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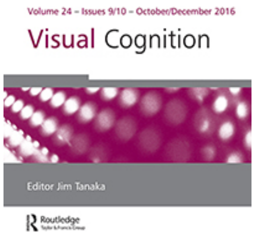

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Carryover of scanning behaviour affects upright face recognition differently to inverted face recognition

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ABSTRACT

Face perception is characterized by a distinct scanpath. While eye movements are considered functional, there has not been direct evidence that disrupting this scanpath affects face recognition performance. The present experiment investigated the influence of an irrelevant letter-search task (with letter strings arranged horizontally, vertically, or randomly) on the subsequent scanning strategies in processing upright and inverted famous faces. Participants' response time to identify the face and the direction of their eye movements were recorded. The orientation of the letter search influenced saccadic direction when viewing the face images, such that a direct carryover-effect was observed. Following a vertically oriented letter-search task, the recognition of famous faces was slower and less accurate for upright faces, and faster for inverted faces. These results extend the carryover findings of Thompson and Crundall into a novel domain. Crucially they also indicate that upright and inverted faces are better processed by different eye movements, highlighting the importance of scanpaths in face recognition.

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Eye movements; carryover; face perception; face inversion effect; scanpaths

Attention is crucial to many aspects of human cognition and perception (e.g., Luck & Ford, 1998) and directed attention to the most task-relevant source of information is vital for accurate coding of the visual scene (e.g., Brockmole & Henderson, 2006; Jonides & Yantis, 1988; Wolfe, Butcher, Lee, & Hyle, 2003). A scene or a stimulus can have several important features. In face perception, this invariably means that attention is directed toward the internal features (the eyes, nose, and mouth) given their salience (e.g., Haig, 1986). Eye-tracking studies have demonstrated that the eyes receive the largest number of fixations and the longest time being viewed compared to all other features (Heisz & Shore, 2008). For example, Janik, Wellens, Goldberg, and Dell'Osso (1978) showed that while viewing faces for 15 s, 43.4% of fixation time was directed to the eyes. Henderson, Falk, Minut, Dyer, and Mahadevan (2003) found that 60% of fixation time was dedicated to the eyes and 90% to the eyes, mouth, and nose combined. In addition, when presented with a face to learn for a period of 10 s, participants spent over 4 s examining the eyes, whereas the other facial features were each fixated for a maximum of 1 s (Henderson, Williams, & Falk, 2005). This is more pronounced for familiar faces over unfamiliar faces (Luria & Strauss, 1978; Meinhardt-Injac, Persike, & Meinhardt, 2010). Not only are the eyes the most fixated feature, horizontal eye movements between the eyes are the most common (Althoff & Cohen, 1999; Bindermann, Scheepers, & Burton, 2009) with over 75% of saccadic eye movements when viewing faces being horizontal. This pattern of eye movements demonstrates a highly stereotyped scanpath when viewing faces: a triangular pattern of eye movements with many saccades between the eyes and fewer downward saccades toward the nose and mouth (Yarbus, 1967).

This scanpath appears to be fundamental in the recognition of faces. Indeed, Hills, Ross, and Lewis (2011) have shown that face recognition is disrupted if the mouth is cued rather than the eyes. This manipulation disrupts the face-specific scanpath causing participants to fixate more on the mouth than they would typically. In turn, recognition of own-ethnicity faces is poorer than without such cueing. There is also evidence that this scanpath is altered when looking at faces of another ethnicity (Goldinger, He, & Papesh, 2009; Hills & Pake, 2013). Other-ethnicity faces are typically recognized less accurately than own-ethnicity

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faces (e.g., Hills & Lewis, 2006; Meissner & Brigham, 2001). Both lines of evidence suggest that the deployment of the face-specific fixation pattern is vital for accurate recognition of faces. However, the importance of saccadic movement between features has not been verified.

Crucially, inverting faces also disrupts the scanpath. Eye movements whilst viewing inverted faces involve more first fixations to the mouth and fewer fixations to the eyes than in upright faces (Barton, Radcliffe, Cherkasova, Edelman, & Intriligator, 2006; Henderson et al., 2005; Hills, Sullivan, & Pake, 2012; Xu & Tanaka, 2013). Furthermore, the eyes may not always be the first feature attended to in inverted faces (Hills et al., 2013). Some studies have indicated viewing similarities between upright and inverted faces (e.g., Sekuler, Gaspar, Gold, & Bennett, 2004; Williams & Henderson, 2007). Methodological differences may explain such discrepant findings: Sekuler et al. asked six observers to view 10,000 trials with stimulus contrast adjusted to ensure participants retained a constant accuracy level of 71%. There are significant individual differences in eye movement strategies when viewing faces in terms of features viewed (Mehoudar, Arizpe, Baker, & Yovel, 2014) and in the amount of local or global viewing strategies employed (Miellet, Caldara, & Schyns, 2011). Consequently, Sekuler et al.'s work may have been influenced by participants who utilized similar local strategies for all faces. Similarly, the contrast manipulation may have had an influence on eye movements in unexpected ways. In Williams and Henderson's (2007) study, faces were presented for 10 s each, well beyond the functional time needed to make a recognition judgement (typically 1500 ms), and faces were blocked according to orientation. Both procedures may have encouraged more extensive scanning to the face than is required to make recognition judgements. Nevertheless, both studies did report slight differences in fixations for upright and inverted faces (with pixels to the outer edge of the eyes being fixated more in the recognition of inverted faces than upright faces in Sekuler et al.'s study; and more time spent viewing the mouth in inverted faces than upright faces, if the more appropriate one-tailed test was run).

Inversion reliably causes deficits in the accuracy and speed of recognition of faces (Valentine, 1988; Yin, 1969), potentially due to the disruption to the scanpath. Scanning faces is mostly goal-driven (top-down) potentially due to expertise humans have with processing faces (Leder & Bruce, 2000). While inversion seems to impact on the scanpath, this effect may be indirect. Thus far, no research has directly tested whether disrupting the initiation of the face-specific scanpath affects face recognition, yet there is evidence from other domains that suggest it might.

In visual search, two orienting systems are known to exert influence on coding (Posner, 1980). These are exogenous (bottom-up) and endogenous (top-down). While the former is stimulus-driven, fast, and automatic, the latter is goal-driven, slower, and voluntary (i.e., it can be consciously suppressed). Bottom-up influences direct our attention to objects and information that are highly salient, whereas top-down influences guide our attention according to our knowledge of the demands of the task (Buschman & Miller, 2007; Connor, Egeth, & Yantis, 2004). Sometimes, if the demands of a certain task change, a corresponding change in visual search behaviour should occur. However, this is not what researchers have found. For example, Leber and Egeth (2006) showed that participants carried their attentional set from one task to another, even if the attentional set was detrimental to performance on the second task (see Lewis, Mills, Hills, & Weston, 2009; Muller & Krummenacher, 2006a, 2006b; Wolfe et al., 2003). Similarly, Thompson and Crundall (2011) demonstrated that eye movements carried over from a letter-search task to a hazard-perception task in driving, causing slower hazard detection when these eye movements did not match the strategy most appropriate for the driving task.

