Cognitive and neural markers of super-recognisers' face processing superiority and enhanced cross-age effect

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Abstract

Super-recognisers inhabit the extreme high end of an *adult* face processing ability spectrum in the population. While almost all research in this area has evaluated those with poor or mid-range abilities, evaluating whether super-recognisers' superiority generates distinct electrophysiological brain activity, and transcends to different age group faces (i.e., children's) is important for enhancing theoretical understanding of normal and impaired face processing. It may also be crucial for policing, as super-recognisers may be deployed to operations involving child identification and protection. In Experiment 1, super-recognisers (n = 315) outperformed controls (n = 499) at adult and infant face recognition, while also displaying larger cross-age effects. These findings were replicated in Experiment 2 (super-recognisers, n = 19; controls, n = 28), although one SR with frequent infant exposure showed no cross-age effect. Compared to controls, super-recognisers also generated significantly greater electrophysiological activity in event-related potentials associated with pictorial processing (P1) and explicit recognition (P600). Experiment 3, employing an upright and inverted sequential matching design found super-recognisers (n = 24) outperformed controls (n = 20) at adult and infant face matching, but showed no upright cross-age matching effects. Instead, they displayed larger inversion effects, and cross-age inversion effects, implicating the role of holistic processing in their perceptual superiority. Larger cross-age effects in recognition, but not matching suggests that super-recognisers' adult face recognition is partly driven by experience. However, their enhanced infant face recognition suggest super-recognisers' superiority is also experience-independent, results that have implications for policing and for models of face recognition.

Key words: super-recognisers, face processing, cross-age effect, inversion effect, ERP

0.1. Introduction

Recent research suggests that *Super-Recognisers* (SRs) and *Developmental Prosopagnosics* (DPs) inhabit the extremes of a large spectrum of individual differences in face recognition ability (e.g., Bobak, Bennetts, Parris, Jansari, & Bate, 2016; Russell, Duchaine, & Nakayama, 2009, for a review see Noyes, Phillips, & O'Toole, 2017). These differences are moderated by genetics (e.g., Shakeshaft & Plomin, 2015), holistic processing style (e.g., Wang, Li, Fang, Tian, & Liu, 2012), personality (e.g., Lander & Poyarekar, 2015; Li, Tian, Fang, Xu, Li, & Liu, 2010; Megreya & Bindemann, 2013), empathetic (e.g., Bate, Parris, Haslam, & Kay, 2010) and autistic traits (e.g., Deruelle, Rondon, Gepner, & Tardiff, 2004). However, experience/exposure drives expertise. Adults who matured in large towns outperform those from small towns (e.g., Balas & Saville, 2015), while cross-ethnicity (Meissner & Brigham, 2001), and cross-age effects (e.g., Backman, 1991) reveal exposure moderates own- over out-group face recognition (e.g., Macchi Cassia, Kuefner, Picozzi, & Vescovo, 2009; Meissner, Brigham, & Butz, 2005; for a review see Brigham, Bennett, Meissner, & Mitchell, 2007). Nevertheless, despite having typical exposure to faces (and with no identified brain damage), DPs display a congenitally impaired ability to process faces (Behrmann & Avidan, 2005). Therefore face exposure and experience appear to play a minimal role in their face processing deficits. On the other hand, it is unclear whether face exposure/experience is associated with SRs' face processing expertise, possibly reflected in distinct perceptual strategies or electrophysiological activity.

0.1.1. Super-recognition

SRs are exceptionally good at recognising briefly viewed faces (Russell et al., 2009), and exceed controls at familiar and unfamiliar face recognition (e.g., Bobak, Hancock, &

Bate, 2016), and simultaneous face matching (e.g., Bobak, Hancock et al., 2016; Davis, Lander, Evans, & Jansari, 2016). Their abilities are mainly face-specific (e.g., Bobak, Bennetts et al., 2016), and may be linked to efficient eye gaze (Bobak, Parris et al., 2016), and holistic processing strategies (e.g., Bobak, Bennetts et al., 2016; Russell et al., 2009).

There is however no agreed SR definition, although no evidence suggests they possess qualitatively different characteristics to the general population (see Noyes et al., 2017). SR group inclusion criteria in research have typically been anecdotal extraordinary ability self-reports; and face recognition scores two standard deviations (SD) above control means (e.g., Bobak, Bennetts et al., 2016; Russell et al., 2009), representing the top 2% of the population, and mainly measured by the standardised *Cambridge Face Memory Test: Extended* (CFMT+). However, self-reports may be unreliable, and varying control CFMT+ statistics representing the estimated population mean have generated different minimum SR thresholds (see Bobak, Pampoulov, & Bate, 2016). Furthermore, some SRs meeting these criteria perform poorly on tests such as simultaneous face matching (e.g., Bobak, Bennetts et al., 2016; Davis et al., 2016), suggesting that SR like DP (e.g., Bate & Bennetts, 2014), is a heterogeneous concept (see Noyes et al., 2017). It is important that research clarifies SR definitions, and examines their capabilities, as organisations employing staff to visually verify the identity of adults or children may benefit (e.g., policing, forensics, border control: Davis et al., 2016; Robertson, Noyes, Dowsett, Jenkins, & Burton, 2016; White, Philips, Hahn, & O'Toole, 2017).

0.1.2. The cross-age effect (CAE) and the inversion effect

No research has examined SRs' susceptibility to the cross-age effect (CAE), in which people are mainly better at recognising own-age than other-age faces. For instance, young adults are worse at recognising (e.g., Anastasi & Rhodes, 2005) and matching (e.g., Macchi

Cassia, Picozzi, Kuefner, & Casati, 2009) child and elderly faces compared to young adult faces (Macchi Cassia, Kuefner et al., 2009; Kuefner, Macchi Cassia, Picozzi, & Bricolo, 2008; Wiese, Komes, & Schweinberger, 2012; for a review see Macchi Cassia, 2011). Effects are modulated by other-age exposure. Harrison and Hole (2009) showed that young adults' (20 - 25 years old) recognition of children's faces (aged 8 – 11 years old) was worse than that of faces of their own age. In contrast, trainee teachers (interacting with children on a daily basis) performed similarly with faces of both age groups. Macchi Cassia, Picozzi et al. (2009) generated similar findings, demonstrating that paediatric nurses, working with large numbers of infants, outperformed controls at infant face matching, but displayed no adult face advantage. No effects were found with women who had recently given birth. Exposure to one newborn face does not result in generalised proficiency. Both studies support an exposure-based explanation of the cross-age effect.

One explanation is that own- and other-age faces drive different levels of holistic processing (i.e., perceiving a face as a whole rather than as independent face parts) (e.g., Kuefner et al., 2008). This is plausible as holistic processing style (Maurer, Le Grand, & Mondloch, 2002) correlates with face recognition (e.g., Richler, Cheung, & Gauthier, 2011; Wang et al., 2012, although see Konar, Bennett, & Sekuler, 2010). Indeed, the CAE has been examined using the *Inversion Effect* (Yin, 1969), a holistic processing marker, in which upright faces are better recognised than inverted faces, suggesting inversion disrupts holistic processing. Employing a *cross-age inversion effect* paradigm, Macchi Cassia, Picozzi et al. (2009; see also Kuefner et al., 2008) found that whereas adult controls displayed adult face inversion effects only, paediatric nurses demonstrated inversion effects for adult *and* infant faces, a consequence of greater infant face exposure.

Employing infant and adult faces, the current research examined the CAE in adult SRs and controls. Infants' homogeneous appearance makes them hard to discriminate (Kuefner et al., 2008), and as most people rarely encounter large numbers, they provide an exposure-free face recognition ability baseline. Recognition performance differences between adult and infant faces, or the *strength* of the CAE (see Macchi Cassia, Picozzi et al., 2009), will therefore reflect experiential factors such as adult face exposure.

0.1.3. Electrophysiological markers of face recognition ability and the cross-age effect

Although no published research has investigated this in SRs, electroencephalography (EEG) studies demonstrate that face recognition proficiency is reflected in specific electrophysiological correlates. Compared to individuals with poor abilities, good face recognition is associated with greater amplitudes in P1 (positive peak at around 100ms after stimulus onset) (Turano, Marzi, & Viggiano, 2016), an Event Related Potential (ERP) associated with attention allocation and pictorial processing (Luck, 2005). Turano et al. (2016) also found that N170, a negative peak approximately 170ms after stimulus onset, and associated with face structural encoding (e.g., Bentin, Allison, Puce, Perez, & McCarthy, 1996) is enhanced in reaction to recognised faces in individuals with good, but not poor recognition ability. N250 (negative peak between 200-300ms) and P600 (positive peak between 500-700ms, interchangeably referred to as Late Positive Component), ERPs linked to implicit and explicit face recognition, respectively (e.g., Düzel, Yonelinas, Mangun, Heinze, & Tulving, 1997; Eimer, Gosling, & Duchaine, 2012), also generate weaker amplitudes in DPs than controls (e.g., Eimer et al., 2012; for a review see Towler & Eimer, 2012).

N250 and P600 characteristics also parallel the CAE. With young adults, negative amplitudes in N250 become greater in reaction to repeated (versus novel) young adult, but not elderly faces (Wiese, 2012; Wiese, Komes, & Schweinberger, 2013). Wiese, Wolff, Steffens, and Schweinberger (2013) also showed that Late Positive Component (P600) was greater in amplitude to other (elderly) age faces, compared to own (young adult) age faces, potentially indicating that other age faces require more processing. In line with the exposure-based hypothesis of the CAE, this was only observed in young adult participants who reported having little exposure to members of the other age group (elderly). Importantly, participants of different age groups may demonstrate ‘mirror’ or opposite CAE patterns at the level of P600. Indeed, Wiese et al. (2012) found enhanced P600 amplitudes in the hit rates of young adults correctly recognising young adult faces, whereas elderly participants showed higher amplitudes for correct rejections of previously unseen elderly, but not young adult faces. This ‘mirror’ pattern could reflect different own-age face learning encoding strategies, driving electrophysiological reactions when correctly rejecting previous unseen faces. No CAE effects have been found in relation to P1 or N170 (e.g., Wiese, 2012; Wiese, Wolff et al., 2013), suggesting that the CAE operates following structural encoding.

0.1.4. The current research

The three experiments described in this paper aimed to investigate the CAE in different samples of SRs and controls. Consistent with previous research, the primary SR inclusion criteria were exceptionally high CFMT+ scores (Russell et al., 2009), verified in Experiments 1 and 2 by a second face recognition test, and a self-belief in SR ability. Controls were selected based on ‘average-range’ performances on the two tests. Experiment 1 recruited a large number of online adult participants to examine whether SRs’ adult face recognition superiority transfers to infant faces (i.e., whether their CAE is of the same magnitude to that of controls). Experiment 2 employed the same tests while simultaneously recording EEG, to determine whether face recognition proficiency-based CAE differences have electrophysiological correlates. Employing a sequential matching design with upright and inverted faces, Experiment 3 examined whether between-group cross-age inversion effects were related to reliance on holistic processing mechanisms. When comparing SRs and controls, analyses were conducted at a group, and in Experiments 2, at an individual level to investigate SR response homogeneity.

Across the three experiments it was predicted that SRs would outperform controls at adult face recognition; and based on the CAE literature, that adult faces would be better recognised than infant faces. In addition, it was predicted that SRs would display a stronger CAE than controls.

1.1. Experiment 1

Employing adult and infant face stimuli, Experiment 1 recruited large numbers of participants online to explore the *Cross Age Effect* (CAE) in SRs and average-ability controls.

