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Research Report

Experiencing simultanagnosia through windowed viewing of complex social scenes

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ABSTRACT

Simultanagnosia is a disorder of visual attention, defined as an inability to see more than one object at once. It has been conceived as being due to a constriction of the visual "window" of attention, a metaphor that we examine in the present article. A simultanagnosic patient (SL) and two non-simultanagnosic control patients (KC and ES) described social scenes while their eye movements were monitored. These data were compared to a group of healthy subjects who described the same scenes under the same conditions as the patients, or through an aperture that restricted their vision to a small portion of the scene. Experiment 1 demonstrated that SL showed unusually low proportions of fixations to the eyes in social scenes, which contrasted with all other participants who demonstrated the standard preferential bias toward eyes. Experiments 2 and 3 revealed that when healthy participants viewed scenes through a window that was contingent on where they looked (Experiment 2) or where they moved a computer mouse (Experiment 3), their behavior closely mirrored that of patient SL. These findings suggest that a constricted window of visual processing has important consequences for how simultanagnosic patients explore their world. Our paradigm's capacity to mimic simultanagnosic behaviors while viewing complex scenes implies that it may be a valid way of modeling simultanagnosia in healthy individuals, providing a useful tool for future research. More broadly, our results support the thesis that people fixate the eyes in social scenes because they are informative to the meaning of the scene.

1. Introduction

Simultanagnosia[1] is an inability to see more than one object at a time resulting from bilateral lesions to the parieto-occipital junction (Bálint, 1909; Holmes and Horrax, 1919; Riddoch et al., 2010; Rizzo and Vecera, 2002). It can be so severe that patients appear "functionally blind" (Kim and Robertson, 2001), with little or no understanding of the fragmented world they

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[1] Here we are discussing dorsal (as opposed to ventral) simultanagnosia (Farah, 1990), which is an attentional limitation that prevents patients from seeing more than one object at a time.

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perceive. Their perception is often "captured" by local elements of a scene, in that they report local details of a scene or object at the expense of the global whole (Karnath et al., 2000). For example, when viewing impoverished stimuli like hierarchical letters, which consist of global letters made up of several repetitions of a local letter, patients report only the local letters of large, sparse, stimuli (Dalrymple et al., 2007; Huberle and Karnath, 2006).

Recently, we showed that the local capture of simultanagnosia could be modeled in healthy subjects by using an artificially limited field of vision to simulate a spatially restricted zone of attentional processing (Dalrymple et al., 2010). Healthy subjects viewed hierarchical letters through a gaze-contingent aperture, which allowed them to see only a small part of the stimulus at one time. Subjects under this limitation showed patterns of inaccuracy that were highly similar to those seen in a patient (SL), in that they identified local elements well but not the global letters, particularly when those letters were large and had widely spaced local elements, despite having unlimited time to accomplish the task. This suggests that a narrowed window of visual processing – from either a small visual window in our simulation in healthy subjects or a constricted focus of attention in simultanagnosia, coupled with normal limits in the ability to integrate spatial information across fixations – is sufficient to account for the poor global report in simultanagnosia.

A handful of studies have investigated where simultanagnosics look when they explore these and other impoverished stimuli (e.g., Clavagnier et al., 2006; Dalrymple et al., 2009; Nyffeler et al., 2005; Tyler, 1968), but little work has systematically investigated how simultanagnosics scan more complex stimuli, such as social scenes. Tyler (1968) recorded the eye movements of a patient who looked at a photograph of five dolls and a line drawing of a desert scene, but these stimuli were still quite simple, and the eye movement patterns were described but not quantified. It remains unclear how patients with simultanagnosia explore more complex stimuli, which may better represent their experience in the real world.

The purpose of the present study was twofold. Our first aim was to assess and quantify where simultanagnosic patients look when they scan complex social stimuli. Social scenes were used because much is known about how healthy individuals explore these scenes (e.g., Birmingham et al., 2007, 2008a,b; Smilek et al., 2006). Our second and more ambitious aim was to assess how their scanning behavior relates to the spatial constriction of visual processing that underlies the simultanagnosic deficit, by using our gaze-contingent paradigm to model this restriction of processing in healthy subjects. If a spatial constriction of processing itself is pivotal to the visual exploration in simultanagnosia, our paradigm of seeing only a small portion of a stimulus at a time should generate simultanagnosic behaviors in healthy subjects engaging in a complex task, such as describing complex scenes.

In Experiment 1, we studied the distribution of fixations made during scanning and reporting of complex scenes and compared a patient with simultanagnosia (SL) to healthy subjects and to two brain-damaged control patients (KC and ES). The goal of this experiment was to establish where healthy subjects look when viewing social scenes under normal viewing conditions and to determine where a simultanagnosic patient looks when viewing the same stimuli.

In Experiment 2, we investigated where healthy subjects look while viewing scenes through a gaze-contingent aperture that allowed them to see only a small portion of the scene at one time. The goal of this experiment was to test whether healthy subjects viewing social scenes through a spatially constricted viewing window would distribute their fixations in a similar way to a patient with simultanagnosia. By using an eye monitor to produce a small gaze-contingent aperture, healthy subjects saw only a small portion of the scenes around their point of fixation at any point in time. Gaze-contingent displays have been used in the past with a variety of tasks, such as reading (McConkie and Rayner, 1975), visual search (Pomplun et al., 2001), and scene exploration (Loschky et al., 2005) and even to simulate simultanagnosic behavior with simple stimuli (Dalrymple et al., 2010). We then compared their scanning patterns to those of SL and the control subjects from Experiment 1. If the findings from our simultanagnosic patient in Experiment 1 are related to a restricted window of visual processing, then healthy subjects viewing scenes through a restricted gaze-contingent visual window should allocate their fixations to the different regions of the scenes in a similar fashion.

In Experiment 3, we compared our gaze-contingent paradigm to a mouse-contingent paradigm to determine whether the restricted viewing window itself is crucial to produce the simultanagnosia-like behaviors. Specifically, the movement of the gaze-contingent aperture must be controlled through eye movements to "empty space". Because any area of the display that is outside the viewing aperture is blank, eye movements cannot be initiated based on information in the periphery, and this could have led to any abnormal scanning patterns of the gaze-contingent group. In addition, the dual task of using the eyes to move the aperture concurrently with seeing through it may lead to unnatural scanning patterns. We tested this possibility in Experiment 3, by replicating Experiment 2 with a mouse-contingent rather than a gaze-contingent window. Using a mouse to control the movement of the window allows subjects to move the window to a location prior to initiating an eye movement.[2] This would therefore minimize any anomalies in fixation patterns that might be due to the unusual situation of initiating eye movements to empty space, while still confining them to processing information within a small window at any given point in time. We also reasoned that moving the window with a computer mouse rather than the eyes is a more natural scenario to participants who are experienced computer users, allowing them more control and freedom to move the window to a desired location. If our paradigm is valid and a spatially constricted window of visual processing indeed contributes to complex ocular motor

[2] We confirmed the assumption that participants in the mouse-contingent condition move their eyes to the location of the window with a supplementary analysis of eye position relative to the window. Participants move their eyes and the window together and commit the majority of their eye movements to the center of the mouse-contingent window.

behaviors seen in simultanagnosia, we predict that healthy subjects viewing scenes through a small aperture should allocate their fixations to the different regions of the scene in a more similar way to SL, than to control subjects with unrestricted viewing. This should be the case regardless of the method of controlling the viewing aperture.