Using the paradigm of Thompson and Crundall, we devised an experiment to disrupt the initiation of the face-specific scanpath to assess the importance of the scanpath on face recognition. Participants performed a letter search task followed by an identification task of upright or inverted famous faces. Letter strings were arranged horizontally, vertically, or randomly across the screen and were shown to elicit eye movement changes (Hills et al., 2016). Given that during upright face processing there is a distinct scanpath consisting of proportionally more horizontal saccades (moving between the eyes) than vertical saccades (e.g., Rizzo, Hurtig, & Damasio, 1987), we would expect that the carryover from the horizontal letter string will aid processing of a face by speeding up the recognition of the face, whereas carryover from a vertical letter string may be detrimental to face processing. This is because the carryover from a vertical letter string will reduce the amount of saccades between the eyes (which are the primary diagnostic feature for recognition, e.g., Henderson et al., 2003). Given the lack of a specific scanpath when viewing inverted faces (e.g., Xu & Tanaka, 2013), the same effects should not be observed. Indeed, it is possible for the converse to be true, since the first fixation when viewing an inverted face is more likely to be to the nose or mouth (Hills et al., 2012) than in an upright face. In order to scan the eyes, a vertical saccade would be required to move attention to the eye region and it would make sense to engage this early in the encoding of the face. We would therefore expect the disruption of an early vertical saccade to be more detrimental to the recognition of inverted faces. Thus, we predict that there would be an interaction between orientation of the faces and the orientation of the letter strings for face recognition response times. We measured the saccadic direction for the entire duration that the face was on screen since the carryover of eye movement effect typically lasts for up to 2 s (Thompson & Crundall, 2011), though is stronger for the first 1000 ms than the second 1000 ms (Thompson, Howting, & Hills, 2015). Indeed, we found no difference in any effect if we measured the first saccade or all the saccades during which the face was viewed, and face identification decisions were made on average within 1167 ms.

Method

Participants

An opportunity sample of 80 (35 male, age range 18–41 years, modal age 20 years) Anglia Ruskin University staff and students with normal or corrected-to-normal visual acuity participated in the experiment. They received either course credits (for psychology students) or monetary reward of £3 as payment and were recruited by responding to an advertisement email, by word of mouth, and using an online research system. Forty participants were allocated to each condition of letter string position (see Design).

Materials

Eighty (40 male, age range 18–60 years, modal age 27 years) famous faces collected from the internet were used as the face stimuli. These were collected by a research assistant who was similar in age to the target population. All were of famous people popular in different areas (e.g., TV, movies, politics, music: for a full list of the celebrities used see the Appendix). All faces displayed a neutral expression and had no extraneous paraphernalia (such as glasses, beards, jewellery). The faces were pre-tested to ensure that they were all familiar to the population and of similar level of distinctiveness. This was achieved by asking 22 participants who did not take part in the main part of the experiment to rate 120 faces for familiarity (on a 1 to 7 scale), provide some semantic information about the face (e.g., the name or a programme they featured in), and rate the face for how distinctive it was visually. The faces selected for the main experiment were those rated at the highest level of familiarity and those for which all participants were able to provide accurate semantic information. The faces were presented in greyscale on a white background and measured 344×425 pixels. Each face had a resolution of 72 dpi and subtended $10.65° \times 8.65°$ of visual angle.

In the letter search task, participants were presented with strings of letters, each containing nine letters of the English alphabet (lower and upper case), presented in black on a white background, using size 18 Verdana font ($0.95° \times 0.95°$). Letters were located within an invisible 9×9 grid and were presented horizontally (across the centre of the grid), vertically (down the centre of the grid) or randomly (arranged randomly across the grid).[1] This grid was located in the top left 75% of the screen rather than the full screen (see Figure 1) in one condition and in the centre of the screen in a second condition. In both conditions, the letter furthest from the centre of the letter string was a maximum of 4.5° of visual angle distant. All letter strings consisted of either five consonants and four vowels or six consonants and three vowels. The letter "I" was not included as it could have been mistaken for a lower-case "L" and participants were made aware of this during the experiment's instructions. When the letter string included two of the same vowels they were counted as two, rather than one vowel.

The experiment was conducted in a well-lit, air-conditioned, sound-attenuated eye-tracker laboratory. It was equipped with a high-resolution 17″ (1280×1024 pixels) LCD colour monitor and the stimuli were

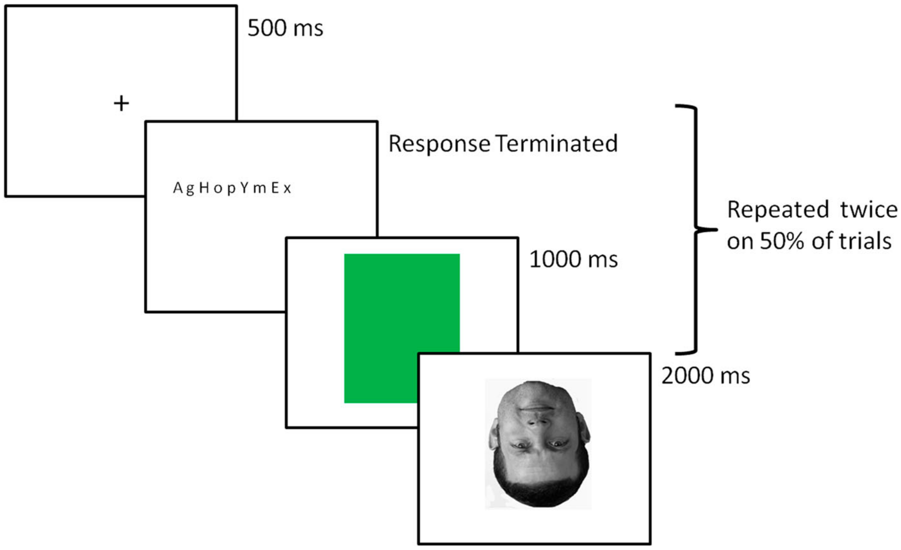

Figure 1. Trial structure. Second screen shows a horizontal letter search. Third screen shows a correct feedback. Fourth screen shows an inverted face.

presented using ClearView 2.7.0 software. Eye movements were recorded using a Tobii 1750 eye-tracker (Falls Church, VA), with embedded infrared cameras with a sampling rate of 50 Hz. The eye-tracker emits near infra-red light that reflects from the cornea. This is then detected by the eye-tracker. Minimum fixation duration was considered as 100 ms with a fixation dispersion of 30 pixels. All participants made their responses on a standard keyboard.