1.2. Method

1.2.1. Design

An independent-measures component allocated participants to SR and control groups based on *Cambridge Face Memory Test: Extended* (CFMT+) and *Adult Face Recognition Test* scores. Analyses compared between-group performances on the *Adult* and *Infant Face Recognition Tests (old/new)*, from which the *Cross Age Effect* (CAE) was calculated. On the Adult and Infant old/new tests, and the CAE derived from the two tests, the dependent variables were hits (correct 'old' responses) and correct rejections (CRs) (correct 'new' responses), and derived signal detection theory (SDT) measures of sensitivity ($d^{/}$) and response bias (criterion: C) (see Green & Swets, 1966; Macmillan & Creelman, 1991). High positive values of $d^{/}$ indicate good discrimination of 'old' and 'new' stimuli. Negative values of C are indicative of conservative response biases or a tendency to respond 'new' under conditions of uncertainty; positive values indicate liberal response biases or a tendency to respond ‘old’.

1.2.2. Participants

The sample initially consisted of 1,425 adults recruited online (age range = 16-76 years, *M* = 32.48, *SD* = 10.95; male = 523 (36.7%); female = 792 (55.6%); White-Caucasian = 1025 (71.9%), British-Asian = 74 (5.2%), Black-Afro-Caribbean = 20 (1.4%), Chinese = 23 (1.6%), ‘other’ ethnicity = 173 (12.1%). Note that some demographic data was missing (age: *n* = 136, gender and ethnicity: *n* = 110).

Following Bobak, Bennetts et al. (2016), the CFMT+ classified participants as SRs (threshold = 93/102),[2] while the *Adult Face Recognition Test* (*old/new*) scores were used to verify the level of face recognition ability (i.e. SRs performed highly on the CFMT+ and the Adult Face Recognition Test). Five participants who performed within the SR range on the CFMT+, but who performed poorly on the Adult Face Recognition Test (i.e. 2 SD below the SR mean) were excluded from the SR sample (i.e. their exceptional CFMT+ scores were not verified). To reduce recruitment bias influence, controls scored within 1 SD of Bobak, Pampoulov et al.’s (2016) representative sample CFMT+ mean, with some (*n* = 29) excluded, if their Adult old/new test d' scores were more than 2 SD above or below the control mean.[3] The final groups consisted of 315 SRs and 499 controls, though demographic information was only available for 282 SRs and 377 controls. Table 1 depicts the participant groups’

[2] Note that Bobak, Pampoulov et al. (2016) propose a higher CFMT+ threshold of 95/102, being 2 SD higher than their participant mean. However, taking previous SR studies into consideration (e.g., Bobak, Bennetts et al., 2016; Bobak, Dowsett et al., 2016; Bobak et al., 2017; Davis et al., 2016; Russell et al., 2012), 1 SD below the mean obtained from all SR groups is approximately 93/102, the value chosen here. To support this threshold, no significant differences were found when using t-tests to compare the 93/94 (*n* = 123) and ≥ 95 CFMT+ (*n* = 197) scorers on any adult or infant face recognition test, or CAE outcome reported below ($p > .05$).
[3] Note that when a 1 SD old/new test threshold was employed instead of 2 SD; excluding additional SRs (*n* = 42) and controls (*n* = 132); replicated Experiment 1 old/new test conclusions were identical, albeit with slightly stronger effect sizes.

characteristics with independent-measures t-tests and Chi-square tests comparing the groups on demographic data and face recognition performance (only *p* values are reported). Note: All remaining participants falling outside the SR and control group criteria were excluded from analyses (*n* = 611).

Table 1. SRs' and controls' characteristics and scores on face recognition

	SRs (*n* = 315)	Controls (*n* = 499)	*p* value
Gender	Male = 111 Female = 171	Male = 189 Female = 273	> .200
Age	32.67 (9.07)	32.20 (11.79)	> .200
Ethnicity	White = 214 Non-white = 68	White = 377 Non-white = 85	.061
CFMT+ (out of 102)	95.50 (2.07)	74.48 (6.76)	< .001
Adult face recognition (old/new) test (d')	2.61 (0.65)	1.79 (0.46)	< .001

1.2.3. Materials

Cambridge Face Memory Test (extended) (CFMT+) (Russell et al., 2009): In the 102-trial extended version of the original 72-trial CFMT (Duchaine & Nakayama, 2006), participants memorise six faces from their internal features, for later recognition from different viewpoints in different lighting conditions using a three-alternative forced-choice paradigm. Later trials employ visual-noise; vary facial expressions, while regularly repeating distractors increase difficulty.

Adult Face Recognition Test (old/new): The adult face stimuli were from the Park Aging Mind database at The University of Texas at Dallas (Minear & Park, 2004). Adobe Photoshop was used to remove external features (e.g., hair) and distinguishing marks (e.g., freckles), and images were approximately 6.5 cm x 9 cm on a typical 20 cm x 30 cm laptop. To avoid floor effects from learning 40 faces in one phase, it consisted of two learning (20 trials per block) and two recognition blocks (40 trials per block) with images randomly ordered within each.

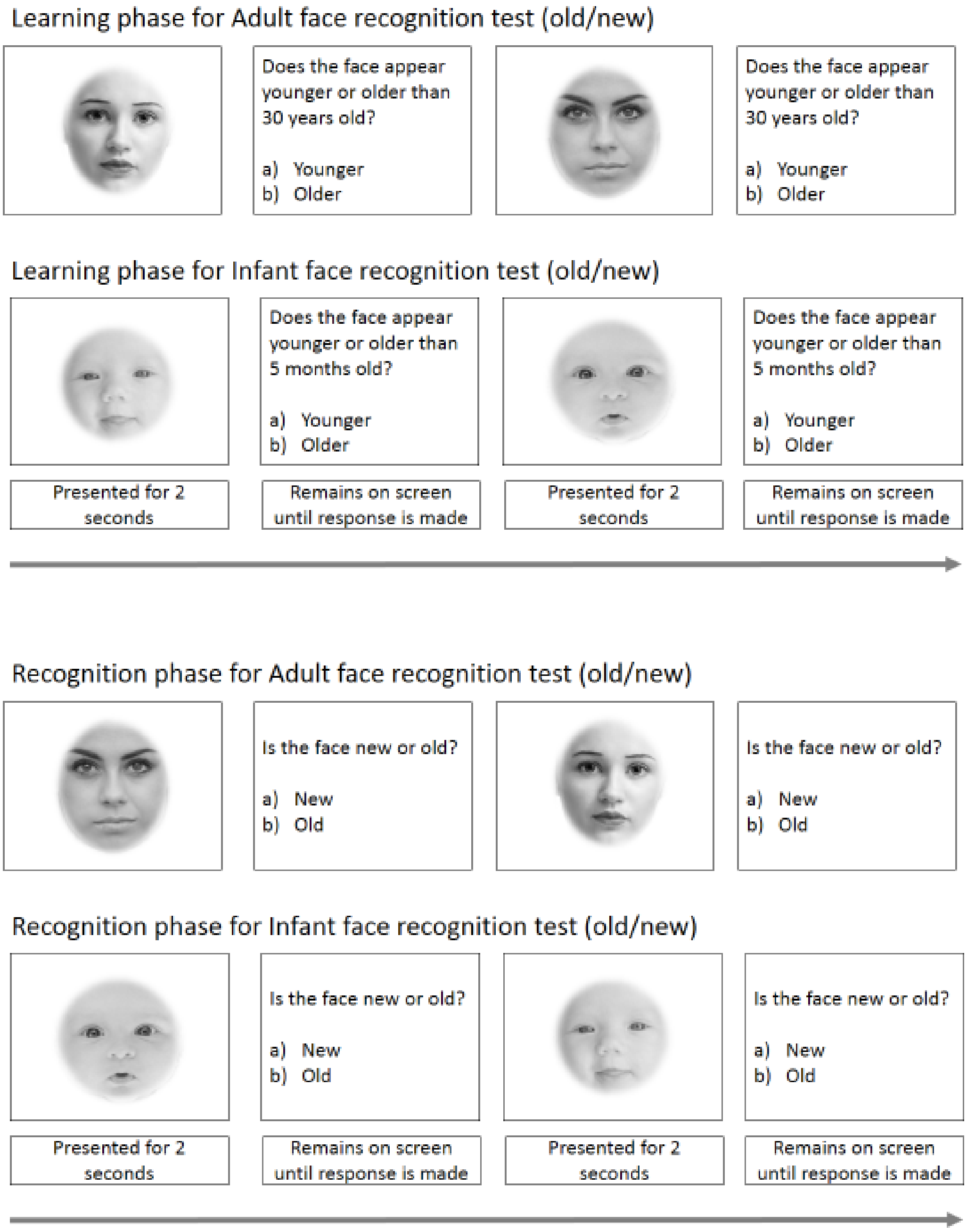

Figure 1. An example of the adult and infant face (old/new) recognition tests. Images used for this figure were acquired from free stock photos at www.pexels.com

Learning phase faces sequentially appeared for 2 seconds, and to encourage familiarisation, participants responded they appeared a) 'older' or b) 'younger' than 30-years. Following a brief break, in the recognition phase, half the trials depicted learning phase faces. Participants responded a) 'old' or b) 'new' to each. There were no time limits. The second learning and recognition block started shortly after completion of the first (see Figure 1). Analyses were conducted on hits (max = 40), CRs (max = 40), sensitivity ($d' = z(Hits) – z(False\ Alarms)$) and response bias (criterion: C) statistics (e.g., Green & Swets, 1966). Minimum threshold for inclusion in analyses on all old/new tests was set at 40/80 correct or chance levels.

Infant Face Recognition Test (old/new): Infant faces ($n = 80$, aged 4 and 6 months) were kindly provided by Macchi Cassia, Picozzi et al. (2009). With similar stimuli numbers, blocks, and procedure, the design was virtually identical to the adult face test, except that participants reported whether infant faces were 'older or 'younger' than 5 months in the learning phase, and images took up approximately 9 cm x 9 cm on a 20 cm x 30 cm laptop (see Figure 1).

1.2.4. Procedure

Upon clicking on the online Qualtrics (2017, Provo, UT) link, participants were warned that optimal image viewing required the use of a laptop or desktop PC. After providing informed consent, they completed the CFMT+ followed by the adult and infant face recognition tests (old/new) in a counterbalanced order. The entire experiment took approximately 60 minutes, and all participants were fully debriefed and provided with their test scores. In all experiments, IBM SPSS was used for analyses and unless otherwise reported α was set at $p = .05$.

1.3. Results

The mean performances of SRs and controls on the old/new tests and the CAE (calculated by subtracting infant face recognition scores from adult face recognition scores) are depicted in Table 2. Independent measures t-tests compared group performances on all measures though only *p* values are reported. The results of all ANOVAs and post-hoc t-tests are reported in Table 3.

