

Fig. 2. Illustration of the trial sequence in the experiment. A fixation display was presented for 675 ms, followed by a cue display which was either gaze or arrow direction. The cue was displayed for either 100, 300, or 700 ms, then a target was presented, either to the right or left of the cue, and irrespective of cue direction.

145 reported normal or corrected-to-normal vision, and were unaware of the pur-
 146 poses of the experiment.

147 This study was approved by the ethical committee at our institutions, and all
 148 subjects gave their informed consent to participation.

149 2.2. Stimuli

150 The experiment was controlled by Superlab software, and the stimuli were
 151 presented on a 14 in. computer monitor. There were two blocks to the exper-
 152 iment: the first block used arrow direction as the cue, and the second block
 153 used schematic faces with gaze direction as the cue. The cues were black line
 154 drawings as illustrated in Fig. 2.

155 In the first, arrow block, a cross subtending 3.9° horizontally and 1.9° verti-
 156 cally appeared in the center, of which the intersection served as the fixation point.
 157 This was displayed for 675 ms, followed by the cue display. In the cue display,
 158 arrowheads or vertical bars appeared at each horizontal end of the cross. Arrow-
 159 heads ($1.3^\circ \times 0.6^\circ$) at both ends pointed in the same direction, cueing either to
 160 the right or left. The vertical bars (1.3°) served as the neutral cue, similar to
 161 straight gaze in the second block. The cue was presented for either 100, 300
 162 or 700 ms randomly (stimulus onset asynchrony; SOA), after which a target, X,
 163 subtending 0.6° , appeared either to the right or left of the cue, 7.1° from the
 164 fixation point.

165 In the second, gaze block, the fixation display was composed of one central
 166 circle subtending 0.4° , and two ellipses, the axes of which are $1.8^\circ \times 0.9^\circ$, and the
 167 center of which is 1.0° above, and 1.4° to the left and right of the central circle.
 168 A large circle subtending 8.0° surrounded the central circle and the ellipses.
 169 The central circle was used as the fixation point, and was displayed for 675 ms,
 170 followed by the cue display. In the cue display, a black circle subtending 0.9° ,
 171 appeared within each ellipse, positioned either centrally (straight gaze), or 11°
 172 off the center to the right or left (right/left gaze). The cue was presented for
 173 either 100, 300 or 700 ms randomly (stimulus onset asynchrony; SOA), after
 174 which a target, X, subtending 0.6° , appeared either to the right or left of the cue,
 175 7.1° from the central circle.

176 2.3. Design

177 There were two cue types (arrows and gaze), each in a separate block. The
 178 order of the blocks remained fixed among subjects. Within each block, cue-target
 179 SOAs (100, 300, 700 ms), cue-target relations (congruent, incongruent, neutral),
 180 and target locations (right, left) were randomly selected with equal probability
 181 to make up a non-predictive, spatially-cued, target detection test. Ten catch trials
 where no target followed the cue were randomly dispersed within each block.

2.4. Procedure

182 Participants sat 45 cm from the monitor. Subjects were instructed to maintain
 183 fixation throughout each trial, and upon target detection, to press the spacebar
 184 on the keyboard with their dominant index finger. The nature of the cue stimuli
 185 (e.g. the resemblance thereof to arrows or eyes) was never mentioned, nor was
 186 the probability in relation to cue-target congruency. Fifteen practice trials were
 187 given before each block. The RT from the onset of the target, to the pressing of the
 188 key was recorded. Time out was set at 1500 ms, with an inter-stimulus interval
 189 of 3000 ms. A total of 190 trials consisted one block, which took approximately
 190 15 min to complete. Subjects were given a minimum of 10 min between blocks
 191 to rest. Four control subjects completed both blocks within the same day, and the
 192 remainder completed them on separate days. All control subjects completed each
 193 block once. On the other hand, M.J. completed each block twice, on two separate
 194 days. This was because her hemianopia prevented her from responding reliably to
 195 left targets, whose RTs were therefore not included for further analysis; to ensure
 196 a sample size equivalent to each control subject, she completed the experiment
 197 twice. Trials with left targets were discarded, and the remaining trials with right
 198 targets were evaluated.