Design

A 2 (face orientation) × 3 (letter string orientation) × 2 (letter string location) mixed design was used. There were two conditions of face orientation (upright or inverted) and three conditions of letter string orientation (horizontal, vertical, random) manipulated within-subjects. The letter string location (in the top-left corner or centrally positioned) was manipulated between-subjects. The dependent variables were response time (in ms) to identify the face, accuracy of facial identification, saccadic direction following the first fixation on the face (including transitions between features), and fixation duration to various features of each face. The presentation order of faces was randomized (there was no blocking of experimental conditions).

Procedure

Participants sat 60 cm from the computer screen and were instructed to keep their head movements to a minimum. Participants were calibrated to the eye-tracker by following a blue circle moving around a white screen to five pseudo-random locations. Following this, participants were presented with 72 trials (split equally across each condition type: 24 for each letter string orientation, half of each were presented upright and half were inverted).

Each trial began with a central fixation cross for 500 ms. Participants were then presented with a string of randomly-selected letters, each containing either three or four vowels and oriented horizontally, vertically, or randomly across the screen. Participants had to count the number of vowels in the string and press the corresponding numerical key (3 or 4) on the keyboard. Each string appeared on the screen until a response was made. After each response, direct feedback was provided for 1000 ms; participants saw a green screen if their response was correct or a red screen if their response was incorrect. This feedback occupied the location of the subsequent face and acted as a cue to its location (see Wu, Laeng, & Magnussen, 2012). Typical face recognition paradigms employ fixation crosses as a cue to the location of the face, however fixation crosses inadvertently affect performance (Hills et al., 2011), therefore we chose a masking image to cue the location of the face (Wu et al., 2012). The feedback length was chosen to allow participants' fixation to return to the centre of the screen. At the end of the feedback screen, participants eyes were roughly at the centre of the image following the horizontal (169 px by 206 px), vertical (172 px by 205 px), and random (168 px by 202 px) letter strings (as recorded with the eye--tracker). Eye position did not differ significantly across conditions ($F(2, 158) = 0.59$, $MSE = 529.61$, $p = .557$ in the x axis and $F(2, 158) = 0.61$, $MSE = 568.78$, $p = .543$ in the y axis) and therefore was in the position that the centre of the face would appear. Any trials where the eyes were not fixated on the screen where the face would appear were removed from the subsequent analysis (this occurred in less than 1% of trials). In half the trials a further two letter searches oriented in the same way as the first were presented, in order to enhance the unpredictability of the timing of when the pictures were presented (see Hills et al., 2016; Thompson & Crundall, 2011). The different numbers of letter strings prior to the main task prevents participants developing anticipatory strategies that inhibit the carryover effect (see Thompson et al., 2015, for a more extensive discussion). In this study, the number of letter searches prior to the face task did not affect the carryover effect nor interact with any of the other variables (all $ps > .67$) similar to Thompson and Crundall (2011).

Following either 1 or 3 letter strings, a picture of a famous face was shown for 2000 ms. This appeared in the centre of the screen and participants were told to press the spacebar as soon as they could identify the person.[2] They then had to verbally state the identity: in this case identity was the name or some specific semantic information about the person (such as a TV show that they appeared in). The accuracy of this was recorded by the experimenter. For each condition, half the trials had with 1 letter search and the other half had 3 letter searches. All trials were presented in a random order. At the end of the experiment, participants were debriefed and thanked for their time and effort.

Results

Data collected included the response times and recognition accuracy to identify the faces and proportion of horizontal and vertical eye movements when viewing the faces (these data are summarized in Table 1). We also collected data regarding fixation location, the overall spread of fixations, and the number of transitions between features. We excluded any trials in which participants did not count the number of vowels correctly (less than 1% of trials), and any trial when the first fixation was not to the face (less than 1% of trials). Errors were not significantly different across conditions, $F(2, 158) = 0.05$, $MSE < .01$, $p = .936$. In the subsequent analyses, where Mauchley's test of sphericity was significant, we employed the Huynh-Feldt correction when the epsilon values were above .7 and the Greenhouse-Geisser correction when the epsilon values were below .7 (Girden, 1992). We report the corrected *MSE* and significance level, but the uncorrected degrees of freedom.

Behavioural performance

Response time to identify the face was analysed using a 2 (face orientation) × 3 (letter string orientation) × 2 (location of letter string) mixed-subjects ANOVA. This revealed a main effect of face orientation, $F(1, 78) = 7.39$, $MSE = 81668$, $p = .008$, $\eta_p^2 = .09$, in which upright faces were responded to faster than inverted faces (mean difference = 71 ms), consistent with the standard face-inversion effect (Valentine, 1988). The main effect of letter string orientation was not significant, $F(2, 156) = 0.33$, $MSE = 70500$, $p = .68$, $\eta_p^2 < .01$, however the interaction between the two variables was significant, $F(2, 156) = 16.64$, $MSE = 86329$, $p < .001$, $\eta_p^2 = .18$, consistent with the hypothesis. To explore this interaction, we employed Bonferroni-corrected within-subjects *t*-tests between the response times for recognizing upright and inverted faces following each letter string orientation. These revealed a significant face-inversion effect, with faster recognition for upright than inverted faces following the horizontal, $t(79) = 4.62$, $p < .001$, and random, $t(79) = 4.34$, $p < .001$, letter strings. However, participants were faster at recognizing inverted faces than

Table 1. Mean (and standard error) response time, naming accuracy (%), number of horizontal and vertical eye movements and saccadic length (px) for upright and inverted faces split by letter string orientation.

	Upright faces			Inverted faces		
Letter string	Horizontal	Vertical	Random	Horizontal	Vertical	Random
Response time (ms)	1087 (30)	1226 (41)	1080 (30)	1271 (41)	1100 (34)	1234 (38)
Recognition Accuracy (%)	98.59 (0.33)	95.19 (0.21)	99.10 (0.45)	94.62 (0.36)	95.35 (0.37)	95.75 (0.35)
Number of horizontal eye movements	3.78 (0.11)	1.21 (0.11)	3.61 (0.09)	4.03 (0.09)	1.62 (0.09)	3.49 (0.13)
Number of vertical eye movements	2.22 (0.11)	4.78 (0.12)	2.39 (0.09)	1.97 (0.10)	4.38 (0.08)	2.51 (0.13)
Saccadic length (px)	91.13 (2.88)	87.26 (3.08)	96.97 (3.11)	62.25 (2.64)	57.83 (2.78)	67.48 (3.71)

upright faces following the vertical letter strings, $t(79) = 2.42$, $p = .015$.