2. Results

2.1. *Experiment 1*

Summary of main findings: representative scan paths and corresponding verbal descriptions can be found in Fig. 1 and Table 1. Young and age-matched controls demonstrated the standard preferential bias to the eyes of people in the scenes (e.g., Birmingham et al., 2007, 2008a,b) and did not differ from each other in terms of proportions of fixations to any of the regions and were therefore combined into a single group when compared to SL. SL had a significantly smaller proportion of fixations on the eye region compared to healthy control subjects and compared to control patients KC and ES (Fig. 2a). This result emerged as early as 5 s and persisted for the duration of the trials. Control patients KC and ES did not differ from each other in terms of their proportions of fixations to any region and all groups fixated the head region equally. These results are presented in detail below.

Young controls vs. age-matched controls: there was a main effect of region indicating that the young and age-matched control groups both allocated different proportions of

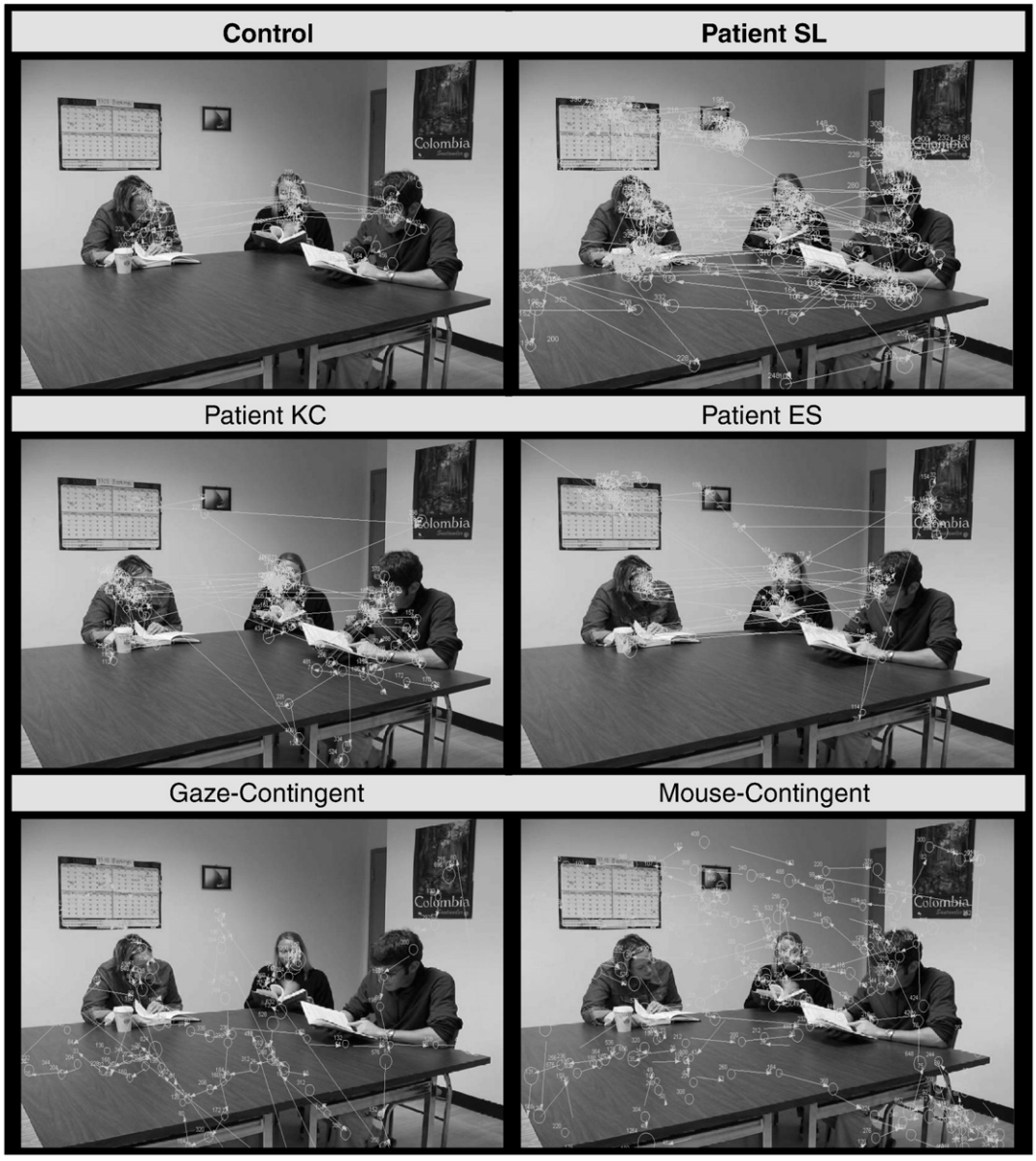

Fig. 1 – Representative scan patterns for each patient and group. Circles represent fixations. The size of the circles represents the duration of the fixation (larger = longer). Lines represent movement from one fixation to another.

Table 1 – Representative verbal descriptions from each patient and group. Descriptions correspond to scan patterns from Fig. 1.

Group	Verbal description
Young control	*Subject 1:* This is… three people in a room reading books, aaa woman on the left has a coffee in front of her and a jean jacket, aaaa woman in the middle has a blue book, she's flipping the pages, and there's guy on the right with glasses and a blue sweater… reading a book. *Subject 2:* Here people are reading, um, and that girl—one girl is drinking coffee. Posters and a calendar on the wall.
Age-matched Control	*Subject 1:* Uh it's a room with three people in it. Uuhhh, uh, a male and I believe two females, one has a coffee cup. There's a calendar a wall, there's a…a picture on a wall. There's a poster of Columbia on the wall. There's uh, there's a green colored door. Uhhmm… there's a table they're seated around uhh with and they're… and they're in three chairs. (Pause). Uh, one of the males is wearing a blue… a blue top and is wearing a…a wrist watch on his right hand. The female is wearing a black top. Uhhmm, the other person is wearing a denim top um… with some kind of hair braid or whatever they're called. Uhh and all three are reading from books. One of the books is red, one is blue and the other one I believe is black. Ok. *Subject 2:* Inside, uh, office. Central table. Three chairs… occupied by three people… two female, one male. Appear all are reading out of different books. One has a paper takeout Starbucks coffee. Large calendar on the wall with some notations and dates marked off. Umm, picture on the wall.
ES	Uh that's three students studying. One's got like a Starbucks coffee in front of her. And there's ahh… they're at a table and there's a poster in the background that says "Columbia". And it's two females and one male and the one male who is wearing a wristwatch and glasses. And one girl's flipping through the pages in the middle there, with the long blonde hair. And there's a calendar in the background, a four-month calendar by the looks of it.
KC	Uhh ok, this looks very, very familiar, I've seen these people before, I've certainly seen the one in the middle with the, with the uhhh uh, dirty blond, straight hair. She's reading a book this time, I think she was doing something else the last time. She's wearing a black sweater and then there's the man reading from a book and he's has a blue sweater, shirt, whatever it is and light pants. And then the woman to the left is wearing the dark jean jacket, I've seen her before. And she has the streaked red, blond, and black and brown hair, and… I don't know, I can go on forever.
SL	Oh. I see students and they are reading… books uh 1, 2, 3..4 people, students, and there's a coffee mug there too and there's a calendar behind them and there's a picture there, Columbia picture on it. They're… they're sitting on the chairs, and the last student has got glasses, umm… they… he's wearing a wrist watch, uhh they are flipping pages… and the table is brown color. And there is a picture behind… next door to the calendar too, ummm is it a moon picture or something? Earth or something? And there is a yellow color on the picture, and I think I see green door there, or a green… something green on the wall… at the back there.
Gaze-contingent	*Subject 1:* There's a female reading again, from the first picture. Uhmm… there's no… there's a guy that another (inaudible) I guess… they're studying this time instead of playing board games, uhm, the Columbia poster again… and they're in the same room as before but they're just studying and there's nothing new around. *Subject 2:* Here's a girl kind of… half smiling, blond hair down. She's reading. There's a guy to her right with glasses and dark hair... He's also reading and playing with something on the page. He's wearing a blue shirt (pause). He's wearing a watch (pause). Then there on the left side there's some other girl with her head tilted to… her right, but my left and she a barrette and blond hair. She's wearing a jean jacket. She's also reading and she has coffee in front of her. She's wearing a pink… er, I guess a pink shirt under her denim jacket. And above her… there's…. a calendar… with 3308… bookings… on the top…. (pause). And there's a table and all three of them are studying on it. It's wooden (pause). And there's the same Columbia poster.
Mouse-contingent	*Subject 1:* A guy, a girl, another girl reading books (inaudible word), drinking coffee…. Poster. Columbia poster. Calendar, picture frame… table… *Subject 2:* Ok, next scene. The girl's got a book in front of her. Another guy's got another book in front of him. Third girl, same thing. She's got a coffee. All the books are on the table. They're all sitting on chairs, and… it looks like they're… not in a library, they're in, again, what looks like a classroom, or a TA room or something because there's a calendar on the wall… with some dates on it…. Yeah, and Columbia something… sectionals or something.