199 Eye movements were not monitored for the control subjects, for it has been
 200 confirmed in a number of studies that normal subjects reliably do not move their
 201 eyes on similar experiments (Friesen & Kingstone, 2003; Friesen et al., 2004;
 202 Posner, 1980). M.J.'s eyes were monitored by direct viewing of the experimenter,
 203 and was confirmed that she maintained fixation on all valid trials. Note that for
 204 trials with left targets, which fall in M.J.'s defective visual field, she did show
 205 eye movements to the left on some occasions. However, after the offset of the
 206 stimulus, and during the inter-stimulus interval of 3 s, she directed her gaze back
 207 to the center, enabling her to fixate centrally in the following trial.
 208

209 3. Results

210 Errors, defined as anticipations (RTs < 100 ms), RTs longer
 211 than 1000 ms, time-outs (no response), and incorrect responses
 212 (pressing a key other than the correct spacebar), were first dis-
 213 carded from further analysis, which eliminated less than 1% of
 214 normal data. M.J. performed flawlessly on trials with right tar-
 215 gets. The mean RTs, standard deviations, and error rates of all
 216 trials for the control group, and of trials with right targets for
 217 M.J., are presented in Table 1. M.J. showed significantly longer
 218 overall RTs than the controls ($p < 0.001$). Before further analy-

Table 1
Mean reaction times, standard deviations, and error rates

Cue type	M.J. (right targets)			Normal controls (all targets)		
	RT	S.D.	%E	RT	S.D.	%E
Arrows						
Congruent	421	58	0	357	73	1.10
Incongruent	473	112	0	381	78	1.20
Neutral	442	68	0	381	77	0.11
Overall	442	85	0	373	77	0.81
Gaze						
Congruent	437	94	0	355	80	0.89
Incongruent	433	81	0	366	79	0.67
Neutral	437	119	0	370	88	0.44
Overall	436	99	0	358	80	0.56

Due to her left hemianopia, the results for M.J. include right target trials only. RT; reaction time (in ms), S.D.; standard deviation, %E; error rate.

219 sis, the data for the control group was tested for any significant
220 effect of target presentation side (right or left). *T*-test proved no
221 significant effect of target side ($p=0.747$), and so the data for
222 both target sides were collapsed according to congruency in further
223 analysis for the control group. Mean RTs as a function of
224 congruency and SOA are shown for each cue type in Fig. 3.

225 ANOVAs were then conducted for M.J. and the control group
226 separately, with cue type (arrows, gaze), cue-target congruency
227 (congruent, incongruent, neutral) and SOA (100, 300 and
228 700 ms) as the within-subject variables. For the control group,
229 the main effect of cue type, congruency and SOA were all highly
230 significant [respectively; $F(1,14)=18.72, p<0.001$ (slower for
231 arrows); $F(2,14)=32.42, p<0.001$ (fastest for congruent conditions);
232 $F(2,14)=33.72, p<0.001$ (fastest at SOA 300 ms)], but
233 none of the interactions were significant. On the other hand, M.J.
234 demonstrated significant main effect of SOA [$F(2,19)=7.64,$
235 $p=0.001$] (slowest at SOA 700 ms), but the main effects of
236 cue type nor congruency reached significance [respectively;
237 $F(1,19)=0.443, p=0.506, F(2,19)=2.335, p=0.098$]. Importantly,
238 there was a significant interaction of congruency \times cue
239 type [$F(2,19)=3.21, p=0.042$]. Such interaction did not exist
240 for the control group, indicating that M.J. differs from the control
241 group in that cue type modifies congruency effect.

242 To explore this interaction of congruency by cue type in M.J.,
243 two ANOVAs were conducted separately for each cue type,

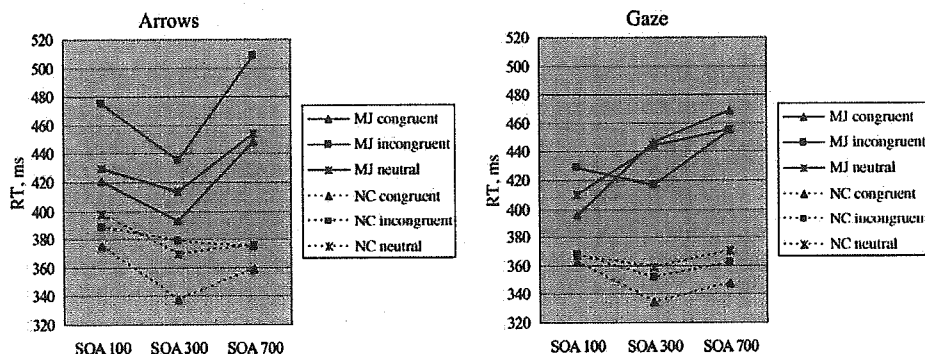


Fig. 3. Results of the experiment. The mean RTs of M.J. (lines) and normal controls (NC; dotted lines) for each cue type, as a function of cue-target congruency and SOA length. (Note that the results for M.J. include right target trials only).