The main effect of letter string location was not significant, $F(1, 78) = 1.98$, $MSE = 272813$, $p = .164$, $\eta_p^2 = .03$, nor any of its interactions: with letter string orientation, $F(2, 156) = 0.98$, $MSE = 70500$, $p = .369$, $\eta_p^2 = .01$, with face orientation, $F(1, 78) = 0.07$, $MSE = 81668$, $p = .787$, $\eta_p^2 = .01$, with both letter string and face orientation, $F(2, 156) = 0.05$, $MSE = 86329$, $p = .921$, $\eta_p^2 < .01$.

We ran a parallel analysis on the accuracy data, also presented in Table 1. This revealed a main effect of face orientation, $F(1, 78) = 54.14$, $p < .001$, $MSE = 12.65$, $\eta_p^2 = .41$, in which upright faces were recognized more accurately than inverted faces (mean difference = 2.34%), consistent with the standard face-inversion effect (Valentine, 1988). The main effect of letter string orientation was significant, $F(2, 156) = 22.77$, $MSE = 8.29$, $p < .001$, $\eta_p^2 = .23$, with significantly greater recognition accuracy following the random letter string than the horizontal letter string (mean difference = 0.82%, $p = .025$) and the vertical letter string (mean difference = 1.33%, $p < .001$) and greater accuracy following the horizontal letter string than the vertical letter string (mean difference = 2.15%, $p < .001$). The interaction between the two variables was significant, $F(2, 156) = 20.53$, $MSE = 9.61$, $p < .001$, $\eta_p^2 = .21$, consistent with the hypothesis. Bonferroni-corrected within-subjects *t*-tests revealed that the face-inversion effect was found following the horizontal, $t(79) = 8.14$, $p < .001$, and the random letter string, $t(79) = 7.93$, $p < .001$, but not the vertical letter string, $t(79) = 0.26$, $p = .792$.

The between-subjects main effect of letter string location was not significant, $F(1, 78) = 1.98$, $MSE = 272813$, $p = .164$, $\eta_p^2 = .03$, nor any of its interactions: with letter string orientation, $F(2, 156) = 0.19$, $MSE = 8.29$, $p = .825$, $\eta_p^2 < .01$, with face orientation, $F(1, 78) = 0.34$, $MSE = 12.65$, $p = .559$, $\eta_p^2 < .01$, with both letter string and face orientation, $F(2, 156) = 0.53$, $MSE = 9.70$, $p = .590$, $\eta_p^2 < .01$.

Saccadic direction

To analyse the saccadic direction during the face recognition task we employed an analytical structure similar to Gilchrist and Harvey (2006) and Thompson and Crundall (2011). The direction of each saccade was measured in degrees (zero degrees represents a vertical upwards saccade and 180° represents a vertical downward saccade) and each was coded into bins that represented upward (covering 316° to 45°), downward (covering 126° to 225°), leftward (covering 226° to 315°), and rightward (covering 46° to 125°) movements. All eye movement analyses were conducted after the initial fixation on the face: we discounted the first fixation to the face due to contamination from the trial structure.

Figure 2 represents the mean number of saccades made in each direction. Since the resulting number of horizontal and vertical eye movement across the entire trial were frequency data, we subjected these to a hierarchical log-linear analysis. This analysis revealed that the model that included the main effects and the interactions between letter string orientation and saccadic direction and between saccadic direction and face orientation explained the data adequately, $\chi^2 = 1024$, $p < .001$: this model excluded the three-way interaction and the interaction between letter string orientation and face orientation. Table 2 shows the standardized residuals indicating that rightward saccades were significantly more likely following

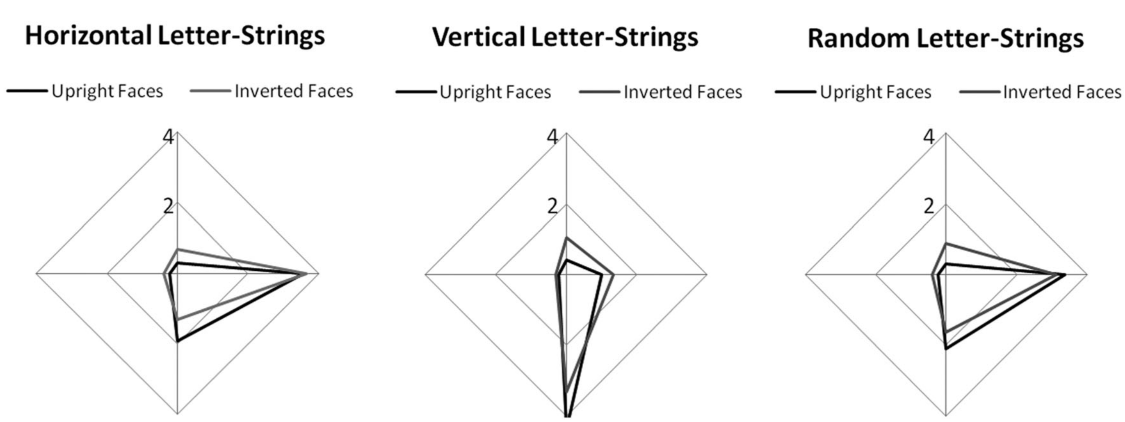

Figure 2. Mean spread of fixations following the letter strings split by facial orientation. Values represent the mean number of fixation in the direction.

Table 2. Standardised residuals from the log-linear analysis of the saccadic direction. This is collapsed across the face orientation variable as the three-way interaction was not significant.

		Saccadic direction			
		Upward	Downward	Rightward	Leftward
Letter string orientation	Horizontal	−2.8	−9.5	10.3	.3
	Vertical	3	16.2	−16.5	−1.2
	Random	−.2	−6.7	6.2	.9

horizontal and random letter strings and significantly less likely following vertical letter strings than would be expected by chance (since the standardized residuals were larger than 1.96; Agresti, 1990; Howell, 2010). Similarly, downward saccades were more likely following vertical letter strings and significantly less likely following horizontal and random letter strings than would be expected by chance. Conditional odds revealed that rightward eye movements were 9.32 times more likely that leftward eye movements and downward eye movements were 4.06 times more likely than upward movements. Odds ratios (Ω) revealed that horizontal eye movements were 6.12 times more likely following horizontal letter strings than vertical letter strings; vertical eye movements were 3.84 times more likely following vertical letter strings than horizontal letter strings; and horizontal eye movements were 4.70 times more likely following random letter strings than vertical eye movements. These results clearly demonstrate the influence of the letter string on subsequent eye movement behaviour.