fixations to the different regions, $F(4,60)=183.44$, $p<0.001$. Critically, fixations were allocated significantly more to the eyes than to any other region in the scenes. There was no main effect of group, $F(1,60)=0.11$, $p=0.741$, or group-by-region interaction, $F(4,60)=0.06$, $p=0.994$, indicating that the young and age-matched controls did not differ from each other in terms of how they allocated their fixations to the different regions in the scenes, e.g., the bias to look at the eyes was the same for young and aged-match controls.

SL vs. healthy controls: SL had a smaller proportion of fixations on the eye region, $t(17)=-10.52$, $p<0.001$, but a larger proportion of fixations on the body region, $t(17)=6.12$, $p<0.001$ compared to healthy control subjects. She did not differ from them in terms of fixations to any other region (all $ps>0.100$).

KC vs. ES: there was a main effect of region indicating that KC and ES both allocated different proportions of fixations to the different regions, $F(4,60)=183.44$, $p<0.001$. Like the healthy participants, both patients' fixations were allocated significantly more to the eyes than to any other region in the scenes. KC and ES did not differ from each other in terms of proportions of fixations to any region (all $ps>0.160$).

SL vs. KC: SL had a smaller proportion of fixations on the eye region, $t(14)=3.96$, $p=0.001$, but a larger proportion of fixations on the body, $t(14)=-3.86$, $p=0.005$; object, $t(7.30)=-4.09$, $p=0.004$; and background region, $t(14)=-5.26$, $p<0.001$. These patients did not differ in terms of proportions of fixations on the head region, $t(14)=0.21$, $p=0.834$.

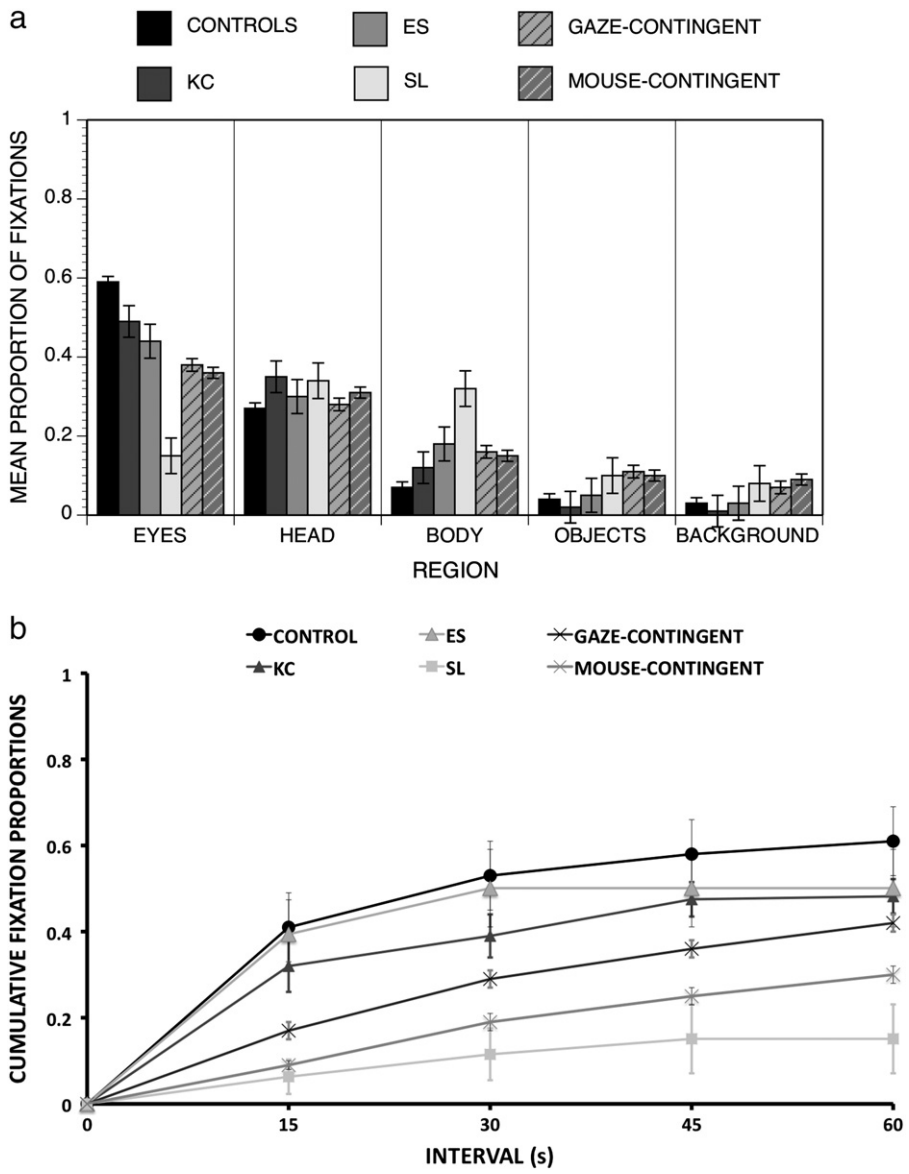

Fig. 2 – (a) Fixation proportions for control subjects and patients KC, ES, and SL, who viewed the scenes under natural viewing conditions; gaze-contingent subjects who viewed the scenes through a 2° × 2° gaze-contingent aperture; and mouse-contingent subjects who viewed the scenes through a 2° × 2° mouse-contingent aperture. Fixation proportions are normalized for the size of the region. (b) Cumulative fixation proportions to the eye region for controls, KC, ES, SL, and the gaze- and mouse-contingent groups over time. Error bars represent standard error.

SL vs. ES: SL had a smaller proportion of fixations on the eye region, $t(14) = 2.14$, $p = 0.050$ and a larger proportion of fixations on the background region, $t(14) = -3.16$, $p = 0.007$, but these patients did not differ in terms of fixations to any other region (all $ps > 0.07$).

Temporal analysis: this analysis was performed to determine the time course of the observed effects. The healthy control group fixated the eye region more than SL within the first 5 s of viewing the scenes, $t(17) = -2.66$, $p = 0.017$. This difference persisted for each remaining interval (all $ps < 0.01$). In contrast, patients KC and ES, who are not simultanagnosic, did not differ from controls at any time interval (all $ps > 0.01$). These results are presented in Fig. 2b.

2.1.1. *Discussion of results from Experiment 1*

We monitored the eye movements of simultanagnosic patient SL while she verbally described social scenes to determine whether she allocates her fixations differently from healthy young, healthy aged-matched, and patient control subjects. Our regions-of-interest analysis showed that SL had an abnormally small proportion of fixations on the eye region of the scenes compared to the healthy and patient control participants. SL's tendency to ignore the eyes emerged early in the trials and persisted for the duration of each trial. This behavior is particularly noteworthy because it is well documented that healthy participants typically allocate disproportionately high numbers of fixations to eyes in social scenes (Birmingham et al.,

2007, 2008a,b; Smilek et al., 2006), an effect that was replicated here in our healthy and patient control participants.