Table 2. Adult and infant face recognition tests (old/new) performances in Experiment 1

	SRs (*n* = 315)			Controls (*n* = 499)			
	M	(SD)	95% CI	M	(SD)	95% CI	*p*
	Adult Face Recognition Test (old/new)						
Hits	0.87	(0.08)	0.87, 0.88	0.78	(0.10)	0.77, 0.78	< .001
CR	0.89	(0.08)	0.88, 0.90	0.82	(0.10)	0.81, 0.83	< .001
d'	2.61	(0.65)	2.53, 2.68	1.79	(0.46)	1.75, 1.83	< .001
C	0.04	(0.34)	0.01, 0.08	0.10	(0.32)	0.07, 0.12	.027
	Infant Face Recognition Test (old/new)						
Hits	0.80	(0.10)	0.79, 0.81	0.70	(0.11)	0.69, 0.71	< .001
CR	0.77	(0.11)	0.76, 0.78	0.71	(0.11)	0.70, 0.71	< .001
d'	1.70	(0.54)	1.66, 1.80	1.13	(0.43)	1.09, 1.16	< .001
C	-0.06	(0.31)	-0.10, -0.01	0.01	(0.26)	-0.02, 0.03	.002
	Cross-age effect (adult – infant scores)						
Hits	0.07	(0.10)	0.06, 0.09	0.08	(0.11)	0.06, 0.09	> .200
CR	0.12	(0.10)	0.11, 0.14	0.11	(0.11)	0.10, 0.12	> .200
d'	0.91	(0.58)	0.79, 0.94	0.66	(0.51)	0.60, 0.73	< .001
C	0.10	(0.32)	0.06, 0.15	0.09	(0.28)	0.04, 0.11	> .200

Table 3. Group analyses on SRs' and controls' Cross Age Effect in Experiment 1

Mixed ANOVAs 2 (group: SR, Control) x 2 (stimuli-type: Adult, Infant)		*df*	*F*	*η²*	*t*	*d*	*P*
Hits							
	Group	1,812	257.16	.24			<.001
	Stimuli-type	1,812	397.20	.33			<.001
	Interaction	1,812	<1	<.01			>.2
CRs							
	Group	1,812	106.29	.12			<.001
	Stimuli-type	1,812	1035.96	.58			<.001
	Interaction	1,812	<1	<.01			>.2
$d^/$							
	Group	1,812	492.67	.38			<.001
	Stimuli-type	1,812	1651.64	.67			<.001
	Interaction	1,812	36.56	.04			<.001
Follow-up paired t-tests (stimuli-type)							
	SRs	314			27.51	1.44*	<.001
	Controls	498			29.48	1.28*	<.001
C							
	Group	1,812	9.19	.011			.003
	Stimuli-type	1,812	82.88	.09			<.001
	Interaction	1,812	<1	<.01			>.2

* *d* for repeated measures (see Morris & DeShon, 2008)

Results summary

- SRs outperformed controls on both adult and infant face recognition (hits, CRs and $d^/$).
- With small effect sizes, SRs demonstrated a stronger CAE as assessed by $d^/$.
- There were no significant CAE differences in hits, CRs, or C.

1.4. Discussion

Based on CFMT+, and verifying Adult Face Recognition Test scores, Experiment 1 recruited a large number of SRs (*n* = 315). As expected, and despite the very brief (2-seconds) exposure to encoding phase faces, adult faces were recognised more accurately than infant faces, while SRs significantly outperformed 'average-ability' controls (*n* = 499) at adult and infant face recognition. Effect sizes were medium to large. The results also suggest SRs' enhanced recognition skills are modulated by experience. Both groups displayed similar deficits from the impact of the cross-age-effect (CAE) when examining hit and correct rejection (CR) rates. However, analyses of sensitivity ($d^{/}$), which takes both hits and correct rejections into account, revealed that although effect sizes were small, SRs exhibited the expected larger CAE than controls. Although no data were collected of experience with infants, it would be unlikely for this to differ substantially between SRs and controls, as there were no between-group age and gender differences.

Potential reasons for the enhanced CAE in SRs are debated in the General Discussion. Nevertheless, strict experimental control in online studies is difficult. Indeed the recruitment bias attracting better face recognisers, and the large number of participants who did not finish the research limits conclusions. In addition, large SR numbers meant conducting individual analyses were unfeasible. Therefore, Experiment 2 replicated Experiment 1 in a laboratory, and additionally examined whether the CAE could be observed at the level of electrophysiological activity, by recording EEG measurements during testing. An infant experience measure also evaluated exposure.

2.1. Experiment 2

Conducted in a laboratory, Experiment 2 replicated Experiment 1, with the application of EEG, on the *Adult* and *Infant Face Recognition Tests* (old/new). Previous research has revealed that face processing proficiency is reflected in ERPs with greater amplitudes or earlier latencies (e.g., P1, N170: Turano et al., 2016; N250, P600: Eimer et al., 2012; Wiese, Komes et al., 2013), and these formed the focus of analyses. Face processing is also associated with more pronounced patterns of electrical activity in the right hemisphere during early perceptual stages (P1, N170) (e.g., Eimer, 2000), while N250 is normally more pronounced in the left hemisphere (e.g., Pierce et al., 2011; Tanaka, Curran, Porterfield, &

Collins, 2006), and P600 activity - in central sites (e.g., Eimer et al., 2012), thus hemispheric differences were also investigated here.

Higher amplitudes or earlier latencies in ERPs are normally associated with more efficient processing (e.g., Kaltwasser, Hildebrandt, Recio, Wilhelm, & Sommer, 2013); and these effects might be expected for SRs, compared to controls, in at least one face-related ERP. Due to the dissociation between hits and CRs found in previous literature (e.g., Wiese et al., 2012), separate analyses were conducted on these outcomes. Finally, the CAE was expected to be reflected in differing levels of N250 and P600 activity (see Wiese, 2012; Wiese et al., 2012). However, due to the exploratory nature of the research no predictions were made as to whether between-SR and control group CAE effects in N250 and P600 would be exhibited.

2.2. Method

2.2.1. Design

Experiment 2 employed the same design and group membership criteria as Experiment 1. Reaction times were additionally collected on the *Adult* and *Infant Face Recognition Tests*, while EEG recording was administered. Individual level analyses also compared SR outcomes with the control group mean using modified t-tests (Crawford, Garthwaite, & Porter, 2010). The individual analyses compared the performance of each SR on all tests against the controls, generating an estimate of the proportion of the general population each SR would be expected to exceed.

2.2.2. Participants

Potential SR participants claiming exceptionally good face recognition ability in advance contacted the researchers after reading media reports. Additional adverts invited university members to participate.

Using Experiment 1's inclusion criteria, four CFMT+ defined SRs and nine CFMT+ defined controls were excluded from analyses as their face recognition ability was not confirmed by the adult face recognition test (old/new). The final sample consisted of white-Caucasian SRs (*n* = 19; CFMT+: 93 - 100) and controls (*n* = 28; CFMT+: 61 - 82). None contributed to the other experiments. All participants were questioned as to their experience with infants. One participant only, a SR (KH) declared extensive exposure to infants in their work place (paediatric hospital), and was therefore excluded from group analyses, but retained for the individual level analyses.

Table 4. SRs' and controls' characteristics in Experiment 2

	SRs (*n* = 19)	Controls (*n* = 28)	*p*
Gender	Male = 9 Female = 10	Male = 13 Female = 15	> .200
Age	38.53 (11.49)	41.38 (14.06)	> .200
Autism Quotient (out of 50)	15.40 (7.42)	17.24 (8.06)	> .200
Empathy Quotient (out of 80)	57.60 (10.85)	46.52 (15.58)	.017
CFMT+ (out of 102)	95.20 (1.64)	73.10 (6.71)	< .001
Adult face recognition (old/new) test (d')	2.51 (0.51)	1.56 (0.39)	< .001

Table 4 depicts participant groups' characteristics. Autistic Quotient (Baron-Cohen & Wheelwright, 2001) comprising 50 items and Empathy Quotient (Baron-Cohen & Wheelwright, 2004) comprising 80 items measuring autistic and empathy traits, respectively, were administered to participants to test if groups matched on these characteristics. The groups' demographic and trait characteristics as well as face recognition scores were compared using independent-measures t-tests and Chi-square tests (only *p* values are reported). In line with research (e.g., Bate et al., 2010), SRs scored significantly higher than controls on the Empathy Quotient (Baron-Cohen & Wheelwright, 2004).[4]

2.2.3 Materials

Adult and Infant Face Recognition Tests (old/new): The same tests were employed as in Experiment 1. Each test consisted of two learning (20 trials per block) and two recognition blocks (40 trials per block) with images randomly ordered within each. As in Experiment 1, stimuli presentation time in both learning and recognition stages was 2 seconds. To encourage learning, participants responded if the adult faces appeared 'older' or 'younger' than 30-years and if infant faces appeared 'older' or 'younger' than 5-months ('O' or 'Y'). During the recognition stage, participants responded 'old' or 'new' ('O' or 'N').

2.2.4. EEG recording and processing

EEG recording: EEG data were recorded using a Mitsar-EEG-201 and 19-channel electrocap with Ag/AgCl electrodes configured to a standard 10-20 placement with FPz used as the ground electrode. Electrode impedance was maintained at <5kΩ throughout the

[4] Note: Autism and Empathy scores were not recorded for controls ($n = 3$).

recording and we used an average ear reference. Data were sampled at 512Hz and a low-pass filter of 150Hz applied, further bandpass filtered to 0-45Hz range at final analysis (Cohen, 2014; Dickter & Kieffaber, 2014; Luck, 2005).

EEG pre-processing and analysis: EEG data were screened using WinEEG software following recommended guidelines for minimising artefacts (Thompson et al., 2008). Specifically, ocular artefacts were removed using Independent Component Analysis, with localised EEG spikes >100µV (e.g., from electrode movement) also removed. Data were divided into 120 one-second epochs (-300 to 700ms) for each trial type, with -300 to 0ms used for baseline correction. In line with previous research (e.g., MacKenzie & Donaldson, 2007), only participants with ≥ 15 trials in each condition were retained as our minimum inclusion criterion to ensure reasonable signal-to-noise ratio.

The following left and right hemisphere ERPs were examined given that previous research has found these may play a key role in face processing: (a) P1 channels O1/O2, time range 70–160ms (e.g., Turano et al., 2016), (b) N170, T5/T6, 110–220ms (e.g., Turano et al., 2016), (c) N250, T5/T6, 220–310ms (Yang et al., 2014), (d) P600, P3/Pz/P4, 500–700ms (e.g., Düzel et al., 1997). For learning trials on the *Adult* and *Infant Face Recognition Tests*, grand-averages were computed for P1/N170 to measure early perceptual components. For recognition trials, only correct responses (Hits, CRs) with all four ERPs were employed (Cohen, 2014). Amplitude was quantified using the local peak method (Luck, 2005), and latency based on the time occurrence of this peak.

2.2.5. Procedure

After providing informed consent, participants supplied demographic details, including occupation and exposure to infants (children, nieces, workplace etc.); completed the Autism and Empathy Quotient scales and on a computer screen, the CFMT+, following which the EEG equipment was set up, with participants situated approximately 60cm from the monitor. They then completed the *Adult* and *Infant Face Recognition Tests* (old/new) in a counterbalanced order. The entire experiment took approximately 60 minutes and all participants were fully debriefed.

2.3. Results

The mean performances of SRs and controls on the *Adult* and *Infant Face Recognition Tests* (old/new) and the CAE, are depicted in Table 5, while the analyses are reported in Table 6. Five 2 (group) x 2 (stimuli-type) ANOVAs were performed on hits, CRs, d/, C and RTs, although no effects were significant for the latter and these are not reported (p > .05).