We ran correlations between naming speed and number of horizontal saccades. Speed and accurate naming of upright faces was related to increased horizontal scanning, $r(78) = .67$, $p < .001$ (for response time) and $r(78) = .50$, $p < .001$ (for accuracy). Naming speed of inverted faces was negatively correlated with more horizontal saccades, $r(78) = -.26$, $p = .018$ (response time), and there was a non-significant trend for accuracy to negatively correlate with number of horizontal saccades, $r(78) = -.19$, $p = .092$ (accuracy). Scatter plots for these relationships are presented in Figure 3.

To further demonstrate the causal nature of the effect of scanning on speed of recognition responses, we coded the eye movement data according to mean saccadic direction. We entered saccadic direction as either mostly horizontal or mostly vertical (we excluded trials in which these eye movements were split equally across the two cardinal directions), and analysed this with orientation of the face. For this we collapsed across the letter string orientation and letter string location because we were interested in whether saccadic direction saccade directly predicted recognition speed and accuracy generally.

The resulting data, shown in Table 3, was subjected to parallel 2 × 2 within-subjects ANOVAs. For response times, neither main effect was significant: $F(1, 79) < 0.01$, $MSE = 178897$, $p = .990$, $\eta^2_p < .01$ (saccadic direction) and $F(1, 79) = 0.24$, $MSE = 405781$, $p = .625$, $\eta^2_p < .01$ (face orientation). This analysis revealed a significant disordinal interaction, $F(1, 79) = 15.08$, $MSE = 129992$, $p < .001$, $\eta^2_p = .16$. Horizontal scanning typically led to faster recognition responses for upright faces than vertical scanning, $t(79) = 2.49$, $p = .015$, whereas vertical scanning typically led to faster

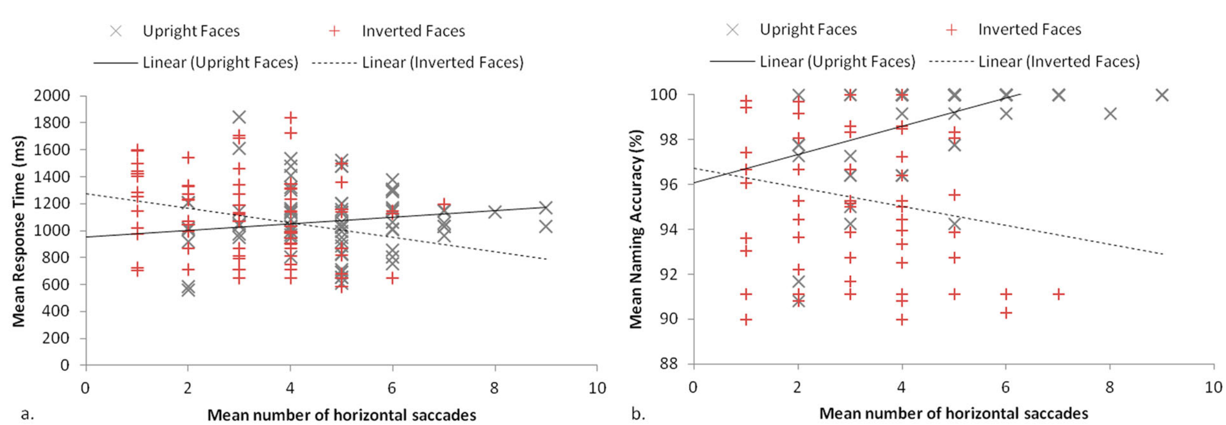

Figure 3. The relationship between mean number of horizontal saccades and a. Mean response time (ms) and b. Mean naming accuracy.

Table 3. Mean recognition response time (ms) and recognition accuracy (%) as a function of mean saccadic direction and orientation of the face. Standard error represented in parentheses.

		Inverted faces	Upright faces
Response time (ms)	**Horizontal eye movements**	1157 (73)	965 (61)
	Vertical eye movements	1001 (72)	1122 (91)
Recognition accuracy (%)	**Horizontal eye movements**	94.93 (0.21)	99.52 (0.21)
	Vertical eye movements	96.29 (0.36)	98.91 (0.31)

recognition responses to inverted faces than horizontal scanning, $t(79) = 2.55$, $p = .013$.

For recognition accuracy, the main effect of face orientation was significant: $F(1, 79) = 130.87$, $MSE = 7.95$, $p < .001$, $\eta_p^2 = .62$, in which upright faces (99.22%, $SE = 0.20$) were recognized more accurately than inverted faces (95.61%, $SE = 0.26$). The main effect of saccadic direction was not significant, $F(1, 79) = 2.01$, $MSE = 5.55$, $p = .161$, $\eta_p^2 = .03$. The interaction was significant, $F(1, 79) = 10.54$, $MSE = 7.29$, $p = .002$, $\eta_p^2 = .12$. There was a non-significant trend for horizontal scanning to lead to more accurate recognition for upright faces than vertical scanning, $t(79) = 1.82$, $p = .073$, whereas vertical scanning led to more accurate recognition to inverted faces than horizontal scanning, $t(79) = 2.96$, $p = .004$.

In order to assess whether the letter strings affected other aspects of saccadic programming, we measured the saccadic amplitude (i.e., the mean length of each saccade in pixels). These data, presented in Table 1, were subjected to a 2 (face orientation) × 3 (letter string orientation) × 2 (letter string location) mixed ANOVA. This revealed a main effect of letter string orientation, $F(2, 156) = 6.78$, $MSE = 556.96$, $p = .002$, $\eta_p^2 = .08$. Bonferroni-corrected pairwise comparisons revealed that saccades were longer following the random letter string than the vertical letter string (mean difference = 9.68, $p = .001$). No other pairwise comparisons were significant: between horizontal and vertical (mean difference = 4.15, $p = .358$) and between horizontal and random (mean difference = 5.54, $p = .153$). There was also a main effect of face orientation, $F(1, 78) = 195.07$, $MSE = 526.64$, $p < .001$, $\eta_p^2 = .71$, in which saccades were longer to upright (91.79, $SE = 2.15$) than inverted faces (62.52, $SE = 2.58$). The interaction between these variables was not significant, $F(2, 156) = 0.01$, $MSE = 408.26$, $p = .973$, $\eta_p^2 < .01$. The main effect of letter string location was not significant, $F(1, 78) = 0.25$, $MSE = 2173.97$, $p = .618$, $\eta_p^2 < .01$, nor any interactions with this variable: with letter string orientation, $F(2, 156) = 0.29$, $MSE = 556.96$, $p = .746$, $\eta_p^2 < .01$, with face orientation, $F(2, 156) = 2.62$, $MSE = 526.64$, $p = .109$, $\eta_p^2 = .03$, nor the three-way interaction, $F(2, 156) = 0.27$, $MSE = 328.62$, $p = .763$, $\eta_p^2 < .01$.