2.2. Experiment 2

Summary of main findings: the gaze-contingent group differed from the control group most notably by having an abnormally small proportion of fixations on the eye region and a corresponding increase in fixations to other regions. This is precisely how SL differed from the control group. Like SL, this effect for the gaze-contingent group emerged early and persisted throughout the duration of each trial. These results are presented in detail below.

Gaze-contingent vs. controls: compared to the healthy control participants who described the scenes in the unrestricted viewing condition, the gaze-contingent group had a smaller proportion of fixations on the eye region, $F(1,29)=39.33$, $p<0.001$, but a higher proportion of fixations on the body, $F(1,29)=49.33$, $p<0.001$; object, $F(1,29)=66.18$, $p<0.001$; and background regions, $F(1,29=66.44$, $p<0.001$. There was no difference between these groups in the proportion of fixations on the head region, $F(1,29)=0.05$, $p=0.826$.

Gaze-contingent vs. SL: although mirroring the pattern of behavior of SL, in absolute terms, the gaze-contingent group had a larger proportion of fixations on the eye region, $t(14)=-4.76$, $p<0.001$, but a smaller proportion of fixations on the body region, $t(14)=3.39$, $p=0.004$ compared to SL. They did not differ in terms of proportion of fixations to any other region (all $ps>0.200$).

Temporal analysis: this analysis revealed that the control group fixated the eyes significantly more than the gaze-contingent group as early as 5 s and that this effect persisted for each remaining interval (all $ps<0.001$). This result is presented in Fig. 2b.

2.2.1. Discussion of results from Experiment 2

This experiment was designed to test whether healthy subjects viewing social scenes with a constricted field of visual processing would simulate the scanning behavior of a patient with simultanagnosia. We predicted that healthy subjects under these conditions would show small proportions of fixations to the eyes in social scenes, similar to simultanagnosic patient SL. Our results show that, like SL, our gaze-contingent group fixated the eyes significantly less than the control subjects under natural viewing conditions. This effect emerged early and persisted for the duration of each trial. All groups fixated the head region equally.

These results indicate that the restriction of visual information imposed on the gaze-contingent group made them perform more similarly to simultanagnosic patient SL than to control subjects who viewed the scenes under natural viewing conditions. In particular, like SL, the gaze-contingent group made an abnormally low proportion of fixations to the eye region, while allocating an abnormally high proportion of fixations to the body, object, and background regions.

2.3. Experiment 3

Summary of main findings: the mouse-contingent group, like the gaze-contingent group, demonstrated a significant decline in fixations to the eyes in the natural scenes. Indeed, the mouse-contingent group did not differ from the gaze-contingent group in terms of their fixation proportions on any of the five regions. These results are reported below.

Mouse-contingent vs. gaze-contingent vs. controls: the ANOVAs revealed that while the mouse-contingent group did not differ from the gaze-contingent group in any way, these groups both differed from the control group. There was a main effect of group for the proportion of fixations on the eye region, $F(2,45)=33.64$, $p<0.001$. A post hoc Bonferonni multiple comparison *t*-test indicated that the mouse- and gaze-contingent groups had lower proportions of fixations on the eye region. Post hoc Bonferonni *t*-tests also revealed that the mouse-contingent and gaze-contingent groups both had a higher proportion of fixations on body, $F(2,45)=27.70$, $p<0.001$, Object, $F(2,45)=37.05$, $p<0.001$, and background regions, $F(2,45)=26.76$, $p<0.001$, compared to the control group, and that there were no differences between any groups in the proportion of fixations on the head region, $F(2,45)=1.96$, $p=0.153$. All post hoc *t*-tests used a critical value of $t=2.49$.

Mouse-contingent vs. SL: although mirroring the pattern of behavior of SL, in absolute terms the mouse-contingent group had a higher proportion of fixations on the eye region, $t(17)=-3.00$, $p=0.010$, compared to SL. These groups did not differ in terms of their proportions of fixations to any of the other regions (all $ps>0.200$).

Temporal analysis: the analysis revealed that the control group fixated the eyes significantly more than the mouse-contingent group as early as 5 s and that this effect persisted for each remaining interval (all $ps<0.001$). This result is presented in Fig. 2b.

2.3.1. Discussion of results from Experiment 3

The mouse-contingent group replicated the previous finding of the gaze-contingent group – a significant disregard for the eyes of others – a pattern that mirrors the behavior of SL. This indicates that the small proportion of fixations on the eyes by the gaze-contingent group in Experiment 2 was not due to how the viewing window was controlled but due to the restriction of visual processing imposed on the participants by the window itself.

3. General discussion

In Experiment 1, we showed that, unlike healthy control subjects from this and other studies (Birmingham et al., 2008a, b; Smilek et al., 2006), simultanagnosic patient SL made very few fixations on the eyes in social scenes. SL also made fewer fixations on the eyes than our two control patients KC and ES, who have similar bilateral posterior lesions to SL, but no simultanagnosia. This suggests that it is simultanagnosia, rather than non-specific effects of brain damage, that generates the reduced fixations on the eyes. In Experiment 2, we showed that healthy subjects who viewed scenes through a gaze-contingent aperture also show reduced fixations on the eyes of people in the scenes compared to controls, who described the scenes in an unrestricted viewing condition. Experiment 3 replicated this result with a mouse-contingent aperture, indicating that the effect that spatial restriction of visual processing has on behavior – specifically, its ability to produce a profound reduction in healthy participants'

attention to the eyes of others – has nothing to do with how the aperture is controlled, i.e., oculomotor or manual control. Our temporal analysis of the fixation proportions on the eye region indicates that while healthy control subjects and control patients KC and ES look at the eyes of people in the social scenes early and consistently, patient SL and the gaze- and mouse-contingent groups do not. When taken together, these findings provide converging evidence that a model of spatial constriction of visual processing can mimic not only the perceptual performance of simultanagnosic patients with hierarchical letters (e.g., Dalrymple et al., 2010) but also their scanning behavior while viewing complex natural scenes.

Several aspects of our study point specifically to a restricted area of visuospatial processing as being key to these results. First, simultanagnosic patient SL showed reduced fixations on the eye region, compared to healthy controls, but also compared to our control patients KC and ES—who did not have simultanagnosia and demonstrated normal visuospatial processing. Second, this reduced fixations on the eyes was mimicked by a literal restriction to the viewing window of healthy subjects in our gaze-contingent paradigm. Finally, our mouse-contingent group, who viewed the same scenes through the same window as our gaze-contingent group, showed the same reduction in fixations on the eye region, even though they moved the window with a mouse rather than with their eyes. Again, this indicates that it was the window itself that was crucial to creating this abnormal behavior, not the method of controlling the window.

We use a restriction of the visual window in healthy individuals to model the restriction of attention that is proposed to underlie the simultanagnosic deficit. By restricting the spatial viewing area that is available for healthy subjects, we also restrict the spatial area within which subjects can attend. Thus, healthy subjects in our window groups are experiencing a restriction visual attention. We previously used this same method to model simultanagnosic accuracy patterns for naming hierarchical letters (Dalrymple et al., 2010). Healthy subjects viewing hierarchical letters through a gaze-contingent window showed the same pattern of accuracy for identifying global and local levels of hierarchical letters of different sizes and densities as simultanagnosic patient SL. Combined with the present results, our restricted viewing model of simultanagnosia has successfully modeled two very distinct simultanagnosic behaviors. In addition, beyond the link between restricted viewing in healthy individuals and the restricted window of attention in simultanagnosia, there is no *a priori* reason to predict that viewing scenes through a restricted window of vision would lead to reduced proportions of fixations on the eyes by healthy individuals. It is therefore reasonable to assume that restricting the viewing area of healthy subjects is a valid way of modeling simultanagnosic behavior, both on practical and theoretical grounds.