Table 5. Mean group performances in Experiment 2 [5]

	SRs (n = 18)			Controls (n = 27)		
	M	*(SD)*	95% CI	M	*(SD)*	95% CI
			Adult face recognition test (old/new)			
Hits	0.82	*(0.12)*	0.76, 0.88	0.79	*(0.08)*	0.76, 0.83
CR	0.91	*(0.08)*	0.87, 0.90	0.75	*(0.09)*	0.81, 0.78
d/	2.51	*(0.51)*	2.26, 2.76	1.56	*(0.39)*	1.40, 1.71
C	0.22	*(0.43)*	0.01, 0.44	-0.06	*(0.30)*	-0.19, 0.03
RT	0.72	*(0.32)*	0.56, 0.87	0.93	*(0.48)*	0.73, -1.12
			Infant face recognition test (old/new)			
Hits	0.79	*(0.09)*	0.74, 0.83	0.76	*(0.08)*	0.73, 0.79
CR	0.73	*(0.15)*	0.66, 0.81	0.63	*(0.14)*	0.58, 0.69
d/	1.51	*(0.36)*	1.33, 1.69	1.09	*(0.36)*	0.94, 1.23
C	-0.09	*(0.36)*	-0.27, -0.09	-0.16	*(0.32)*	-0.28, -0.03
RT	0.78	*(0.36)*	0.60, 0.96	0.82	*(0.37)*	0.66, 0.97
			Cross-age effect (adult - infant scores)			
Hits	0.03	*(0.09)*	-0.01, 0.08	0.03	*(0.10)*	<0.01, 0.07
CR	0.18	*(0.12)*	0.11, 0.24	0.12	*(0.08)*	0.08, 0.14
d/	1.00	*(0.45)*	0.78, 1.23	0.47	*(0.45)*	0.28, 0.64
C	0.31	*(0.37)*	0.13, 0.49	0.10	*(0.26)*	<0.01, 0.21
RT	0.06	*(0.19)*	-0.03, 0.16	-0.11	*(0.40)*	-0.27, 0.05

[5] Note that due to technical errors, although EEG data were collected, infant face recognition performance (SR n = 1; control = 1) and RTs (controls = 2) were not recorded, excluding participants from relevant analyses.

The group main effects were significant for CRs and d/, but not hits or C. SRs outperformed controls but only at correctly rejecting faces not seen before, and at discriminating old and new faces.

All stimuli-type main effects were significant. Adult faces were better recognised than infant faces, mainly driven by a response bias against responding 'new' to infant faces

Table 6. Group analyses investigating CAE in Experiment 2

Mixed ANOVAs 2 (group: SR, Control) x 2 (stimuli-type: Adult, Infant)		*Df*	*F*	η^2	*t*	*d*	*p*
Hits							
	Group	1,43	2.16	.05			.149
	Stimuli-type	1,43	5.15	.11			.028
	Interaction	1,43	0.01	0			>.2
CRs							
	Group	1,43	15.90	.27			<.001
	Stimuli-type	1,43	89.85	.68			<.001
	Interaction	1,43	4.78	.10			.034
Follow-up t-tests (group)							
	Adult faces	45			5.56	1.68	<.001
	Infant faces	43			2.22	0.67	.032
d/							
	Group	1,43	40.42	.49			<.001
	Stimuli-type	1,43	114.57	.73			<.001
	Interaction	1,43	15.63	.27			<.001
Follow-up t-tests (group)							
	Adult faces	45			6.20	1.85	<.001
	Infant faces	43			3.87	1.22	<.001
C							
	Group	1,43	3.42	.08			.071
	Stimuli-type	1,43	19.70	.31			<.001
	Interaction	1,43	4.99	.10			.031
Follow-up t-tests (stimuli-type)							
	Adult faces	45			2.34	0.67	.024
	Infant faces	43			0.69	0.21	.492
t-tests CAE effect (group: SR, Control)							
		df			*t*	*d*	*p*
	Hits	43			0.08	0.57	>.2
	CRs	43			2.19	0.64	.034
	d/	43			3.95	1.21	<.001
	C	43			2.23	0.66	.031
	RT	42			1.75	0.57	.089

There were significant interactions on all measures except hits. SRs generated greater CR rates and greater $d^{/}$ than controls on both, adult and infant face recognition tests. SRs showed a more conservative bias than controls on adult face recognition but there were no between-group response biases with infant face recognition.

Five between-group independent-measures t-tests found SRs displayed significantly larger CAE effects when assessed by $d^{/}$. There were also marginally significant Bonferroni-corrected (p = .01) between-group CAE differences when evaluating CRs and response bias (C).

Individual analyses: Modified t-tests for single cases (Crawford et al., 2010), compared CFMT+, and Adult and Infant Face Recognition ($d^{/}$), $CAE_{sensitivity}$ ($d^{/}$) and $CAE_{Criterion}$ (C) scores of each SR against the control mean (n = 27). The results are reported in Table 7. For brevity, the results of Hits and CRs analyses are not reported. Significant comparisons are marked as appropriate.

All SRs significantly outperformed controls on the CFMT+ ($p < .05$), and almost all exceeded the control ($d^{/}$) mean on the Adult (n = 19, 100%) and Infant (n = 18, 94.7%) Face Recognition Tests, some significantly (Adult: n = 11, 57.9%; Infant: n = 3, 15.8%). On the infant face test, as expected, this included KH (SR13), excluded from group analyses due to regular exposure to large numbers of infants.

In addition, most SRs (n = 18, 94.7%), exceeded the control $CAE_{sensitivity}$ mean, some significantly (n = 4, 21.1%), indicative of stronger CAE effects. For 3 SRs, this was driven by significant $CAE_{\textit{Criterion}}$ effects, providing more conservative responses to adult than infant faces. As predicted, KH, the SR excluded from the group analysis (based on their daily exposure to infants in the workplace) showed no CAE. Note however, that SR16 demonstrated a significantly inverse CAE in their response bias (i.e. more conservative during infant face recognition). RTs are not reported as none of the SRs showed a significantly different CAE_{RT} (p > 05).

Table 7. Individual analyses comparing SR against the control mean (n = 27) on CFMT+, recognition tests (d'), CAE $_{sensitivity}$, and CAE $_{criterion}$

SR	1	2	3	4	5	6	7	8	9	10	11	12	*13*(KH)	14	15	16	17	18	19
CFMT+ (Control *M* = 73.1, *SD* = 6.71)																			
CFMT+	93	94	94	94	94	94	94	95	95	95	95	95	95	96	96	96	96	98	100
t	2.91	3.06	3.06	3.06	3.06	3.06	3.06	3.21	3.21	3.21	3.21	3.21	3.21	3.35	3.35	3.35	3.35	3.65	3.94
p	.007	.005	.005	.005	.005	.005	.005	.003	.003	.003	.003	.003	.003	.002	.002	.002	.002	.001	<..001
95% CI	98.17	98.62	98.62	98.62	98.62	98.62	98.62	98.97	98.97	98.97	98.97	98.97	98.97	99.24	99.24	99.24	99.24	99.60	99.80
	99.99	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Adult Face Recognition ($_{Sensitivity}$) (Control *M* = 1.56, *SD* = 0.39)																			
d'	** 2.89	**^ 2.02	** ^2.56	**^2.63	**2.80	^2.48	1.99	**^2.56	*2.56	1.75	1.88	**^2.72	1.75	**3.08	3.40	2.80	1.88	**3.29	1.91
t	2.88	1.07	2.19	2.34	2.70	2.03	1.00	2.19	2.19	0.50	0.77	2.53	0.50	3.28	3.95	2.70	0.77	3.72	0.84
p	.008	.296	.037	.027	.012	.053	.325	.037	.037	.620	.446	.018	.620	.003	.001	.012	.446	.001	.411
95% CI	97.99	72.60	93.52	94.85	97.17	91.68	70.79	93.52	93.52	54.17	63.62	96.22	54.17	99.08	99.79	97.17	63.62	99.64	65.66
	99.99	94.02	99.84	99.91	99.98	99.68	93.09	99.84	99.84	81.81	88.77	99.96	81.81	100.0	100.0	99.98	88.77	100.0	90.09
Infant Face Recognition ($_{Sensitivity}$) (Control *M* = 1.09, *SD* = 0.36)																			
d'	1.25	1.39	1.75	1.37	1.88	1.21	1.12	^1.47	*2.04	1.43	1.14	1.88	*1.97	1.28	*2.19	1.39	^0.83	1.76	1.79
t	0.49	0.82	1.66	0.77	1.96	0.40	0.19	1.01	2.34	0.91	0.23	1.96	2.17	0.56	2.69	0.82	-0.49	1.68	1.75
p	.628	.421	.109	.447	.060	.694	.853	.324	.027	.370	.817	.060	.039	.579	.012	.421	.628	.104	.091
95% CI	53.79	65.10	86.24	63.57	90.89	50.34	42.39	70.87	94.83	68.05	44.17	90.89	93.33	56.32	97.14	65.10	18.50	86.65	87.83
	81.50	89.74	98.86	88.74	99.60	78.64	71.55	93.13	99.91	91.55	73.19	99.60	99.82	83.51	99.98	89.74	46.21	98.94	99.16
Cross Age Effect (CFE $_{Sensitivity}$) (Control *M* = 0.46, *SD* = 0.45)																			
d'	1.64	0.63	0.81	1.27	0.92	1.27	0.87	1.09	0.53	0.32	0.74	0.84	-0.22	1.80	1.21	1.41	1.05	1.53	0.11
t	**2.58	0.37	0.76	1.77	1.00	1.77	0.89	1.38	0.15	-0.31	0.61	0.83	-1.48	2.92	1.64	*2.07	**1.29	**2.34	-0.76
p	.016	.714	.452	.089	.325	.089	.379	.181	.880	.762	.547	.415	.150	.007	.114	.048	.209	.027	.452
95% CI	96.51	49.35	63.31	88.05	70.82	88.05	67.52	80.48	41.08	24.36	58.09	65.45	1.97	98.14	85.82	92.23	78.43	94.8	11.43
	99.97	77.79	88.57	99.2	93.1	99.2	91.24	97.3	70.32	53.12	84.13	89.96	17.15	99.99	98.77	99.74	96.58	99.91	36.69
Cross Age Effect (CFE $_{Criterion}$) (Control *M* = 0.10, *SD* = 0.26)																			
C	0.82	0.71	0.40	0.48	0.46	-0.17	0.22	0.13	0.42	0.24	0.28	0.50	0.23	0.22	-0.20	-0.49	0.97	0.56	0.06
t	*2.72	*2.31	1.13	1.44	1.36	-1.02	0.45	0.11	1.21	0.53	0.68	1.51	0.49	0.45	-1.13	*-2.23	**3.29	1.74	-0.15
p	.011	.029	.267	.162	.185	.317	.654	.911	.237	.601	.502	.142	.627	.654	.267	.034	.003	.094	.881
95% CI	97.39	94.69	74.76	82.09	80.41	6.76	52.69	39.85	76.74	55.45	60.78	83.66	54.08	52.69	5.18	0.15	99.13	87.79	29.98
	99.98	99.89	94.82	97.68	97.13	28.42	80.17	68.65	95.71	82.41	86.45	98.14	81.31	80.17	25.24	5.98	100.0	99.09	58.71

*Significant comparisons *   Significant comparisons in Hits ^   Significant comparisons in Correct rejections ***

Note: SR13 (KH) reported extensive experience with infant faces from work in a paediatric environment

95% CI reported in the table represent the upper and lower bound confidence intervals of the estimated proportion of the general population expected to fall below each super-recogniser.