Area of interest analysis

We ran a similar analysis on the eye movement data to confirm the interpretation from the saccadic direction analysis. For our first analysis, we calculated the number of transitions between features. We explored the number of transitions between the left and right eye, the eyes and the nose/mouth, the forehead and the eyes/nose/mouth, and the chin and the eyes/nose/mouth, depending on the letter string orientation and face orientation in a log-linear analysis. Only the first transition described represents a horizontal transition (between the eyes), whereas the remaining transitions represent vertical movements. The standardized residuals are presented in Table 4 and indicate that horizontal transitions were more likely than expected by chance following the horizontal letter strings and random letter strings than following the vertical letter strings. Conversely, vertical transitions were more likely following vertical letter strings than following horizontal or random letter strings. The overall log-linear chi-square was significant, χ^2 (6) = 496.74, $p < .001$. Odds ratios (Ω) indicate that horizontal transitions (between the eyes) were 2.1 times more likely than vertical transitions following horizontal letter strings than vertical letter strings. Horizontal transitions were 1.7 times more likely than vertical transitions following random letter strings than vertical letter strings.

We analysed the total duration of fixation to each feature (mapped out as an area of interest, AOI, in a similar manner to Hills et al., 2013), summarized in

Table 4. Standardised residuals from the log-linear analysis of the transitions between features.

		Transition type			
		R-Eye to L-Eye	Eyes to Nose/Mouth	Forehead to Eyes/Nose/Mouth	Chin to Eyes/Nose/Mouth
Upright faces	Horizontal	7.5	−2.7	−3.0	−1.3
	Vertical	−9.6	5.1	2.5	1.2
	Random	2.1	−2.4	0.5	0.1
Inverted faces	Horizontal	8.7	−1.8	−7.9	3.7
	Vertical	−9.3	5.7	4.2	−1.8
	Random	0.7	−3.9	3.6	−1.8

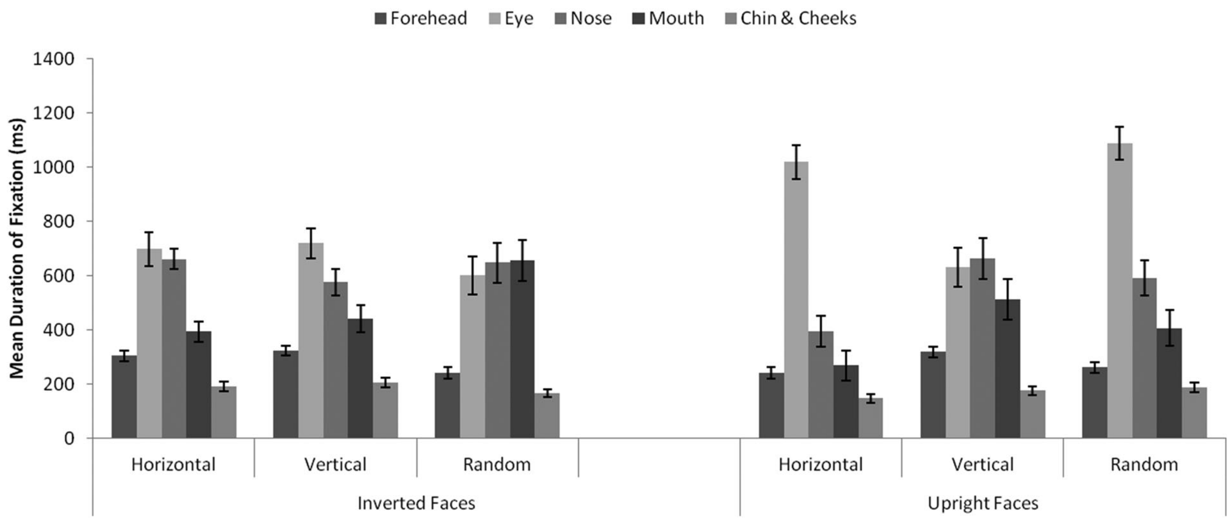

Figure 4. Total fixation duration to different features for upright and inverted faces split by the preceding letter string orientation. Error bars represent standard error of the mean.

Figure 4. These results were entirely consistent with a measure of fixation count. They were subjected to a 3 (letter string orientation) × 2 (face orientation) × 5 (AOI) × 2 (letter string location) mixed ANOVA. This revealed that the three-way interaction between AOI, letter string orientation, and face orientation was significant, $F(8, 624) = 11.69$, $p < .001$, $\eta_p^2 = .13$. We ran Bonferroni-Šidák corrected ($\alpha = .003$) within-subjects *t*-tests between upright and inverted faces for each of the 15 conditions. The results are presented in Table 5. In summary, the eyes received more fixations in upright faces than inverted faces following the horizontal and random letter strings.

We also observed an AOI by letter string orientation interaction, $F(8, 624) = 6.92$, $MSE = 22416$, $p < .001$, $\eta_p^2 = .08$, in which Bonferroni-Šidák corrected simple effects revealed that duration of fixation to each feature was significantly different to each other feature (all *p*s < .001) except following vertical letter strings, in which there was no significant different in duration of fixation to the eyes, nose, and mouth (all *p*s > .127). There was an interaction between face orientation and AOI, $F(4, 312) = 7.68$, $MSE = 545166$, $p < .001$, $\eta_p^2 = .09$, consistent with Barton et al. (2006). This was revealed through longer fixations to the eyes in upright than inverted faces, $t(79) = 4.86$, $p < .001$, but no other significant simple effects were significant (all *p*s > .184). There was also an interaction between letter string orientation and face orientation, $F(2, 156) = 3.20$, $MSE = 113079$, $p = .049$, $\eta_p^2 = .04$, though no simple effects were significant (all *p*s > .238).

The standard feature hierarchy was also observed, $F(4, 312) = 86.44$, $MSE = 585595$, $p < .001$, $\eta_p^2 = .53$, in which the eyes were fixated upon the most followed by the nose, the mouth, the forehead, and the chin and cheeks (all pairwise comparisons, *p*s < .002). While pairwise comparisons were not significant, there was a marginal main effect of letter string orientation, $F(2, 156) = 3.17$, $MSE = 205600$, $p = .053$, $\eta_p^2 = .04$, in which there duration of fixation was longer following the random letter string than either the horizontal (mean difference = 52.78 ms, $p = .097$) or vertical letter strings (mean difference = 24.64 ms, $p = .377$). The main effect of face orientation was not significant, $F(1, 78) = 0.03$, $MSE = 718184$, $p = .874$, $\eta_p^2 < .01$.

Table 5. Within-participants *t*-test comparisons of total duration of fixation for upright and inverted faces. Significant results, after Bonferroni-Šidák correction, are denoted by an asterisk (*).