One might wonder if SL's low fixation count on the eye region can be explained by poor ocular motor control, given the ocular motor apraxia that often forms part of Bálint syndrome. Inaccurate targeting, which may conceivably also occur in healthy subjects attempting to control an unfamiliar gaze-contingent window, could result in fixations intended for the eyes falling outside of that region. However, if this was the case, one would then expect an abnormally high proportion of fixations on the adjacent head region. Instead, our results show that all groups, including healthy participants, fixated the head equally. Furthermore, subjects in the mouse-contingent window condition were free to move their fixation position within the mouse-controlled aperture, thus eliminating the concern of inaccurate saccadic targeting. As we have demonstrated, the mouse-contingent group allocated their fixations to the different regions identically to the gaze-contingent group, suggesting that the dual task of using one's eyes to move the window and to see through it cannot account for the observed scanning patterns.

An alternate possibility for the reduced fixations on the eyes, and the one that we favor, is that the eye region is not especially informative to simultanagnosic patients and to our gaze- and mouse-contingent groups. Birmingham et al. (2007) argue that people look at eyes in social scenes because they provide rich social information regarding the meaning of a scene, especially regarding how people in the scene are allocating their attention to other people and objects within a scene. This interpretation dovetails well with the present findings. Patients with simultanagnosia, and healthy participants using a gaze- or mouse-contingent window, do not have access to visual information beyond a confined perceptual window and are therefore unlikely to be able to infer where people in the scenes are attending. Similarly, items within a scene are unlikely to be perceived as "being looked at" or "not being looked at" by one or more individuals in the scene. Indeed, the present data suggest that this became less relevant for the observers. Of course, what did not become irrelevant to any of the participants is a general interest in people. SL, as well as the gaze- and mouse-contingent groups, continued to allocate a significant amount of their viewing to the heads and bodies of the people in the scenes. What is unique and striking is that they appear to be uninterested in where the people in the scene are allocating their visual attention.

This interpretation converges with the well-established finding that simultanagnosic patients suffer from a global processing deficit. Patients describe scenes in a piece-meal fashion and are unable to see the global aspect of hierarchical letters. While it was originally thought that this global processing deficit was due to "local capture", that is, an inability to disengage from local elements in order to perceive the global whole (Karnath et al., 2000), eye movement data from patients performing this task have since disconfirmed this notion (Clavagnier et al., 2006). Rather than being "stuck" on a few local elements, simultanagnosics produce many eye movements—far more than what is seen from healthy control subjects performing the same task. While control subjects need only make a few fixations to extract the global meaning of a stimulus, simultanagnosic patients scan the stimulus in detail and may even trace the global shape in an attempt to piece together its global meaning (Clavagnier et al., 2006; Dalrymple et al., 2009). This behavior is well accounted for by the *Reverse Hierarchy Theory* (Hochstein and Ahissar, 2002), which suggests that normal vision occurs on a continuum from "vision at a glance", which provides a global gist of a visual scene to "vision with scrutiny", which processes the details of the scene. The restricted spatial area of visual

processing in simultanagnosia would in theory disrupt "vision at a glance", forcing patients to rely on vision for scrutiny to derive meaning from a scene. This theory would therefore predict the pattern of exploration seen with hierarchical letters, as well as the pattern of exploration seen in the present study: rather than allocating a large proportion of fixations to one region, such as the eyes, and deriving the meaning of a scene through "gist", simultanagnosic patients, and our gaze- and mouse-contingent groups, distribute their fixations more evenly across regions, using details to derive global meaning. Increased reliance on "vision with scrutiny" would also predict the abnormally small saccade amplitudes that were produced by these groups, as they move serially from detail to detail within the scene.

Providing additional support for this possible reliance on vision for scrutiny, Nyffeler et al. (2005) recorded the eye movements of a simultanagnosic patient while she read the time on a schematic analogue clock and found that the patient looked at the numbers of the clock in succession, rather than looking at the hands of the clock and the numbers they point to. Without 'vision at a glance' to give the gist of the object and to guide 'vision with scrutiny' to the important details of the clock (i.e., the hands), the patient was forced to make successive fixations to "uninformative" parts of the clock before locating the hands to tell the time. This result is also somewhat analogous to the current findings: while Nyffeler et al.'s patient did not look at the hands of the clock and the numbers they were pointing to, our patients did not look at the eyes in the scenes and what they were looking at.

Our findings of abnormally low fixations on eyes suggest potential deleterious effects of simultanagnosia on how facial information is processed. Previously we showed that patients with simultanagnosia may experience global capture with faces, seeing the face as a whole at the expense of the features (Dalrymple et al., 2007). This suggests abnormal processing of details, including the eyes, and is consistent with results of the present study, which show that simultanagnosics make normal proportions of fixations to the heads of people in scenes, yet reduced fixations to the eyes. There are several implications to this finding, including the possibility that patients are impaired at normal social responses, such as gaze cuing.

Reduced fixations on eyes could have important consequences for the social functioning of patients with simultanagnosia. This behavior can be likened to the robust finding that individuals with autism spectrum disorder, who are known to have severe social impairments (APA, 1994; Volkmar and Klin, 2000), similarly show reduced fixations on eyes when looking at faces (Klin et al., 2002; Pelphrey et al., 2002; Riby and Hancock, 2008; Spezio et al., 2007). However, there is no evidence to date that suggests that patients with simultanagnosia have social impairments. On the contrary, Pegna et al. (2008) found a typical search advantage for angry faces in simultanagnosic patient MC, suggesting that this patient is capable of processing the emotional content of faces. Ultimately the possibility of a social impairment in simultanagnosia is of great interest as an avenue of future research in order to more fully understand the extent of the simultanagnosic deficits.

Despite the strong relationship between the scanning patterns of our patients and model groups, one might question the validity of using an artificially restricted visual window as a model of simultanagnosic behavior. However, the fact that a restricted viewing paradigm led to simultanagnosia-like scanning patterns of social scenes in healthy subjects is likely more than a coincidental convergence of patient and model behaviors. For one, the restricted window paradigm implemented here is a theoretically motivated model of the simultanagnosic deficit, based on descriptions of patient behaviors, empirical tests of what patients can and cannot see (i.e., demonstrating a restricted area of useful visual processing), and based on with the reports of patients regarding their own experience. Secondly, the high proportion of fixations to the eyes in scenes by healthy subjects under normal viewing conditions is a highly replicable finding that occurs across a variety of tasks (e.g., describing or remembering a scene: Birmingham et al., 2007, 2008a,b; Smilek et al., 2006); there is no *a priori* reason to predict that simultanagnosic patients would show reduced fixations to the eyes of people in social scenes. Likewise, there is no *a priori* reason to predict that participants in a restricted viewing condition would show the same abnormal behavior, beyond the link we hypothesized to exist between the reduced window of attention in simultanagnosia and the restricted window of vision in our paradigm. Finally, this same reduced window manipulation has led to simultanagnosic behavior with other simpler stimuli (Dalrymple et al., 2010). Specifically, healthy subjects asked to name the global level of hierarchical letters viewed through a gaze-contingent aperture showed accuracy patterns for global level report similar to patient SL, who performed the same task under natural viewing conditions. For the above reasons, it appears reasonable to conclude that the restricted viewing window in our task is a valid model of the simultanagnosia-like scanning patterns. It also encourages the speculation that visual restriction may in fact be a key underlying mechanism that leads to the abnormal scanning of social scenes in simultanagnosia.