EEG analyses: To examine CAE influence, a series of 2 (group) x 2 (stimuli-type: adult, infant) x 2 (hemisphere: left, right channel) ANOVAs were conducted on both *amplitude* and *latency* for ERPs of interest (*Learning and test phases*: P1: attention resource allocation and pictorial encoding; N170: structural encoding; *Test phase only*: N250: implicit face identity discrimination; P600: explicit face identity discrimination). Learning phase analyses examined ERPs associated with stimuli exposure. Test phase analyses examined ERPs associated with hits and CRs. Participants who did not generate significant numbers of artefact-free trials were removed from analyses (encoding: 2 SRs/1 control; hits: 2 SRs/ 3 controls; correct rejections: 2 SRs/1 control). The average number of valid epochs generated by remaining participants was 29.4 (SRs) and 27.5 (controls) per condition (as there were six conditions this equated to an average of approximately 176 trials for a SR and 165 trials for a control). Grand-average ERPs for adult and infant face recognition (hits) in SRs and controls are depicted in Figure 2 (see Appendices for grand-average ERPs for adult and infant face encoding and correct rejections).

Learning phase: P1: The only significant effect was associated with *latency* which revealed a hemisphere main effect only, $F(1, 34) = 12.91$, $p = .001$, $\eta^2 = .28$. P1 peaked earlier in the right hemisphere, indicative of hemispheric dominance.

Learning phase: N170: With *amplitude* only, a main effect of stimuli-type, $F(1, 34) = 4.68$, $p = .038$, $\eta^2 = .12$, was due to greater negative amplitudes to adult than infant faces potentially reflecting an electrophysiological reaction to superficial physical differences; while a hemisphere main effect, $F(1, 34) = 4.39$, $p = .044$, $\eta^2 = .11$, revealed right hemisphere negative amplitudes were greater, indicative of hemispheric dominance.

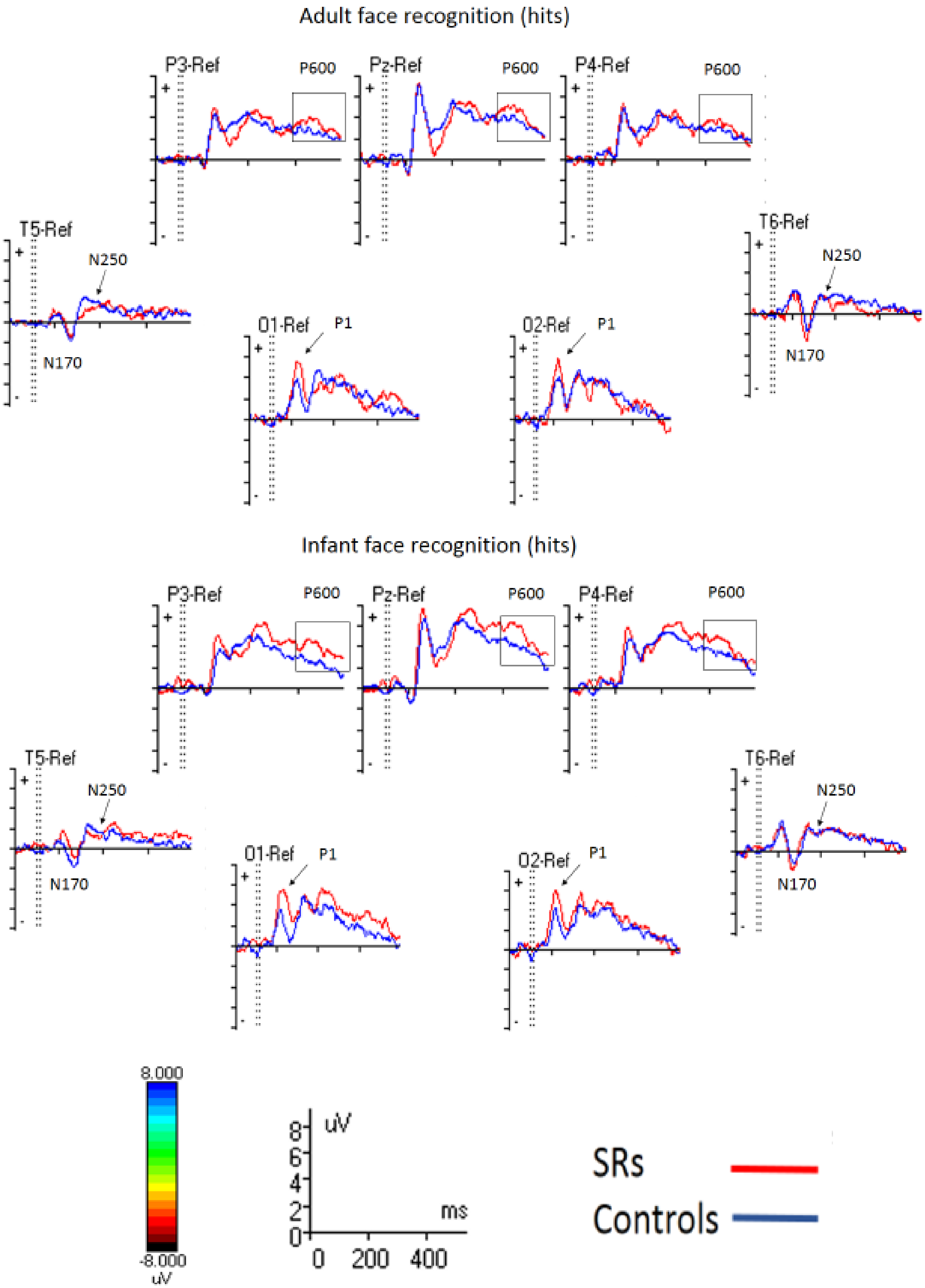

Figure 2. Average amplitudes during adult and infant face recognition (hits) in SRs and controls. Left channels are marked with odd numbers (i.e., O1, T5, P3) and right channels are marked with even numbers (i.e., O2, T6, P4). Z channel (i.e. Pz) stands for central location.

Test Phase: P1 Hits: With *amplitude,* a main effect of group only, $F(1, 33) = 5.37$, $p = .027$, $\eta^2 = .14$, was due to SRs displaying greater positive amplitudes than controls, reflecting either more effective attentional resource allocation or pictorial processing. With *latency*, a hemisphere main effect, $F(1, 33) = 5.58$, $p = .024$, $\eta^2 = .15$, was due to earlier right hemisphere peaks.

Test Phase: P1 CRs: There was only a main effect of hemisphere for *amplitude*, $F(1, 33) = 4.14$, $p = .050$, $\eta^2 = .11$. Larger left hemisphere amplitudes indicated dominance, indicative of a mirror effect at this ERP, given the opposite hits hemispheric effect.

Test Phase: N170 Hits: With *amplitude*, there was a marginal stimuli-type x group interaction, $F(1, 33) = 4.04$, $p = .053$, $\eta^2 = .11$. Simple effects analyses revealed that SRs, $F(1, 33) = 3.52$, $p = .070$, $\eta^2 = .10$, but not controls, $F(1, 33) < 1$; showed marginally greater negative amplitudes for adult than infant faces, providing tentative indications of proficiency-related CAE activity differences.

Test Phase: N170 CRs: With *amplitude*, the three-way interaction was significant, $F(1, 33) = 7.54$, $p = .010$, $\eta^2 = .19$. Simple interaction effects revealed that controls displayed a hemisphere x stimuli-type interaction, $F(1, 19) = 5.81$, $p = .026$, $\eta^2 = .23$, whereby adult faces generated only a marginally greater amplitude in the left hemisphere, $F(1, 19) = 3.51$, $p = .076$, $\eta^2 = .16$; while infant faces generated roughly similar amplitudes across the two hemispheres, $F(1, 19) < 1$. The interaction effects for SRs were not significant, $F(1, 19) = 2.41$, $p = .143$, $\eta^2 = .15$.

With *latency,* there was a hemisphere x group interaction, $F(1, 33) = 7.91$, $p = .008$, $\eta^2 = .19$, the left hemisphere showed a bigger group difference, with SRs generating later latencies than controls, $F(1, 33) = 6.29$, $p = .017$, $\eta^2 = .16$, and the opposite between-group pattern was observed in the right hemisphere, though it did not reach statistical significance, $F(1, 33) = 1.95$, $p = .172$, $\eta^2 = .06$.

There was a three-way interaction, $F(1, 33) = 4.58$, $p = .040$, $\eta^2 = .12$. However, the only marginally significant simple interaction effect was that controls generated earlier latencies in the left than right hemisphere, $F(1, 19) = 4.65$, $p < .1$, $\eta^2 = .20$. No simple interaction effects were significant with SRs ($p > .2$).

Test Phase: N250 Hits: With *latency*, a main effect of stimuli-type, $F(1, 33) = 5.23$, $p = .029$, $\eta^2 = .14$, revealed adult faces generated earlier N250 peaks than infant faces, indicative of an electrophysiological marker of the CAE; whereas a significant hemisphere effect, $F(1, 33) = 7.51$, $p = .010$, $\eta^2 = .19$, revealed left hemisphere dominance in line with previous research.

Test Phase: N250 CRs: No effects were significant ($p > .05$).

Test Phase: P600 Hits: With *amplitude* a main effect of group, $F(1, 33) = 4.74$, $p = .037$, $\eta^2 = .13$, revealed SRs notably generated higher amplitudes than controls. There was a main effect of channel, $F(1, 33) = 22.77$, $p < .001$, $\eta^2 = .41$, in line with previous research, demonstrating greater amplitudes generated by the central site - Pz.

Test Phase: P600 CRs: With *amplitude*, a stimuli-type main effect, $F(1, 33) = 6.49$, $p = .016$, $\eta^2 = .16$, revealed lower amplitudes in adult than infant faces, potentially reflecting the CAE; while a channel main effect, $F(1, 33) = 33.37$, $p < .001$, $\eta^2 = .50$, revealed higher amplitudes associated with the central site, Pz.

Results summary

- SRs outperformed controls on adult (CRs and d') and infant face recognition (d') and displayed a greater CAE (d') than controls
- At the individual level, most SRs outperformed controls on adult and infant face recognition, while only one SR (with daily exposure to infants at workplace), as expected, did not show the CAE (d')

- SRs generated greater amplitudes in P1 and P600 in reaction to recognised faces (regardless of the faces' age)
- CAE was reflected in greater N250 amplitudes in reaction to adult faces and greater P600 amplitudes in reaction to infant faces

2.4. Discussion

Consistent with Experiment 1 and hypotheses, adult faces were recognised more accurately than infant faces; while SRs outperformed controls at both adult and infant face recognition, although significant effects were only found when analysing correct rejections (CRs) and sensitivity ($d^{/}$). In contrast to Experiment 1, and partly driven by SRs' responses being more conservative with adult faces, the effect for hits was not significant, possibly due to lower participant numbers and reduced statistical power. However, SRs again displayed a stronger *cross age effect* (CAE) than controls, although unlike with Experiment 1 in which effects were found for sensitivity ($d^{/}$) only, in Experiment 2, the CAE was additionally found with CRs. This suggests that SRs' own-age face advantage may partly originate in correctly recognising that a face has not been seen before. Greater experimental control in Experiment 2 may also explain the between-experiment differences in between-group CAE outcomes, although in both experiments a medium CAE $d^{/}$ effect size was revealed.

