our regression model. Furthermore, the measured RT reflected the aggregate times of perceptual, cognitive, and motor processes required for responding. Since all of these aspects of the task were held constant while the timing of the distractor was varied, the *increase* in RT must have been due to changes related to distractor interference. Consequently, the argument advanced above—namely that the greater disruption of slower patients reflects a severity effect (with slow RTs being markers of greater severity)—is most plausible.

We did not test our patients at standard times postinjury. To test all individuals early after injury would have required us to exclude most potential participants who were either too impaired or on excluded medications. On the other hand, to test all participants late would have allowed the less severely impaired participants to recover to the point that the distractibility effect might have been less evident. In addition, many of these participants would have been unavailable for such extensive testing at a later time. However, we believe that the nonstandard testing was appropriate in view of our desire to clarify the types of deficits commonly seen when doing clinical work in a rehabilitation setting. In such settings, the tasks undertaken are guided more by the patients’ current functional level than by their absolute time postinjury, and we believe that we have demonstrated an important deficit in patients who are still significantly disabled and receiving comprehensive rehabilitation services at the time of testing. Furthermore, the correlation between time postinjury and degree of distractor-induced slowing was also negligible ($r_s = .13$).

Future research may be able to clarify the time course of recovery of the form of distractibility described here. Additional permutations of the timing of targets and distractors may also allow a more precise characterization of the cognitive processes involved in disruption of performance by extraneous distractors and the role that conscious inhibition, on the one hand, and habituation, on the other, play in this phenomenon. In addition, we are currently in the process of analyzing the relation between distractor-induced slowing, as measured in this experiment, and more naturalistic measures of distractor-induced orienting recorded during independent work in a noisy environment. In this way, we hope to clarify whether the deficit measured here can help account for some of the observable behavioral signs used to label patients as distractible.

CONCLUSIONS

Distractibility has been a common complaint of survivors of TBI, their families, and the clinicians who work with them. Modeling such problems in the laboratory has been difficult due to the variety of ways in which distraction has been operationalized. Using a visual go–no-go RT task and salient extraneous distractors, we have documented a transient abnormality in susceptibility to visual distractions among individuals with significant TBI-related disability. The fact that this abnormality affects RT alone, dissipates over time, and is best demonstrated by distractors appearing *after* target presentation, has important implications for future research. Further research, using larger samples, will be required to verify the neurologic correlates of this deficit, and to examine the extent to which distractibility, as defined in this research, correlates with inattentiveness in naturalistic settings.

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REFERENCES

Chadwick, O.M., Rutter, M., Brown, G., Shaffer, D., & Traub, M. (1981). A prospective study of children with head injury: II. Cognitive sequelae. *Psychological Medicine*, *11*, 49–62.

Dencker, S.J. & Lofving, B. (1958). A psychometric study of identical twins discordant for closed head injury. *Acta Psychiatrica Neurologica Scandinavica*, *33* (Suppl. 122), 5–48.

Gronwall, D.M.A. & Sampson, H. (1974). *The psychological effects of concussion*. London: Oxford University Press.

Jacobs, H. (1988). The Los Angeles Head Injury Survey: Procedures and initial findings. *Archives of Physical Medicine and Rehabilitation*, *69*, 425–431.

Kewman, D.G., Yanus, B., & Kirsch, N. (1988). Assessment of distractibility in auditory comprehension after traumatic brain injury. *Brain Injury*, *2*, 131–137.

McKinlay, W.W., Brooks, D.N., Bond, M.R., Martinage, D.P., & Marshall, M.M. (1981). The short term outcome of severe blunt head injury as reported by relatives of the injured persons. *Journal of Neurology, Neurosurgery and Psychiatry*, *44*, 527.

McLean, A., Temkin, N., Dikmen, S., & Wyler, A. (1983). The behavioral sequelae of head injury. *Journal of Clinical Neuropsychology*, *5*, 361–376.

Miller, E. (1970). Simple and choice reaction time following severe head injury. *Cortex*, *6*, 121–127.

Miller, E. & Cruzat, A. (1981). A note of the effects of irrelevant information on task performance after mild and severe head injury. *British Journal of Clinical Psychology*, *20*, 69–70.

Ponsford, J. & Kinsella, G. (1992). Attention deficits following closed-head injury. *Journal of Clinical and Experimental Neuropsychology*, *14*, 822–838.

Rappaport, M., Hall, K.M., Hopkins, K., Belleza, T., & Cope, D.N. (1982). Disability rating scale for severe head trauma: Coma to community. *Archives of Physical Medicine and Rehabilitation*, *63*, 118–123.

Schmitter-Edgecombe, M.E., Marks, W., Fahy, J.F., & Long, C.J. (1992). Effects of severe closed-head injury on three stages of information processing. *Journal of Clinical and Experimental Neuropsychology*, *14*, 717–737.

Stablum, F., Leonardi, G., Mazzoldi, M., Umilta, C., & Morra, S. (1994). Attention and control deficits following closed head injury. *Cortex*, *30*, 603–618.

Stuss, D.T., Stethem, L.L., Hugenholtz, H., Picton, T., Pivik, J., & Richard, M.T. (1989). Reaction time after head injury: Fatigue, divided and focused attention, and consistency of performance. *Journal of Neurology, Neurosurgery and Psychiatry*, *52*, 742–748.

Teasdale, G. & Jennett, B. (1974). Assessment of coma and impaired consciousness. *Lancet*, *2*(7872), 81–84.

Vakil, E., Weisz, H., Jedwab, L., Groswasser, Z., & Aberbuch, S. (1995). Stroop color-word task as a measure of selective attention: Efficiency in closed-head-injured patients. *Journal of Clinical and Experimental Neuropsychology*, *17*, 335–342.

van Zomeren, A.H. (1981). *Reaction time and attention after closed head injury*. Lisse, The Netherlands: Swets & Zeitlinger, B.V.

van Zomeren, A.H. & Brouwer, W.H. (1987). Head injury and concepts of attention. In Levin, H.S., Grafman, J., & Eisenberg, H.M. (Eds.), *Neurobehavioral recovery from head injury* (pp. 398–415). New York: Oxford University Press.

Whyte, J., Fleming, M., Polansky, M., Cavallucci, C., & Coslett, H.B. (1997). Phasic arousal in response to auditory warnings after traumatic brain injury. *Neuropsychologia*, *35*, 313–324.

Whyte, J., Polansky, M., Cavallucci, C., Fleming, M., Lhulier, J., & Coslett, H.B. (1996). Inattentive behavior after traumatic brain injury. *Journal of the International Neuropsychological Society*, *2*, 274–281.

Whyte, J., Polansky, M., Fleming, M., Coslett, H.B., & Cavallucci, C. (1995). Sustained arousal and attention after traumatic brain injury. *Neuropsychologia*, *33*, 797–813.