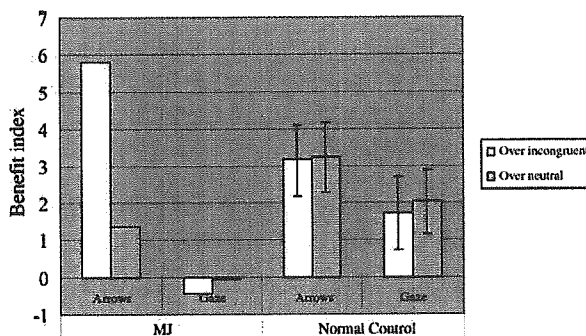


Fig. 4. Benefit of congruent over incongruent/neutral cues. Benefit indices are calculated as $(RT_{\text{incongruent}} - RT_{\text{congruent}})/(RT_{\text{incongruent}} + RT_{\text{congruent}}) \times 100$, and $(RT_{\text{neutral}} - RT_{\text{congruent}})/(RT_{\text{neutral}} + RT_{\text{congruent}}) \times 100$, respectively. Positive (negative) values indicate benefits (costs), of congruent cues in detecting targets. Error bars indicate the 95% confidence interval for the normal control group.

244 with congruency as the variable. The main effect of congruency
245 was significant for arrows [$F(2,19)=6.88, p=0.001$] (slow-
246 est for incongruent conditions), while not significant for gaze
247 [$F(2,19)=0.03, p=0.971$]. In comparison, the control group,
248 when analyzed separately for each cue type, showed a highly sig-
249 nificant main effect of congruency for both cue types, with RTs
250 being fastest in congruent conditions [arrows; $F(2,14)=28.86,$
251 $p<0.001$], [gaze; $F(2,14)=10.13, p<0.001$].

252 The consistent congruency effect seen in both cue types in
253 the control group can be summarized as a benefit of congruent
254 over incongruent or neutral cues in detecting peripheral targets.
255 Such benefits can be quantified by the following equations:

256 congruent over incongruent benefit

$$257 = (RT_{\text{incongruent}} - RT_{\text{congruent}})/(RT_{\text{incongruent}} + RT_{\text{congruent}})$$

$$258 \times 100,$$

259 congruent over neutral benefit

$$260 = (RT_{\text{neutral}} - RT_{\text{congruent}})/(RT_{\text{neutral}} + RT_{\text{congruent}}) \times 100$$

261 These benefit indices were calculated for M.J. and for each
262 individual in the control group, using the mean RTs collapsed
263 according to congruency within each cue type. The averaged
264 benefit indices for the control group are illustrated in Fig. 4,

255 together with M.J.'s benefit indices. The benefits of congruent
256 cues in the control group are very consistent across cue types,
257 and irrespective of whether compared against incongruent or
258 neutral cues. In contrast, only arrows elicited a reliable bene-
259 fit of congruency for M.J.; the benefit of congruent gaze cues
270 was non-existent. It can thus be concluded that gaze direction
271 affords M.J. no cue in detecting peripheral targets, in the face of
272 a relatively normal cueing effect for arrows.

273 4. Discussion

274 In this experiment, we have first confirmed that normal
275 subjects demonstrate faster detection of targets when cued by
276 central gaze or arrows that are directionally congruent with tar-
277 get location, opposed to incongruent or neutral cues, as have
278 been previously reported in a number of studies (Driver et al.,
279 1999; Friesen & Kingstone, 1998; Friesen et al., 2004; Ristic
280 et al., 2002; Tipples, 2002; Zorzi, Mapelli, Rusconi, & Umiltà,
281 2003). This facilitation of RTs in congruent conditions might be
282 termed as 'gaze (or arrow) effect', and reflects the significance
283 of such signals in orienting the viewer's attention. In striking
284 contrast, M.J., whose right STG is nearly completely damaged
285 (and thus, right half of whose STS is damaged), has been shown
286 to demonstrate no such gaze effect whatsoever, in the face of a
287 quite normal arrow effect. Her error rates (Table 1) show that
288 she understood the instructions thoroughly, and was attentive
289 throughout the entire experiment. M.J.'s results can be summa-
290 rized as a dissociative ability in utilizing directional information
291 from biological (gaze) versus non-biological (arrows) signals to
292 orient her attention: impaired for gaze but intact for arrows.