At the electrophysiological level, no reliable between-group face-related ERP differences at N170 or N250 were found. However, test phase differences were revealed when analysing P1 and P600, the latter potentially indicative of SRs' explicit face recognition advantage. Surprisingly, given that earliest ERPs associated with face recognition are activated later (N250), SRs' P1 amplitudes for recognised faces (hits) were significantly greater than controls. Enhanced P1 activation in good, but not poor recognisers (1 SD above or below the estimated population mean on the CFMT, respectively) was also found by

Turano et al. (2016), although this was during encoding rather than recognition. The authors suggested effects indicated more effective allocation of attentional resources during face learning. However, given that the current study found no encoding effects, SRs' enhanced P1 for hits is likely to reflect more effective pictorial processing of faces they have previously been exposed to, and subsequently responded 'old' to. Indeed, Turano et al. (2016) demonstrated that early ERP amplitudes can be modulated by face familiarity in good recognisers. Therefore the recognised face identities appear to have attenuated P1 amplitudes in SRs, potentially resulting in a more effective processing. Although no between-group effects were found when analysing the behavioural data for hits, this is the first tentative electrophysiological indication of SRs' face processing advantage, taking place at the earliest face-related component.

SRs' superiority was however more reliably reflected in greater amplitudes derived from P600, an ERP associated with explicit recognition (e.g., Eimer et al., 2012). This could potentially be a consequence of the electrophysiological advantage observed at P1, as earlier ERPs may contribute to later ERP activity (e.g., Kaltwasser et al., 2013; Towler & Eimer, 2012).

The CAE was also observed at the level of electrophysiological activity. In line with predictions (e.g., Wiese et al., 2012; 2013), N250 peaked significantly earlier for adult than infant faces, indicative of more efficient processing (e.g., Kaltwasser et al., 2013), and implicit face discrimination (e.g., Eimer et al., 2012). Higher amplitudes at P600 were also found with correctly rejected (CR) infant than adult faces. Previous research has found that higher amplitudes during this time interval may potentially accompany more demanding processing (e.g., Wiese, Wolff et al., 2013), possibly suggesting that infant face processing was indeed more demanding than adult face processing. It is noteworthy that hits and CRs reflect different types of processing, which is observed on the electrophysiological level as well. Indeed, Experiment 2 showed that CRs induced left hemisphere dominance for P1, as opposed to the right hemisphere dominance reported for hits in previous literature (e.g., Bentin et al., 1996; Eimer, 2000).

There was also a marginal finding that SRs, but not controls, displayed greater negative amplitudes for adult than infant faces at N170, providing tentative indications of proficiency-related CAE activity differences. However, due to the heterogeneous individual SR response patterns displayed in Table 7, strong conclusions are not possible. Nevertheless, this electrophysiological marker should form the focus of future research, and it is possible that if instead of the earlobes, the nose had been used as a reference point, stronger differences between SRs and controls might have emerged. The nose was not used in this manner in Experiment 2 as the researchers had previously found some participants disliked this method. However, other researchers have found that the tip of the nose, if correctly placed is not uncomfortable, and indeed this has been recommended by some researchers as the most effective technique for examining N170 (e.g., Joyce & Rossion, 2005).

In summary, it is clear that the electrophysiological effect sizes reported in Experiment 2 are inconclusive and require replication. Increasing the number of valid segments to average per participant would improve the signal to noise ratio and provide more robust results.

3.1. Experiment 3

Experiment 3 was designed to examine whether the enhanced CAE found in SRs when recognising adult and infant faces in Experiment 1 and 2, would be replicated using a sequential matching design drawing minimally on memory. Inverted stimuli were also employed, and as inversion effects are enhanced in SRs (e.g., Bobak, Bennetts et al., 2016), and smaller in DPs (e.g., Behrmann & Avidan, 2005) similar effects were predicted here. In addition it was possible to examine the *Cross-Age Inversion Effect*, in order to test whether the between-group CAE effects found in Experiment 1 and 2 might be related to reduced holistic processing of infant compared to adult faces (see Kuefner et al., 2008; Macchi Cassia, Picozzi et al., 2009).

To hypothesise, SRs were again expected to outperform controls, and to demonstrate stronger Inversion Effects and CAE effects. Given that better face recognition is associated with stronger inversion effects (Bobak, Bennetts et al., 2016), Inversion Effects were predicted to be stronger for adult than infant faces. Finally, SRs were expected to display a larger Cross-Age Inversion effect than controls.

3.2. Method

3.2.1 Design

Unlike in previous experiments, no verifying face recognition test was employed, but using the same CFMT+ group membership criteria, SRs (who all claimed exceptional abilities) and controls completed bespoke *Adult* and *Infant Sequential Face Matching Tests* in *upright* and *inverted* orientations, in order to measure the Cross-Age Inversion Effect.

3.2.2. Participants

Participants had contributed to previous online unpublished research. Based on previous CFMT+ scores matching Experiment 1 and 2's group membership criteria, they were invited via email to contribute to Experiment 3 in the laboratory. Participants included 24 SRs (CFMT+: 94 – 101) and 20 controls (CFMT+: 65 – 81). None had taken part in Experiment 1 or 2. No participant reported unusually high exposure to infants. The groups' characteristics are reported in Table 8, with independent-measures t-tests and Chi-square tests comparing groups on demographic information and face recognition (only *p* values are reported).

Table 8. SRs' and controls' characteristics in Experiment 3

	SRs (*n* = 24)	Controls (*n* = 20)	*P*
Gender	Male = 12 Female = 12	Male = 6 Female = 14	> .180
Age	37.40 (8.40)	29.60 (10.30)	.006
CFMT+ (out of 102)	96.70 (2.30)	71.80 (6.10)	< .001

3.2.3. Materials

Adult/Infant Sequential Face Matching Test (Upright): Employing two blocks (48 trials each) per stimulus condition, this test employed the same stimuli as Experiments 1 and 2, although trial numbers were increased by using some images (*n* = 8) as targets in one trial, and as probes in another. Given the speed of sequential presentation and the requirement to match two stimuli, repetition of a few images was unlikely to influence the results. The test employed a very brief presentation of stimuli in order to encourage matching rather than memorising of face stimuli, as well as to reduce ceiling effects in both groups. Each trial consisted of a central fixation cross (0.5sec), followed by a target face (0.5 sec), an inter-stimulus interval (0.5sec), and a probe face (0.5sec). The probe was followed by another fixation cross which stayed on screen until a response was made. The participants made speeded responses on a keyboard as to whether face pairs were the same ('S') or different ('D'). The visual angle of target image presentation was 4.9° by 5.7° for adult faces and 4.9° by 4.9° for infant faces. As spotting differences is easy with equal size image pairs; the probe images were reduced by 24% in size compared to target images, to encourage judgements based on identity, and not on image variation (see Figure 3).

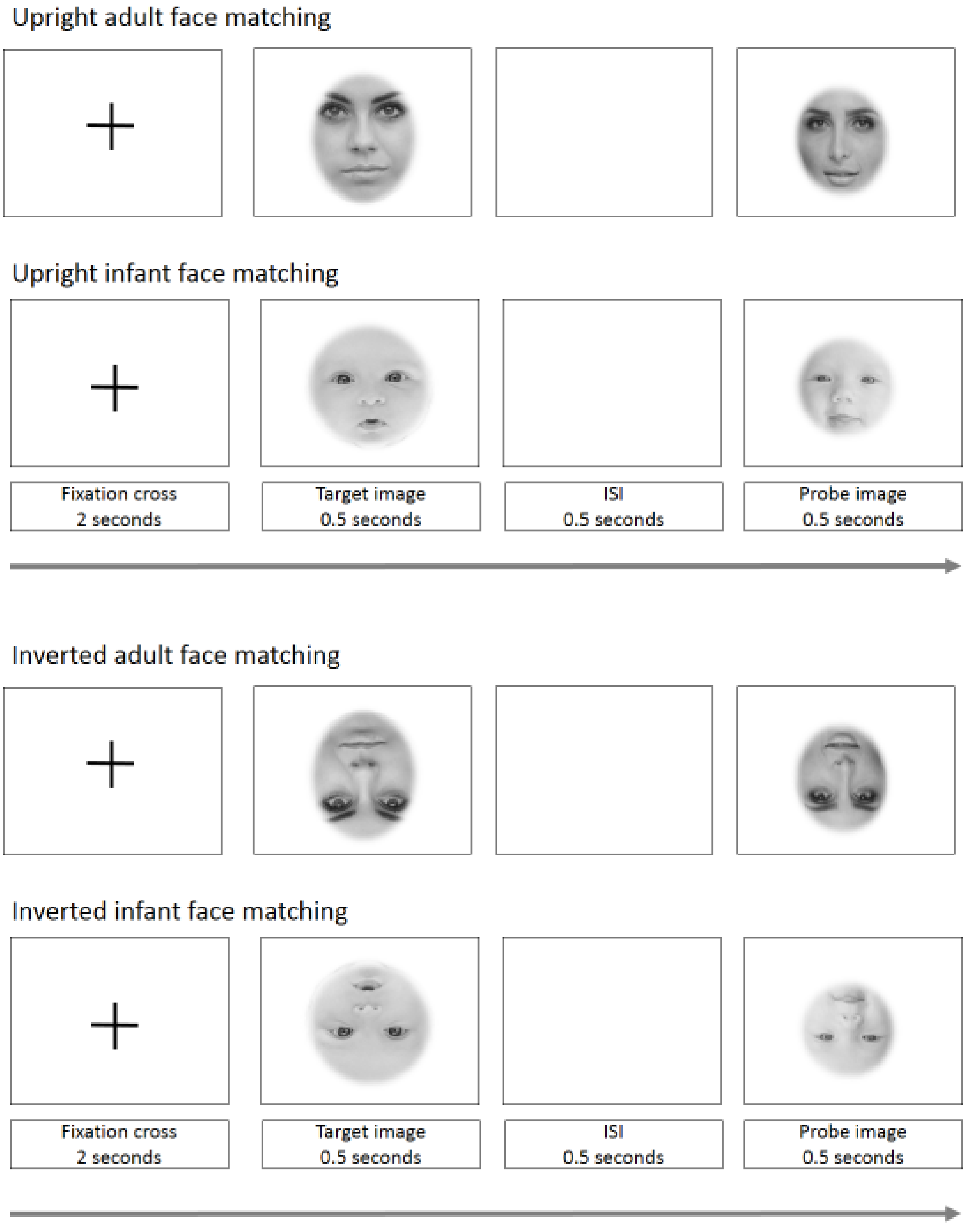

Figure 3. An example of the adult/infant face matching test. Images used for this figure were acquired from free stock photos at www.pexels.com

Adult/Infant Sequential Face Matching Test (Inverted): Using an identical design the same test was administered inverted with all stimuli rotated 180°.

To calculate the upright and inverted CAE, all measures (hits, CR, $d^{/}$, C, and RT) on the infant face matching block were subtracted from those on the adult face matching block in both orientations. To calculate inversion effects, all measures on the inverted face matching blocks were subtracted from those on the upright blocks. Cross-age Inversion effects were also calculated by subtracting the inverted CAE from the upright CAE.

3.2.4. Procedure

After providing permission to access past CFMT+ scores, informed consent, demographic information and experience with infants, participants completed the *Adult/Infant Face Sequential Matching Tests* (*upright* and *inverted*) in a counterbalanced order in a laboratory. There was an opportunity to take between-block breaks. The experiment took approximately 30 minutes after which participants were fully debriefed.

3.3. Results

Table 9 depicts the performance of SRs and controls on upright and inverted adult and infant face matching as well as the CAE, calculated by subtracting inverted scores from upright scores. ANOVAs run on these data are reported in Table 10.

Between-group CAE and inversion effects were analysed using four 2 (group: SRs, controls) x 2 (stimuli-type: adult, infant) x 2 (orientation: upright, inverted) ANOVAs on hits, CRs, sensitivity ($d^{/}$), and criterion (C). Unless evaluating important hypotheses, for brevity only significant effects are reported (p > .05).