Although artificially restricted window viewing leads to complex behaviors similar to those of patients with a restricted window of attention due to brain damage, we do not claim that this model explains all simultanagnosic behaviors, or all the properties of the attentional window itself. For example, there is evidence that patients can be cued to locations outside their useful visual window (Egly et al., 1995), and others have shown that the restricted window of attention in simultanagnosia can be expanded through priming (Shalev et al., 2004). It is unclear how healthy individuals could be cued to a location outside the rigid viewing window used in our study, or how our paradigm could be used to model the expansive properties of the attentional window in simultanagnosia. However, the present data show that the artificial window is a good first step in investigating the link between restricted visual input due to damage to the visual system and an artificial restriction of visual input on individuals with normal brains. In fact, one strength of the current model is its parsimony: a very simple visual manipulation can lead to a complex behavioral pattern akin to one from a complex neurological disorder. Adjusting the current methodology to model other aspects of the restricted window of attention in simultanagnosia is a challenge for future research that can only further inform the nature of this disorder.

In addition to identifying a valid model of simultanagnosic behavior, providing a useful tool for future research on a disorder for which patients are often scarce, the results of the present experiments have two other important implications. First, our results reveal how a spatially constricted window of visual processing affects the acquisition of information from the world. The fact that healthy subjects under natural viewing conditions robustly show disproportionately high fixation rates to the eyes in social scenes across several tasks (Birmingham et al., 2007, 2008b; Smilek et al., 2006) underscores the unusual nature of SL's scanning patterns. Secondly, our results support the idea that people fixate the eyes in social scenes because the eyes are informative to the overall meaning of the scene, in large part because they tell observers where people are directing their attention. When eyes are viewed without the surrounding visual context, they may lose this informative value. Thus, a constricted spatial area of processing, whether from neurological or artificially imposed limitations, has important consequences for how information is acquired from our visual world.

4. Experimental procedures

4.1. *Experiment 1*

4.1.1. *Participants*

4.1.1.1. *Young control subjects*. Young control participants ($n=8$; 5 male) were undergraduate students at the University of British Columbia who ranged in age from 17 to 34 years (mean = 22 years). All participants reported normal or corrected-to-normal vision and gave informed consent prior to participation in the experiments, which were performed in accordance with the ethical guidelines of the University of British Columbia.

4.1.1.2. *Age-matched control subjects*. Age-matched control participants ($n=10$; 6 male) were individuals from the community in the city of Vancouver who ranged in age from 40 to 59 years (mean = 49 years). All participants reported normal or corrected-to-normal vision and gave informed consent prior to participation in the experiments, which were performed in accordance with the ethical guidelines of the University of British Columbia.

We compared the mean saccade amplitudes and mean fixation durations of the age-matched controls and the young controls using 1-way repeated measures ANOVAs with between-subject factor of group. The age-matched group did not differ from the young control group in terms of saccade amplitudes, 5.16º vs. 5.96º, $F(1,15)=3.48$, $p=0.082$, or fixation duration, 307.34 ms vs. 282.66 ms, $F(1,15)=0.96$, $p=0.343$.

4.1.2. *Patients*

4.1.2.1. *Case reports*. SL is a 48-year-old right-handed woman, with 12 years of education. She had idiopathic cerebral vasculitis resulting in bilateral parietal and lateral occipital infarcts (Fig. 3a). She presented with left hemineglect, as assessed with the Sunnybrook Neglect Assessment Battery (Leibovitch et al., 1998) and Bálint syndrome, with ocular motor apraxia, optic ataxia, and simultanagnosia. Her visual examination showed Snellen acuity of 20/25 in both eyes, and a left inferior quadrantanopia. Her optic ataxia was manifested by misreaching for objects and failure to orient her grasp correctly to the axes of objects such as pencils. Her simultanagnosia was evident in testing with four complex displays of visual scenes. For example, she could report elements of the Boston Cookie Theft picture (Goodglass and Kaplan, 1983) but was unable to make sense of the whole scene. She initially reported seeing only "a boy's face… eyes," without reporting the mother on the right side of the display or the second child in the scene, nor did she describe the action in the scene. Neuropsychological evaluation showed normal attention, language, and verbal memory functions. Her reading was in the borderline impaired range, and she tended to guess words based on the first or last letters. She was successful at recognizing simple line drawings of objects and could correctly identify colors and simple shapes. At the time of testing, SL had completed treatment with cyclophosphamide and prednisone 4 months prior but was still taking carbamazepine for a single seizure suffered several months prior. She no longer had left hemineglect, quadrantanopia, or defects in saccadic targeting and generation, as confirmed by her rapid and accurate saccades during the calibration of the eye monitor. She still had optic ataxia when using the left hand to point to targets. This was a specific sensorimotor transformation for the contralateral hand, not a general difficulty with perceptual localization, which would affect both hands. Patient SL has been discussed in previous reports (i.e., Dalrymple et al., 2007; Malcolm and Barton, 2007).

KC is a 55-year-old man with posterior reversible leucoencephalopathy in the setting of Crohn's disease being treated with omisartan as part of an experimental trial. He was seen 2 months prior to testing for fluctuating visual symptoms of several weeks' duration. He stated that he "could see but not perceive". He could see things and recognize them but had trouble locating and searching for household objects and could not reach for items accurately. He saw an "echo" or multiple ghosts of objects when he stared at them. His reading was slow, and at his worst, he had trouble recognizing faces and difficulty with locating objects in depth. All of these problems improved rapidly after omisartan was stopped. He was first examined 4 weeks after onset. His acuity with correction at far was 20/30 od and 20/40 os, which improved by pinhole to 20/25-1 os. Confrontation showed full visual fields. Fixation was steady; pursuit and VOR cancellation were normal. He showed normal initiation of saccades and saccadic accuracy. There was no nystagmus. His reaching was accurate, and he showed correct grasp orientation to objects. Reading was slow but accurate and without a word-length effect. Line cancellation and object cancellation showed a few errors, but these were not lateralized. His recognition of line drawings was normal. With the Boston Cookie Theft picture, he was able to name all objects. Thus, while his initial symptoms were suggestive of bi-parietal dysfunction, at the time of his examination, many of these deficits appeared to

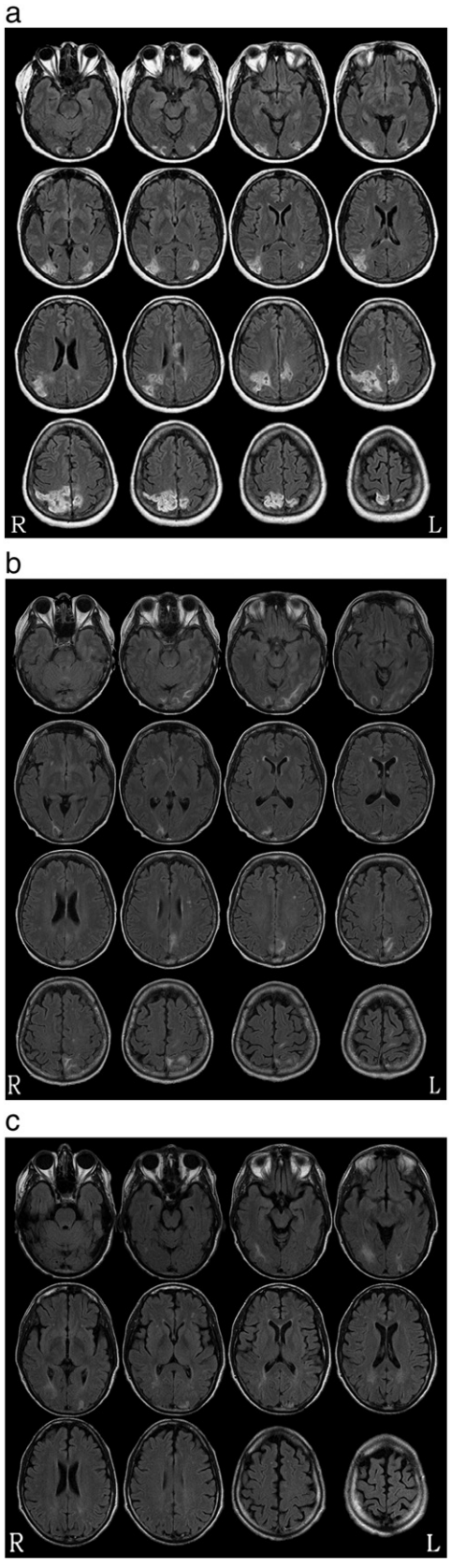

Fig. 3 – MRI scans of patients SL (a), and control patients KC (b), and ES (c).