293 The finding that a lesion to the right STS results not only
294 in defective discrimination of gaze direction (Akiyama et al.,
295 2006), but in a more fundamental deficit in orienting attention
296 toward gaze direction, might have profound implications. Such
297 a deficit would leave victims clueless as to what others are
298 attending to, and their consequential intention or desire. This
299 function of gaze-directed orienting should thus be a precursor
300 to the development of other higher social cognitions, such as
301 gaze following, joint attention, imitation, and intention/belief
302 understanding. Indeed, several lines of evidence implicate the
303 role of the STS in such higher social cognitions. Pelphrey et al.
304 have reported in their two recent fMRI studies that the social
305 context of a perceived gaze differentially modulates STS activa-
306 tion. Gaze shifts which violate the viewer's expectations elicit
307 significantly stronger activation in the STS, opposed to gaze
308 shifts in concordance to expectations (Pelphrey et al., 2003).
309 Likewise, gaze shifts which simulate eye-contact and gaze aver-
310 sion have also elicited differential activity in the STS (signifi-
311 cantly stronger for eye-contact) (Pelphrey, Viola, & McCarthy,
312 2004). These examples demonstrate that the STS is involved
313 not only in the low-level processing of gaze, but also in the
314 processing of subtle social intentions behind it. Another find-
315 ing which might be relevant to the STS involvement in higher
316 social cognition comes from a study of three cases with left
317 temporo-parietal junction (TPJ) lesions demonstrating a rela-
318 tively 'pure' deficit in false-belief understanding (Samson,
319 Apperly, Chiavarino, & Humphreys, 2004). A consecutive study

employing identical tasks in frontal lesion cases also demon- 320-
strated false-belief deficits, but with the contamination of a 321-
general impairment in executive functions (Apperly, Samson, 322-
Chiavarino, & Humphreys, 2004). These studies are suggestive 323-
of the privileged role that the STS/TPJ continuum might play 324-
in social functions such as mentalizing. Finally, from a broader 325-
perspect, a number of functional neuroimaging studies tapping 326-
theory of mind in normal subjects have demonstrated STS activa- 327-
tion (for a recent review, see Gallagher & Frith, 2003), also sup- 328-
porting STS involvement in social cognition. In this line, we have 329-
provided evidence in the current study that a function beyond the 330-
mechanical analysis of gaze can be impaired after STS lesion; 331-
this function, namely, the gaze-directed orienting, reflects the 332-
preparation to make a reaction based on the social relevance 333-
conveyed by gaze direction, which might be crucial in initiating 334-
reciprocal social interaction. M.J. thus offers a neuropsychologi- 335-
cal bridge between social cognition and its possible prerequisite, 336-
biological motion processing, specifically in the STS. 337

338 There are also some limited implications for the hemispheric 339-
laterality of gaze processing. In a previous report, a right-handed, 340-
split-brain patient J.W. demonstrated a laterality in gaze process- 341-
ing, such that gaze processed in the right hemisphere was able 342-
to effectively orient attention in its direction, but gaze processed 343-
in the left hemisphere could not (Kingstone et al., 2000). On the 344-
other hand, arrows showed no such hemispheric laterality in this 345-
patient (Ristic et al., 2002). These findings concord well with 346-
M.J.'s results in the present experiments; gaze processing which 347-
might be dominant in the right hemisphere was impaired, but 348-
arrow processing which might be processed in both hemispheres 349-
was intact, after a right STG lesion. Additional evidence sup- 350-
porting such laterality is a recent fMRI study which investigated 351-
the topography of STS activation elicited by differing biological 352-
motion (Pelphrey, Morris, Michelich, Allison, & McCarthy, 353-
2005). In this report, eye movement was demonstrated to activate 354-
only the right STS, in comparison to mouth and hand movements 355-
which activated bilateral STS. It goes without saying that direct 356-
comparison with a left STG lesion is needed to be conclusive (for 357-
example, see Samson et al., 2004 for left TPJ lesion cases with 358-
gaze discrimination impairment). However, these prior studies 359-
and the current data converge to implicate a right dominance in 360-
gaze processing.

361 Recently, Vecera and Rizzo have tested a frontal lesion case, 362-
EVR, in similar spatial cueing tasks using peripheral versus cen- 363-
tral cues (Vecera & Rizzo, 2004, 2006). Peripheral cues, such 364-
as bright boxes appearing abruptly in the periphery prior to tar- 365-
get presentation, are categorized as exogenous cues in that no 366-
interpretation on the subject's part is necessary, and are thus con- 367-
sidered to allocate attention automatically. Conversely, central 368-
cues, such as the gaze and arrow cues used in this study, and 369-
word cues (e.g. right/left) used in Vecera and Rizzo's studies, 370-
are endogenous in that a processing of the cue stimulus is neces- 371-
sary within the subject before it can become a true spatial cue. In 372-
their studies, Vecera and Rizzo have demonstrated that periph- 373-
eral cues were effective in orienting attention in EVR, while 374-
central cues, in this instance, gaze and word cues, both failed 375-
to show any cueing effect. They have thus concluded that gaze 376-
is no different from other symbolic cues (e.g. words, arrows) in