Table 9. SR and Control performances in Experiment 3 (SD in parentheses)

	SRs (*n* = 24)			Controls (*n* = 20)		
	Adult	Infant	CAE	Adult	Infant	CAE
	Upright sequential face matching					
Hits	0.90 *(0.11)*	0.91 *(0.10)*	<0.01 *(0.06)*	0.85 *(0.12)*	0.84 *(0.12)*	0.01 *(0.12)*
CR	0.65 *(0.24)*	0.56 *(0.23)*	0.09 *(0.10)*	0.59 *(0.17)*	0.55 *(0.16)*	0.04 *(0.09)*
d/	1.90 *(0.66)*	1.63 *(0.58)*	0.27 *(0.47)*	1.44 *(0.43)*	1.25 *(0.48)*	0.19 *(0.42)*
C	-0.49 *(0.59)*	-0.66 *(0.52)*	0.17 *(0.34)*	-0.48 *(0.47)*	-0.49 *(0.39)*	0.01 *(0.34)*
	Inverted sequential face matching					
Hits	0.78 *(0.13)*	0.80 *(0.14)*	-0.02 *(0.11)*	0.78 *(0.16)*	0.80 *(0.11)*	-0.03 *(0.14)*
CR	0.54 *(0.21)*	0.53 *(0.21)*	0.02 *(0.12)*	0.50 *(0.18)*	0.42 *(0.16)*	0.09 *(0.13)*
d/	1.00 *(0.40)*	0.99 *(0.55)*	0.01 *(0.63)*	0.91 *(0.48)*	0.74 *(0.47)*	0.17 *(0.61)*
C	-0.37 *(0.52)*	-0.44 *(0.52)*	0.07 *(0.32)*	-0.44 *(0.51)*	-0.60 *(0.41)*	0.15 *(0.38)*
	Inversion effect					
Hits	0.12 *(0.09)*	0.11 *(0.10)*	<0.01 *(0.11)*	0.08 *(0.10)*	0.04 *(0.11)*	0.04 *(0.14)*
CR	0.11 *(0.15)*	0.03 *(0.18)*	0.07 *(0.14)*	0.09 *(0.11)*	0.13 *(0.13)*	-0.04 *(0.14)*
d/	0.90 *(0.68)*	0.64 *(0.70)*	0.26 *(0.53)*	0.53 *(0.46)*	0.51 *(0.56)*	0.02 *(0.74)*
C	-0.12 *(0.28)*	-0.22 *(0.35)*	0.10 *(0.40)*	-0.03 *(0.28)*	0.11 *(0.30)*	-0.14 *(0.40)*

The only significant group main effects were for d/, with SRs outperforming controls.

There were significant stimuli-type main effects for CRs, d/, and C. Driven partly by a conservative response bias to respond ‘same’ to adult faces, adult face matching was more accurate than infant face matching.

Significant orientation effects were found for hits, CRs and d/. As expected, upright face matching was more accurate than inverted matching.

There were significant group x orientation interactions for hits and C only. Paired t-tests comparing upright and inverted faces for SRs and controls separately found that both generated higher hits for upright face matching, although supporting hypotheses, the size of the Inversion Effect was stronger for SRs when making correct identifications (hits). However, while controls showed similar response biases across orientations, SRs tended to be more liberal with ‘same’ responses in upright orientation.

The only other significant interaction was the three-way for CRs. Simple interaction effects on each group separately, found that SRs displayed the same main effect of stimuli-type as above (greater accuracy for adult versus infant faces), a marginal orientation effect, and a significant interaction; which paired comparison tests revealed was due to a significant inversion effect for adult but not infant faces. For controls, the expected stimuli-type, and orientation effects were significant. However, unlike with the SRs the interaction was not. Thus, SRs but not controls, showed different inversion effects between adult and infant faces, whereby inversion effect was generated by adult but not infant faces.

Table 10: Results for ANOVAs and t-tests as a function of group and stimuli-type in Experiment 3

		df	*F*	η^2	*t*	*D*	*p*
Mixed ANOVAs 2 (group: GRP) x 2 (stimuli-type: STI) x 2 (orientation: ORT)							
Hits							
	Orientation	1,41	52.61	.56			<.001
	Interaction (GRP, ORT)	1,41	5.86	.13			.020
Follow-up paired t-tests (Orientation: ORT)							
	SRs	23			7.24	2.60*	<.001
	Controls	18			3.26	2.45*	.004
CRs							
	Stimuli-type	1,41	18.44	.31			<.001
	Orientation	1,41	21.47	.34			<.001
	Interaction (3-way)	1,41	7.81	.16			.008
Follow-up ANOVAs (Stimuli-type: STI, Orientation: ORT) by Group							
SRs	Stimuli-type	1,23	8.32	.27			<.05
	Orientation	1,23	4.81	.17			<.1
	Interaction	1,23	6.67	.23			<.05
Paired comparisons (Orientation: ORT)							
	Adult face	23			3.41	0.71*	.002
	Infant face	23			0.85	0.18*	>.2
Controls	Stimuli-type	1,18	10.26	.36			<.05
	Orientation	1,18	30.43	.63			<.05
	Interaction	1,18	2.12	.11			>.2
d/							
	Group	1,41	7.48	.15			.009
	Stimuli-type	1,41	5.60	.23			.023
	Orientation	1,41	62.09	.60			<.001
C							
	Stimuli-type	1,41	5.54	.12			.024
	Interaction (GRP, ORT)	1,41	8.40	.17			.006
Follow-up paired t-tests (orientation: ORT)*							
	SRs	23			3.28	0.67*	<.05
	Controls	18			0.83	0.19*	>.2

* *d* for repeated measures (see Morris & DeShon, 2008)

It should be noted that for brevity, no individual analyses are reported for Experiment 3, mainly because similar heterogeneous effects were found as in Experiment 2. However, the more complex design, and subsequently reduced statistical power resulted in far fewer significant individual effects when comparing SRs with the control mean. Indeed, only four (16.7%), two (8.4%), and three (12.6%) SRs out of 24 significantly exceeded the control mean at Upright Face Matching, Inverted Face Matching, and the size of the CAE respectively when evaluating $d^{/}$, and only one SR achieved this on more than one measure. Nevertheless, the authors are happy to supply full data sets for all experiments if requested.

Results summary

- Upright face matching was more accurate than inverted face matching (hits, CR, $d^{/}$)
- Adult face matching was more accurate than infant face matching (CRs, $d^{/}$, C)
- SRs and controls demonstrated CAE of similar magnitude (CRs, $d^{/}$, and C)
- SRs demonstrated greater inversion effects than controls (hits)
- Unlike controls who generated inversion effects for both stimuli type, SRs demonstrated an inversion effect for adult, but not infant faces (CRs)

3.4. Discussion

In Experiment 3, which employed a sequential matching design, as expected, SRs outperformed controls ($d^{/}$ only), upright faces were better matched than inverted faces (hits, CRs, d/) (see also Yin, 1969), and adult faces better matched than infant faces (CRs and $d^{/}$ only) (see also Kuefner et al., 2008), although not all effects on all outcome measures were significant. Furthermore, there was also evidence for the expected stronger Inversion Effect in SRs than controls, but only when evaluating correct identifications (hits), albeit this was driven by a conservative response bias against responding 'same' to inverted faces.

Nevertheless, unlike with the recognition tests employed in Experiment 1 and 2, there was no evidence that SRs displayed stronger CAE than controls. This may be a consequence of the brief presentation of face stimuli in Experiment 3's sequential matching paradigm reducing the influence of the CAE. Indeed, it is possible that the employment of a simultaneous matching paradigm, with longer stimulus presentation times would replicate the findings from Experiments 1 and 2. Furthermore, in applied contexts, such matching tasks are likely to involve longer viewing times. Thus the scope of this study does not allow us to conclude that SRs' CAE is greater only at the level of recognition, but not perception.

Importantly, when evaluating CRs or correct 'different' responses, there was evidence that the Cross-Age Inversion Effect was significantly stronger for SRs than controls. These effects were revealed when examining the t-tests directly comparing these effects reported in Table C1 (Appendix C), as well as the ANOVA in which SRs but not controls displayed a significant 3-way interaction between orientation and stimuli-type. This suggests that SRs showed greater inversion effects for adult faces than for infant faces (correct rejections), potentially implying that there is a reduced influence from holistic processing on SRs' correct decisions when sequentially presented infant faces are mismatched.

4. General Discussion

The three experiments reported in this paper were designed to enhance understanding of the nature of super-recognition (SR) by examining the impact of the *cross age effect (CAE)* using adult and infant facial stimuli. As predicted from previous CAE research (e.g., Macchi Cassia, Picozzi, et al., 2009; Macchi Cassia, Kuefner et al., 2009), and implicating the role of minimal exposure to infant faces, across all experiments, participants recognised adult faces more accurately than infant faces; while SRs outperformed controls at adult *and* infant face recognition; the latter providing the first evidence that SRs' abilities transfer to rarely encountered, perceptually homogenous faces (Kuefner et al., 2008). Indeed, one SR (KH) possessing extensive exposure to infant faces in the workplace was fortuitously recruited to Experiment 2. Although other SRs scored higher at infant recognition than KH (n = 2 out of 20: 10%), KH was the only SR to display a negative CAE effect, as sensitivity scores (d') were higher to infant than adult faces, an expected result given experience with other-age faces may drive the CAE (Macchi Cassia, Picozzi et al., 2009). This is an important observation as it proposes forensic applications for SRs with specific expertise to contribute to police units where identification of children is important (e.g., videoed sex abuse victims).

The size of SRs' CAE was larger than that of controls in Experiments 1 and 2, suggesting that a component of SRs' superior recognition may be enhanced exposure to adult faces. Indeed, similar associations have been made between face recognition ability and face exposure (see Balas & Saville, 2015), and with extroversion (Li et al., 2010), suggesting greater sociability in those with better ability (Lander & Poyarekar, 2015; Megreya & Bindemann, 2013). If SRs interact with more people, then this factor could potentially contribute to SRs' enhanced adult face recognition and CAE.

As has been found previously, individual analyses revealed large SR performance variations on each test in Experiment 2 (and Experiment 3 although results are not reported here). It is important to recognise that this may be a consequence of a multitude of factors nothing to do with face processing ability (environmental distractions, attention, concentration, fatigue), as well as the very brief encoding phase exposure time (2-seconds) not allowing enough time for some SRs to familiarise themselves to faces. However, the results are consistent with a growing body of research suggesting that the label SR is a convenient umbrella term for individuals possessing heterogeneous superior skills, but who may draw on different cognitive mechanisms or processes.

While sensitivity index analyses revealed that SRs demonstrated a greater CAE in the two recognition based experiments, Experiment 3 demonstrated that SRs and controls generated a CAE of similar magnitude (hits, CRs, d', C). Importantly, SRs' CAE in CRs was accompanied by the expected pattern of inversion effects, whereby adult faces generated a greater inversion effect than infant faces. Thus in line with predictions, SRs' performance for infant faces may have suffered owing to a reduced holistic processing of infant faces (e.g., Kuefner et al., 2008; Macchi Cassia, Picozzi et al., 2009).

Experiment 2, employing EEG, additionally revealed two electrophysiological correlates associated with the CAE. In line with previous research (e.g., Wiese, Komes et al., 2012), reflecting CAE at the level of N250, this ERP, associated with implicit identity discrimination (e.g., Eimer et al., 2012), peaked earlier for correct recognitions (hits) of adult than infant faces, suggestive of a more effective processing of adult faces (e.g., Eimer et al., 2012; Kaltwasser et al., 2013). Furthermore, P600, an ERP associated with explicit face recognition, was larger in reaction to infant face recognition, relative to adult faces (correct rejections), potentially indicating that infant faces required more processing relative to adult faces (Wiese, Wolff et al., 2013).