Comparison: Feature	Letter string orientation	Mean difference	*t*-test result
Forehead	Horizontal	−64 ms	$t(79) = 2.57$, $p = .012$
	Vertical	−4 ms	$t(79) = 0.23$, $p = .819$
	Random	19 ms	$t(79) = 0.82$, $p = .416$
Eye	Horizontal	322 ms	$t(79) = 4.23$, $p < .001$*
	Vertical	−90 ms	$t(79) = 1.25$, $p = .214$
	Random	487 ms	$t(79) = 5.66$, $p < .001$*
Nose	Horizontal	−265 ms	$t(79) = 2.67$, $p = .009$
	Vertical	87 ms	$t(79) = 0.92$, $p = .359$
	Random	−56 ms	$t(79) = 0.56$, $p = .575$
Mouth	Horizontal	−125 ms	$t(79) = 1.76$, $p = .083$
	Vertical	72 ms	$t(79) = 0.72$, $p = .473$
	Random	−248 ms	$t(79) = 2.44$, $p = .017$
Chin & Cheeks	Horizontal	−45 ms	$t(79) = 2.22$, $p = .029$
	Vertical	−29 ms	$t(79) = 1.90$, $p = .061$
	Random	22 ms	$t(79) = 0.98$, $p = .328$

The main effect of letter string location, $F(1, 78) < 0.01$, $MSE = 400623$, $p = .983$, $\eta_p^2 < .01$, nor its interaction with feature, $F(4, 312) = 0.02$, $MSE = 585595$, $p = .985$, $\eta_p^2 < .01$, its interaction with letter string orientation, $F(2, 156) = 0.14$, $MSE = 205600$, $p = .840$, $\eta_p^2 < .01$, its interaction with face orientation, $F(1, 78) < 0.01$, $MSE = 718184$, $p = .997$, $\eta_p^2 < .01$, the three-way interaction with feature and letter string orientation, $F(8, 624) = 0.17$, $MSE = 224416$, $p = .965$, $\eta_p^2 < .01$, with feature and face orientation, $F(4, 312) = 0.06$, $MSE = 545166$, $p = .950$, $\eta_p^2 < .01$, with letter string orientation and face orientation, $F(2, 156) = 0.26$, $MSE = 113079$, $p = .744$, $\eta_p^2 < .01$, and the four-way interaction, $F(8, 624) = 0.16$, $MSE = 234003$, $p = .959$, $\eta_p^2 < .01$, were all not significant.

Finally, we ran a hierarchical log-linear analysis on the distribution of fixation data. For this, we calculated the number of first, second, third, and fourth fixations to each AOI split by letter string orientation and face orientation. The overall model, excluding the four-way interaction, provided the best explanation of the data, χ^2 (24) = 355.53, $p < .001$. Table 6 shows the standardized residuals for these data. Any residual greater numerically than 1.96 indicates that the area was scanned significantly more than would be expected by chance, and any residual less than 1.96 indicates that the area was scanned significantly less than would be expected by chance (Agresti, 1990; Howell, 2010). These results indicate that there was a similar fixation pattern for the second, third, and fourth fixations. There was also an overall reduction of scanning of the eye region following the vertical letter strings than the horizontal letter strings and an increase in scanning of the nose (Ω = 1.84), mouth (Ω = 3.66), forehead (Ω = 1.49), but not the chin (OR = 1.00).

Discussion

In this study, we replicated the basic carryover effect first described by Thompson and Crundall (2011): eye movements in the face recognition task were typically influenced by the preceding task. There were more horizontal eye movements leading to more saccadic transitions between the eye region following the horizontal letter strings than following the vertical letter strings: vertical letter strings led to increased vertical scanning and transitions between the eyes and nose and mouth. We hypothesized that carryover of horizontal scanning behaviour would benefit the

Table 6. Standardized residuals from the log-linear analysis of the location of the first four fixations. Any standardized residual numerically greater than 1.96 indicates that the AOI was scanned at a significantly different level than would be expected by chance.

		Fixation number and AOI																			
		First fixation					Second fixation					Third fixation					Fourth fixation				
		Eyes	Nose	Mouth	Fore Head	Chin	Eyes	Nose	Mouth	Fore Head	Chin	Eyes	Nose	Mouth	Fore Head	Chin	Eyes	Nose	Mouth	Fore Head	Chin
Inverted faces	Horizontal	4.9	2.2	−5.9	−5.9	1.9	1.1	−0.8	−2.7	−0.2	1.4	1.1	−1.6	−3.1	−0.8	3.0	1.3	−1.8	−3.0	0.2	1.4
	Vertical	−12.7	1.9	12.4	5.2	2.0	−1.5	−0.4	4.3	2.3	−2.7	−3.8	1.4	4.9	3.8	−2.5	−2.2	6.0	5.0	−0.1	−5.1
	Random	7.6	−4.1	−6.3	0.8	−3.9	0.4	1.2	−1.7	−2.1	1.4	2.8	0.2	−1.8	−3.0	0.6	0.8	−4.2	−1.9	−0.1	3.7
Upright faces	Horizontal	−0.4	−1.7	−1.6	1.8	2.9	3.4	−3.5	−2.4	1.4	0.1	0.2	0.1	−3.7	1.4	1.5	2.0	−3.2	−5.3	0.9	4.2
	Vertical	−0.2	1.5	3.5	−1.4	−2.5	−3.7	4.4	5.8	−2.9	−2.2	−1.3	3.6	5.1	−3.2	−3.0	−6.6	2.7	8.7	0.0	−1.5
	Random	0.7	0.3	−1.7	−0.5	−0.4	0.3	−1.0	−3.4	1.5	2.1	1.1	−3.6	−1.4	1.8	1.5	4.7	0.4	−3.7	−0.9	−2.6

recognition of upright faces and the carryover of vertical scanning behaviour would benefit the recognition of inverted faces. Our results were consistent with these hypotheses. Recognition accuracy was higher and response time was quicker for upright faces following the horizontal letter string than following the vertical letter string. Recognition response time was faster for inverted faces following the vertical letter strings than following the horizontal letter strings.

Consistent with our hypothesis, the detrimental effect of the letter strings was more pronounced for upright faces, that have a distinct scanpath, than inverted faces. We have shown that there is a correlation between the amount of horizontal scanning and recognition response times of upright faces, with more horizontal scanning associated with quicker and more accurate responses. Furthermore, more horizontal scanning than other forms of scanning resulted in faster recognition responses.

The carryover effect had an effect on the fixation location. While there is a large amount of error, on average the second, third, and fourth fixations were in a location shifted in the direction of the letter string from the first fixation. Vertical carryover led to more fixations in the vertical direction (i.e., to the nose and mouth in upright faces and to the eyes in inverted faces) whereas horizontal carryover led to fixations that were similar to the first fixation (as the features are not distributed horizontally). These results advance our understanding of eye movement carryover and face perception in several important ways and offer an interesting methodological advancement for future studies in face recognition. Throughout these analyses there was no main effect, nor interactions with the between-subjects factor of location of the letter string. This is likely due to the point that participants' eyes returned to the centre of the screen during the feedback screen as described above.