have resolved, in keeping with the diagnosis of a reversible leucoencephalopathy, with only some mildly slowed reading and minor difficulty with visual search being found. During the time of his experimental testing 2 months later, his verbal report of scenes provided further corroboration that he was able to perceive multiple elements of complex displays. His MRI showed bilateral parietooccipital and right posterior occipital white matter FLAIR hyperintensities, as well as a small left occipital cortical infarct (Fig. 3b).

Patient ES, like SL, also suffered bilateral posterior occipitoparietal damage (Fig. 3c). Unlike the SL, however, ES never had signs of simultanagnosia or symptoms suggestive of any component of Bálint syndrome. She is a 47-year-old woman with systemic lupus erythematosis, tested several months after presenting with flashing lights, transient visual loss, and headache. Her visual examination was normal, but MR imaging revealed bilateral lesions consistent with either vasculitis or posterior leucoencephalopathy. Subsequently she had a seizure and was treated with phenytoin for 9 months. At her most recent visit, she was taking prednisone, chloroquine, and mycophenolate mofetil. Her visual acuity without correction at far was 20/20 in both eyes. Confrontation showed full visual fields. Fixation, pursuit, and saccades were normal. There was no oculomotor apraxia, optic ataxia, or simultanagnosia as shown by normal report on the Boston Cookie Theft picture. ES matched SL particularly well in age, gender, the chronic phase at testing, and probable pathology, since she also has an underlying condition that is associated with vasculitis.

We compared these patients to each other in terms of basic eye movement measures of mean saccade amplitude and mean fixation duration using two-tailed *t*-tests for each measure. KC made significantly shorter saccades than both SL, $t(14) = -3.17$, $p = 0.007$, and ES, $t(14) = 3.88$, $p = 0.002$, but SL and ES did not differ from each other on this measure, $t(14) = 0.51$, $p = 0.616$, (Means: SL = 4.15º; KC = 3.41º; ES = 4.28º). ES had significantly shorter fixations than both SL, $t(14) = -11.05$, $p < 0.001$, and KC, $t(14) = -12.04$, $p < 0.001$, but SL and KC did not differ from each other on this measure, $t(14) = -1.64$, $p = 0.122$ (means: SL = 322.43 ms; KC = 299.99 ms; ES = 180.96 ms).

4.1.2.2. *Stimuli and apparatus.* Full-color images were taken with a digital camera in different rooms in the Psychology building at the University of British Columbia. Image size was 36.5 × 27.5 (cm) corresponding to 40.1° × 30.8° at the viewing distance of 50 cm, and image resolution was 800 × 600 pixels. Twelve scenes were used in the present experiment. Scenes contained 3 persons either interacting or not interacting. All scenes were comparable in terms of their basic layout: each room had a table, chairs, objects, and background items (e.g., see Fig. 4a).

Eye movements were monitored using the EyeLink II system (SR Research Ltd., www.eyelinkinfo.com). The Eyelink II has a temporal resolution of 4 ms (sampling rate 250 Hz) and a spatial resolution of 0.5°. One high-speed camera tracked the left eye, while a second camera tracked and compensated for head position by monitoring 4 infrared sensors placed on the corners of the display monitor. Cameras were mounted and held in place by a lightweight headband, which was placed and secured on the subjects. Patients ES and KC were tested at

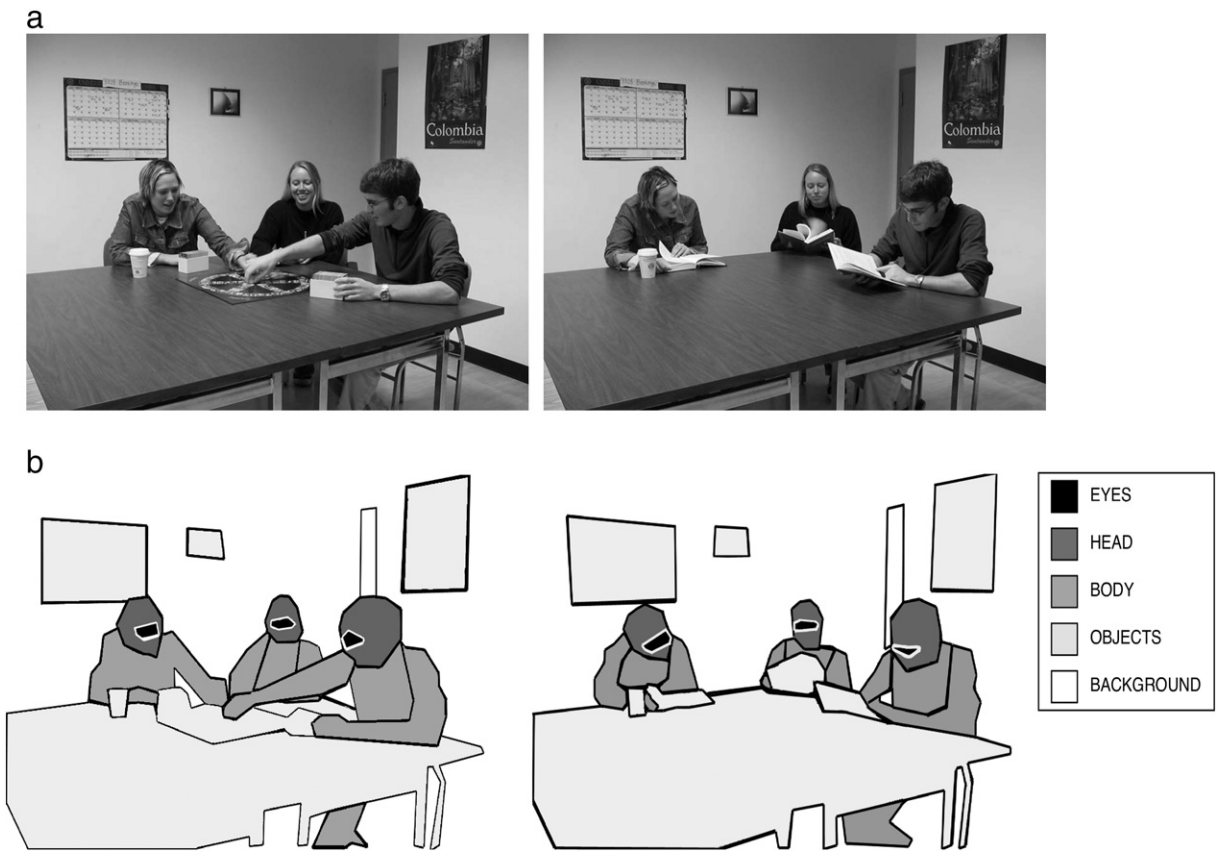

Fig. 4 – Example of scene stimuli (a) and regions of interest (b).

a later date on the Eyelink 1000 system,[3] which differs from the Eyelink II in that it has a temporal resolution of 1 ms (sampling rate, 1000 Hz) and mounts the cameras on the desktop, rather than on a headband. Two computers were used in the experimental setup and were connected to each other via Ethernet, allowing for real-time transfer of saccade and gaze position data. The experimenter computer collected the data from the eye tracker and displayed an image of the participant's eye and calibration information. The display computer displayed the stimuli and recorded key presses.