This experiment also revealed two important electrophysiological activity findings associated with SRs' face processing superiority. First, amplitudes at P1, the earliest face-related ERP, associated with pictorial encoding and directed attentional resources (e.g., Luck, 2005; Turano et al., 2016), were greater for SRs' hits compared to controls. These findings may reflect early perceptual advantages in this group, which may contribute to the electrophysiological advantages observed later. Indeed, SRs' advantage in face processing was also reflected in greater amplitudes at P600, a component associated with explicit recognition. SRs also displayed greater negative amplitudes for adult than infant faces at N170; an effect not found in controls. Although follow-up analyses were only marginally significant, this may be the first tentative evidence of a proficiency-based electrophysiological association with the CAE effect, and it is recommended that this electrophysiological marker should form the focus of future research.

As with previous research, the *Cambridge Face Memory Test: Extended* (Russell et al., 2009), together with a second verifying old/new adult face recognition test, classified high and 'average' scoring participants to SR and control groups respectively in Experiment 1 and 2, and for inclusion in Experiments 2 and 3, SRs provided anecdotal reports of long term exceptional ability. Most past SR research has used a threshold of CFMT+ of 90 out of 102 for group membership. A higher CFMT+ threshold was used here (93/102), although this was lower than (>95/102) recently proposed criteria by Bobak, Pampoulov et al. (2016). However, virtually identical performance was found in Experiment 1 on all adult and infant face recognition outcomes, when comparing SRs scoring 93-94 (n = 123) with those scoring ≥95 (n = 197), suggesting this alternative threshold had little impact on conclusions.

There are some limitations to this study. Statistical power may be low as a consequence of sample size in Experiments 2 and 3. While the online study was used to partially confirm the reliability of the recognition component of the CAE in SRs (Experiment 2), further research could assess the reliability of the perception/matching aspect of the CAE (Experiment 3). Furthermore, Some SRs and controls were excluded from some analyses due to not providing enough artefact-free trials – a common hazard with EEG research. As such, while the current research easily recruited more than the 10 individuals per group commonly used in EEG studies, when atypical heterogeneous populations are investigated, larger sample sizes than those recruited here, generating a larger number of epochs, might have uncovered stronger effects.

5. Conclusions

Overall, SRs' superiority in face recognition is experience-independent as they outperformed controls on both adult and infant face recognition. They also demonstrated the expected larger cross-age effects (CAE) in Experiment 1 and 2 when face recognition was tested, but not Experiment 3 using a sequential face matching design. Instead, Experiment 3 revealed larger Inversion Effects and cross-age inversion effects in SRs. Importantly, SRs' superiority in face recognition was complemented by electrophysiological findings which indicated that their recognition advantage may be reflected in more effective pictorial processing (P1) of faces they have seen before, potentially, but not necessarily, contributing to their more effective explicit recognition (P600). Although most participants demonstrated better adult than infant face recognition ability, in Experiment 2, one SR (KH), with extensive experience of infant faces at their workplace, showed equally superior performance on adult and infant faces. The results of these experiments have important theoretical implications to the study of face recognition. They also have worldwide practical applications in terms of the potential deployment of SRs in security and policing, as their superior recognition performances with even infant faces they have very little experience with, suggests their enhanced skills may be suitable for roles involving the identification of children of all ages.

Declaration of Conflicting Interests

The authors declare that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Appendix

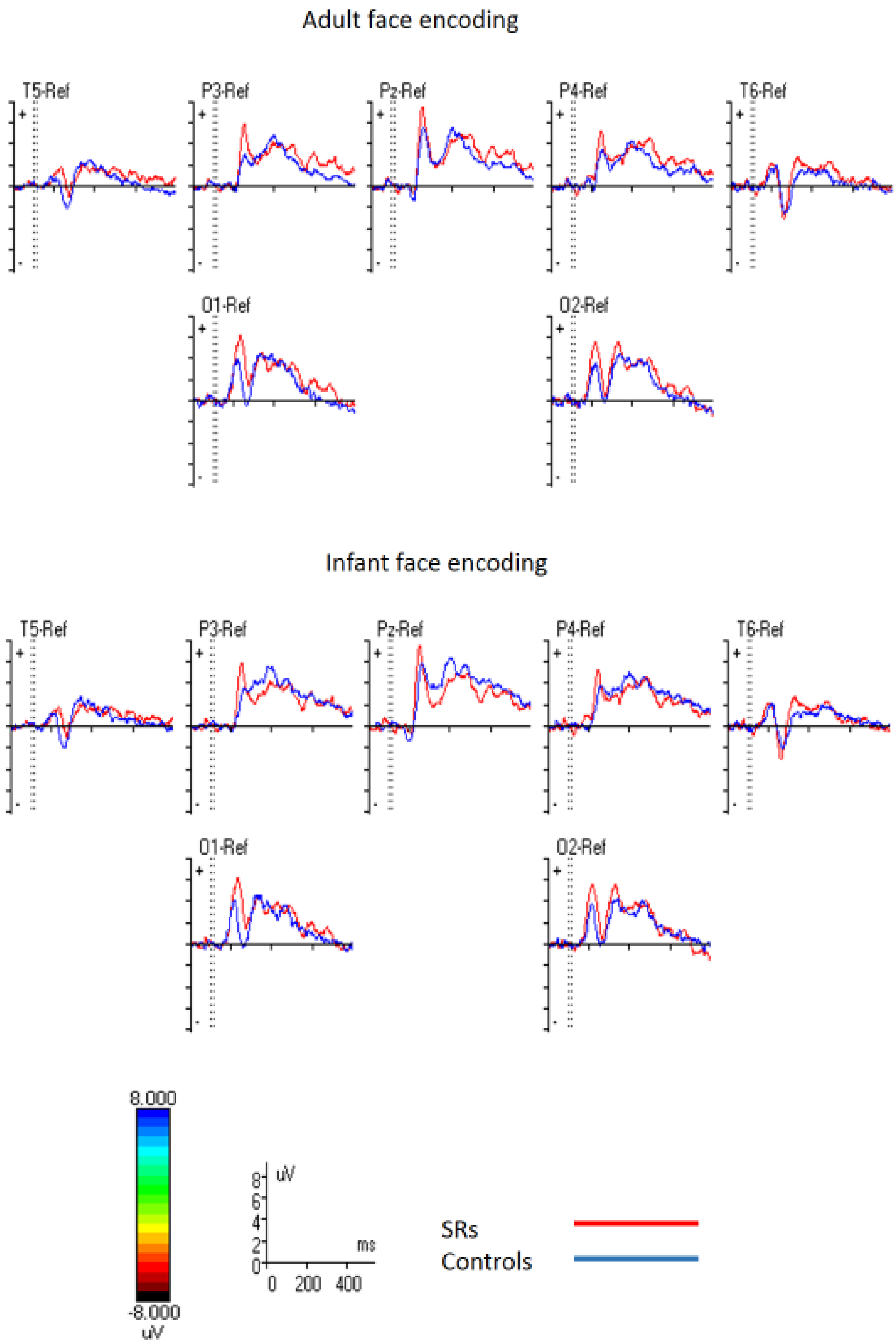

Figure A1. *Average amplitudes during adult and infant face encoding in SRs and controls. Encoding analyses were only performed on channels O1/O2 and T5/T6.*

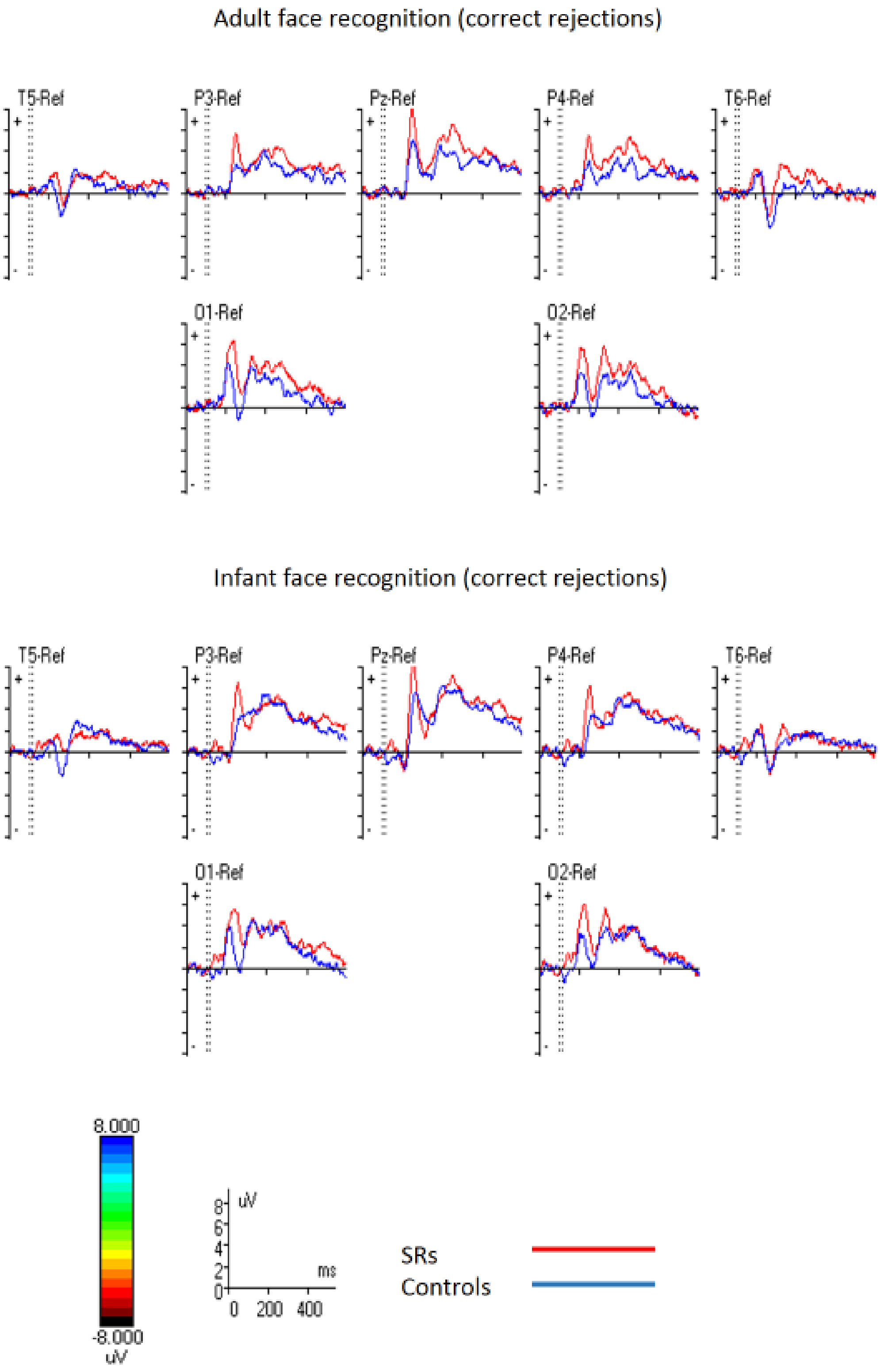

Figure A2. Average amplitudes during adult and infant face recognition (Correct rejections) in SRs and controls.