The first issue our results point to is the fact that there is significant carryover in eye movements from one task to another. Previously, Thompson and Crundall (2011) noted that there was a carryover from letter strings to a hazard perception driving task. We have extended this to show that there can be a carryover to face perception. Both driving and expert face perception are associated with distinct, highly-stereotyped scanpaths. The direct cause of this carryover is under debate. It may be based on a failure to inhibit eye movement behaviour or attentional distribution from one task to another (Hills et al., 2016). It may also be caused by the persistence of attentional weights to various regions of the scene (based on the demands of a preceding task; Thompson et al., 2015; Thompson & Crundall, 2011).

These results indicate that disruption to the scanpath when viewing faces impairs encoding. The vertical letter search, causing vertical eye movements, slowed the recognition of upright faces because the face-specific scanpath when viewing faces typically involves more horizontal scanning between the eyes (Althoff & Cohen, 1999). It disrupted the more common saccadic transitions between the eyes, leading to the transitions between features that are not as typical. The horizontal carryover did not affect the recognition of upright faces as much as the vertical carryover. These results are in accordance with the reported findings of Thompson and Crundall (2011), that there was no significant influence of orientation on the horizontal spread of search. They propose that this is due to the fact that while driving people seem to make more horizontal eye movements. By altering this scan strategy (through causing a vertical scan) we are causing a detriment to face recognition because the least efficient saccades are being made. For inverted faces, the scanpath is not as robust (Barton et al., 2006), but may involve more vertical eye movements given the established pattern of eye movements when viewing inverted faces involves more fixations to the nose and mouth than in upright faces (which require vertical eye movements to move between them).

To understand the mechanisms of this disruption further, we can explore what information is present when the face appears. When the face is upright (in the correct configuration), participants can initiate their face-specific stereotypical scanpath which involves initial and more horizontal saccades around the centre of the face, typically in a triangle (Yarbus, 1967). Additionally, because the face is upright, there is no need to fixate in the centre of each feature because participants can sample more of the face in one fixation but critically not the whole face (Papinutto, Lao, Caldara, & Miellet, 2014). This enables participants to engage in holistic processing (e.g., Rossion, 2008). The implication is that first-order configural information (knowledge of the structure of a face, see Maurer, Le Grand, and Mondloch, 2002) gives participants sufficient information to engage in expert face-specific coding.

When participants are presented with an inverted face (a face in the incorrect configuration), they cannot initiate their face-specific scanpath or holistic processing. Therefore, they must engage in a more atypical scanning pattern indicative of featural processing. Because it is not based on extensive experience, it may be less efficient and involves direct fixations to the centre of each feature. Indeed, analytic featural coding has been shown by such direct fixations to features (Blais et al., 2008). The first saccade is likely to bring the centre of the diagnostic features into the fovea. This may involve upward or downward movements (in order to get the mouth, nose, or eyes into the fovea). The first saccade is, therefore, more likely to be vertical than when examining upright faces as more features can be sampled from the first fixation (Hsiao & Cottrell, 2008; Papinutto et al., 2014). Thus, we have provided experimental evidence that suggests that the disruption to the scanpath when looking at inverted faces is likely to be due to the direction of the saccades.

These results also highlight how disruption to natural eye movements affects face performance, suggesting that scanpaths are important for accurate face coding. Eye movements are clearly functional (Althoff & Cohen, 1999) and disruptions to these disrupt coding. Furthermore, these data highlight that the eye movement patterns (as measured by typical saccadic direction) for upright and inverted faces are different (see Barton et al., 2006). If saccadic direction is disrupted by interference from a previous task, then face recognition is less accurate. This is an important finding as it provides further evidence that the first fixation (Hsiao & Cottrell, 2008) *and* direction of the following saccades are critical for accurate face encoding.

Furthermore, this research (in addition to the work of Thompson and Crundall, 2011) adds to the models of visual search. We suggest that models of visual search patterns should be able to account for the carryover effects between two unrelated tasks in addition to top-down and bottom-up influences. These need to include the moderating factors of task difficulty and pre-programmed attentional sets. By combining these factors, eye movements and fixations can be predicted more successfully.

One final implication of this study is in the investigations of how eye movements affect face perception. Henderson et al. (2005) used a design where they restricted the eye movements of their participants and assessed face perception. Other authors use displays that reveal parts of the face at a time (e.g., Caldara, Zhou, & Miellet, 2010; Schyns, Bonnar, & Gosselin, 2002). Here, we have shown that it may be possible to alter eye movements using a specially designed preceding task. This allows for an alternative method for assessing the importance of eye movements in face recognition.

Notes

1. The random letter string is likely to produce an equal number of vertical and horizontal eye movements, whereas the vertical and horizontal letter strings should engage typical reading patterns (i.e., from left to right and then downwards).
2. While pressing "space" as the method for recording identification is not the most ideal method as it increases error, there is no reason to think that the error would occur in one condition more than another.

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Appendix

List of stimuli used:

Barack Obama	Emma Bunton	Jake Gyllenhaal	Paris Hilton
Ben Stiller	Emma Watson	James Cordon	Patrick Stewart
Beyoncé Knowles	Ewan McGregor	James May	Phillip Scofield
Christian Bale	Fiona Bruce	James Spader	Ricky Gervais
Christopher Eccleston	Frankie Boyle	Jamie Oliver	Robbie Williams
Cuba Gooding Jr	Gary Barlow	Jennifer Anniston	Robin Williams
Dame Judi Dench	George Clooney	Jeremy Clarkson	Shania Twain
Daniel Craig	George W. Bush	John Lennon	Simon Cowell
David Beckham	Gordon Brown	Julia Roberts	Sir Ian McKellen
David Hasselhoff	Gordon Ramsay	Kevin Bacon	Sylvester Stallone
Declan Donnelly	Graham Norton	Kevin Costner	Taylor Swift
Demi Lovato	Gwyneth Paltrow	Kevin Spacey	Terry Wogan
Dermot O'Leary	Halle Berry	Kurt Russell	Tom Baker
Diana Ross	Harrison Ford	Madonna	Tom Cruise
Drew Barrymore	Heath Ledger	Mel Gibson	Tom Hanks
Ed Harris	HRH Elizabeth Windsor	Michael Jackson	Tony Blair
Eddie Izzard	Hugh Grant	Miley Cyrus	Whitney Houston
Elijah Wood	Hugh Jackman	Nicholas Witchell	Will Smith
Elvis Presley	Hugh Laurie	Orlando Bloom	William Shatner
Eminem	Jack Dee	Owen Wilson	Zoe Wannamaker