4.1.3. *Procedure*

Subjects were seated 50 cm from the screen of the display computer with their chin supported by a chin rest. The eye monitor was placed on the subject's head and securely fastened with a lightweight headband. Eye movements were recorded monocularly from the left eye. The eye monitor was calibrated using a 9-dot array. Calibration was validated using the same procedure.

After successful calibration and validation, the subject was asked to fixate a dot at center screen in order to correct for drift in gaze position. Once the dot was fixated, the experimenter initiated the onset of the scene image by key press. The scenes were presented in random order. Subjects were asked to verbally describe the scene while a digital voice recorder recorded their response. They had unlimited time to describe the scene and indicated that their description was complete by saying "Next". At this point, a key press initiated the next trial. Subjects each viewed 8 social scenes.

4.1.4. *Analysis*

4.1.4.1. *Fixation proportions*. For each image, an outline was drawn around each region of interest (e.g., "eye") and each region's pixel coordinates and area were recorded. We defined the following regions: eye, head (excluding eyes), body (including arms, torso and legs), foreground objects (e.g., tables, chairs, objects on the table), and background (e.g., walls, shelves, items on the walls). Fig. 4b illustrates these regions for one scene. To compensate for the different sizes of these regions, we computed area-normalized fixation proportions (Birmingham et al., 2008a; Smilek et al., 2006), by first dividing the number of fixations in each region by the area of the region separately for each image and each participant and then computing proportions based on these normalized data.[4]

[3] The Eyelink 1000 was used for ES and KC because of equipment upgrades that took place after initial testing with the other groups. Both Eyelink systems have the same 0.5° Gaze Accuracy, and the difference between the Eyelink II and Eyelink 1000 sampling rates does not affect the analysis of fixation frequencies.

[4] We also calculated and analyzed normalized fixation durations for each region ((total duration of fixations to a region/area of that region) * sum over all regions), but as these results mirrored the results from the fixation proportions analyses, they are not reported. Saccadic distributions for each group showed no systematic differences, so these, too, are not reported further.

The data from one young control subject were excluded because of a large offset in eye position due to a problem with the head-mounted camera. We first compared young controls to age-matched controls to determine if age affects where subjects allocate their fixations across the scene. This was done by conducting a two-way mixed design ANOVA with between-subjects factor of group (young vs. age-matched) and within-subjects factor of region (eyes, head, body, objects, and background). The groups were identical in terms of where on the scene they allocated their fixations, and so we combined the two groups into a single control group. From here on we refer to this combined control group as the control group.

To compare SL's fixations to the control group, we performed Crawford and Howell (1998) modified *t*-tests using SINGLIMS software (retrieved on September 10, 2009, from http://www.abdn.ac.uk/*psy086/dept/SingleCaseMethods-ComputerPrograms.htm) (Crawford et al., 2009; Sokal and Rohlf, 1995), on the fixation proportions for each region. *T*-test *p* values were compared to a corrected $\alpha = 0.01$, to account for multiple comparisons.

4.1.4.2. *Temporal analysis*. This analysis was designed to determine the time course of participants' fixation tendencies for the eye region. We calculated the cumulative proportions of fixations on the eye region at 5-s intervals for the first 60 s of the trials and compared each patient to the control group at each interval using Crawford and Howell (1998) modified *t*-tests.

4.2. *Experiment 2*

4.2.1. *Participants*

Subjects ($n = 14$, 4 males) were undergraduate students at the University of British Columbia who ranged in age from 18 to 24 years (mean = 20 years). All participants reported normal or corrected-to-normal vision and gave informed consent prior to participation in the experiments, which were performed in accordance with the ethical guidelines of the University of British Columbia.

We compared the mean saccade amplitudes and mean fixation durations of the gaze-contingent group and the controls using 1-way repeated measures ANOVAs with between-subject factor of Group. The gaze-contingent group made significantly smaller saccades, 3.12º vs. 5.49º, $F(1,29) = 61.55$, $p < 0.001$, but did not differ from controls in terms of fixation durations, 320.15 ms vs. 297.18 ms, $F(1,29) = 1.36$, $p = 0.253$.

4.2.2. *Stimuli, apparatus, and procedure*

The stimuli and procedure for Experiment 2 were the same as Experiment 1, except that participants viewed the scenes through a gaze-contingent aperture. A 2° × 2° (square) aperture was generated by the computer and revealed the portion of the stimulus centered on the point of fixation, the screen being white elsewhere: the aperture moved as the subject moved their fixation across the scene.

Subjects underwent a practice trial in which they were instructed to start from a circle at center screen labeled "Start" and follow a line from that circle until they reached a second circle labeled "End". They were then instructed to freely search the screen for a hidden object on the screen. This task was irrelevant to the experimental task and designed to familiarize subjects with and teach them how to control the gaze-contingent aperture. Once they located the hidden object and felt comfortable with the apparatus, the experimental task began. Like subjects in Experiment 1, the gaze-contingent group was asked to verbally describe each scene.

4.2.3. *Analysis*

We compared the data from the gaze-contingent group to the control group from Experiment 1 using 1-way repeated measures ANOVAs with between-subject factor of group. This was done for proportions of fixations to each region and to compare the groups in terms of the cumulative proportion of fixations on the eyes at 5-s intervals. Crawford and Howell (1998) modified *t*-tests were used to compare the gaze-contingent group to SL.[5]

4.3. *Experiment 3*

4.3.1. *Participants*

Subjects ($n = 17$, 7 male) were undergraduate students at the University of British Columbia who ranged in age from 17 to 23 years (mean = 19 years). All participants reported normal or corrected-to-normal vision and gave informed consent prior to participation in the experiments, which were performed in accordance with the ethical guidelines of the University of British Columbia.

We compared the mean saccade amplitudes and mean fixation durations of the mouse-contingent group and the controls using 1-way repeated measures ANOVAs with between-subject factor of group. The mouse-contingent group made significantly smaller saccades than the control group, 2.80° vs. 5.49°, $F(1,32) = 111.47$, $p < 0.001$, but did not differ from them in terms of fixation durations, 290.33 ms vs. 297.18 ms, $F(1,32) = 0.19$, $p = 0.666$.

4.3.2. *Stimuli, apparatus, and procedure*

The stimuli and procedure were identical to those used in Experiment 2, but subjects now controlled the aperture with a computer mouse. A 2° × 2° (square) aperture was generated by the computer and revealed the portion of the stimulus image at the location of the mouse. The aperture was initially placed at the central fixation point at the beginning of each trial, and subjects could move the aperture by moving the mouse. We monitored where subjects looked on the screen while moving this window around.

4.3.3. *Analysis*

We used 1-way repeated measures ANOVAs with between-subjects factor of group to compare the mouse-contingent, gaze-contingent and control groups in terms of proportions of fixations for each region (i.e., separate ANOVAs for each region). Bonferonni multiple comparison *t*-tests were used to follow up any main effects with a critical *t*-value of 2.48 and *p* compared to $\alpha = 0.05$. Two-tailed *t*-tests were used to compare

[5] For all experiments, Crawford and Howell (1998) modified *t*-tests were used to compare *individuals* to groups (e.g., SL to controls) and ANOVAs were used to compare *groups* to groups (e.g., gaze-contingent group to controls).

the Mouse-contingent group to the control group in terms of the cumulative proportion of fixations on the eyes at 5-s intervals. Crawford and Howell (1998) modified *t*-tests were used to compare the mouse-contingent group to sl.

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