terms of the manner in which they allocate attention (voluntary), and even in the neural substrate realizing their function as spatial cues (frontal lobes). Turning to the experiments in this report, M.J. was tested with two endogenous, central cues; arrows which are symbolic cues with strong directional valence but no biological property, and gaze cues which have both strong directional and biological valence. Here, M.J. showed dissociative cueing effects in these two endogenous cues; impaired for gaze, but intact for arrows. It can be argued that M.J.'s impairment in gaze perception precludes any higher cognitive deficits concerning gaze, such as the present lack of cueing effect, but that they should be attributed solely to her perceptual defects. However, when considering the polymodal nature of the superior temporal cortex where M.J.'s lesion lies, it is questionable whether her gaze processing impairment is purely perceptual. Rather, a more naturalistic categorization of her impairment might be called for, such as a modular deficit in gaze processing which includes the specific lack of cueing effect to gaze. The demonstrated dissociation is therefore more likely attributable to the dissociable modular processing of the two directional signals, of which gaze, being a prominent biological motion, resides in the STS and is damaged in M.J. What we would like to emphasize is that although gaze may just be one of the many effective spatial cues to the frontal lobes, it is without doubt a very special cue to the STS. Future studies utilizing a variety of cue stimuli to patient groups with differing lesion locus might yield unique patterns in the impairment of these cueing effects, from which further insight into the neural network subserving spatial cueing effects can be appreciated.

Other minor differences besides the gaze/arrow dissociation were also identified between M.J. and the control group. Firstly, although the effects of SOA were similarly significant for both M.J. and the controls, they were different in the manner SOA affected reaction. For the controls, SOA 300 ms elicited the fastest reaction, with no differences between 100 and 700 ms. On the other hand, M.J. was significantly slower at SOA 700 ms, compared to 100 and 300 ms, the two of which were not significantly different. Secondly, and perhaps more interestingly, the significant arrow effect demonstrated for both M.J. and the controls were different in the manner that congruency affected performance; the controls were fastest for congruent arrows with similar RTs for incongruent and neutral arrows, whereas M.J. was slowest for incongruent arrows with similar RTs for congruent and neutral arrows. In other words, M.J.'s arrow effect reflects the cost from incongruent arrows, in contrast to the controls' which reflects the benefit from congruent arrows. Whether these subtle aberrant performance seen for M.J. are characteristic to STG damage, or reflect a more general feature of brain dysfunction, remains to be seen. Investigating patients with focal lesions in other brain areas should clarify this issue.

The influence of hemianopia in M.J.'s gaze processing, which proved quite complicating in our previous report, also needs to be re-addressed. In this experiment, we believe we were successful in eliminating most such effect, and also in presenting additional evidence that hemianopia is not a confounding factor in her gaze impairment. Firstly, by maintaining central fixation on the 'nose' in this experiment, at least the entire right half

of the cue-stimuli is ensured to fall in M.J.'s intact right visual field, which helps in eliminating gross effects of hemianopia. Secondly, and more importantly, if the influence of hemianopia were a major factor in her gaze impairment, her performance for the gaze cues should have had a systematic trend—congruent right gaze should have cued right targets efficiently, neutral straight gaze might have cued right targets in a way similar to, but to a lesser degree than, congruent gaze (due to a rightward bias in perception often seen in left hemianopia (Barton, Behrmann, & Black, 1998; Doricchi, Onida, & Guariglia, 2002), and incongruent left gaze should have interfered with right target detection, but perhaps to a lesser degree than normal controls due to the influence of hemianopia. However, no such systematic deviation was found in M.J. It were as though gaze afforded no cues for M.J. in orienting her attention.

We have demonstrated in this experiment that a well-circumscribed lesion to the right STG impairs the ability to utilize biological directional information such as gaze, but leaves the non-biological counterpart (arrows) intact. This dissociation implies that indeed, the STG (or perhaps more specifically, the STS) specializes in processing information from biological motion such as gaze, and not in processing similar, but non-biological signals such as arrows. The defective behavior of not being able to orient attention toward gaze direction might be evidence of impairment, due to STS damage, of the earliest components of social cognition, such as joint attention. Gaze and arrows seem quite similar at first glance— but there's so much more to it than what meets the eyes.

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