

Visual Attention and Cardiac Response to Faces in Relation to Emotion Recognition

Sapir Soker-Elimaliah^{1,2,3}, Alexis Rajpersaud², Sabrina Bragerton-Nasert², Dolav Soker⁴, and Jennifer B. Wagner^{1,2}

¹Department of Psychology, The Graduate Center, City University of New York, New York, NY, USA

²Department of Psychology, College of Staten Island, City University of New York, Staten Island, NY, USA

³Mrs. T. H. Chan Division of Occupational Science and Occupational Therapy, University of Southern California, Los Angeles, CA, USA

⁴Department of Computer Science, Ben-Gurion University of the Negev, Be'er Sheva, Israel

Abstract: Rapid and accurate emotion recognition is a crucial skill for social interactions, and visual attention to informative social cues in the environment can facilitate emotion recognition. Studies have found that emotion recognition is also associated with underlying cardiac autonomic responses. The current study examined (1) visual attention and cardiac response (change in heart rate) to emotionally-expressive faces and houses (as a nonsocial control image), and (2) associations between these responses and emotion recognition on the Reading the Mind in the Eyes Test (RMET) in college students. Results showed increased overall attention, but shorter first fixation durations, to faces as compared to houses. Across faces, attention was greater to eyes than mouth, but the magnitude of this difference was dependent on emotion. Analysis of cardiac responses revealed greater heart rate deceleration to happy and fearful faces as compared to neutral faces and houses. Better emotion recognition accuracy on the RMET was related to greater attention to faces, and eyes specifically, as well as greater heart rate deceleration to faces relative to houses. No relations between visual attention and cardiac response were found. The current work points to variations in visual attention and cardiac response while viewing emotional faces that can be markers of emotion processing ability.

Keywords: face processing, emotion recognition, heart rate, eye-tracking

Emotional stimuli are highly informative (Calvo & Lang, 2004; Lemerise & Arsenio, 2000), and facial expressions provide particularly salient socio-emotional nonverbal cues with rich social information when identified correctly. Faces are a unique stimulus with clear neurophysiological processing pathways, and face processing is specifically linked to social behaviors (for a review see Freiwald et al., 2016). Rapid identification and inference of emotions can promote appropriate social responses (Vuilleumier & Pourtois, 2007), that in turn facilitate social interaction (Izard, 1971; Mueser et al., 1996; Saarni, 1999) and support the development of social competence (Garner & Waajid, 2012; Kats-Gold et al., 2007). During social interactions, the process of coding cues, interpreting them, and selecting an appropriate response from an individual's behavioral repertoire happens frequently and should be both quick and accurate. Coding the relevant social cues has been posited to require attentional resources (Crick & Dodge, 1994; Dodge et al., 1986; Eimer et al., 2003), though there are mixed findings regarding the role of attention in emotion recognition, with some studies finding that little to no attentional resources

are needed to code emotional faces and others finding evidence that encoding emotions from faces is an attentionally demanding task (e.g., for a review, see Taylor & Fragopanagos, 2005). Studies that have used eye-tracking to examine gaze shifting as a behavioral marker of attention show differences in visual attention to social stimuli compared with nonsocial stimuli in both children and adults (e.g., Fletcher-Watson et al., 2008; Kikuchi et al., 2009; Ro et al., 2001; Slessor et al., 2016). Different patterns of visual attention to faces are also related to differences in emotion processing and emotion recognition (Hoffman, 1998). For example, visual attention to faces varies as a function of emotion, with more attention allocated to faces that depict fear than happy or neutral faces across development (e.g., Bannerman et al., 2009; for a review, see Vaish et al., 2008). Further, the emotion being viewed has been found to effect attention to core facial features, such as eyes and mouth, with more attention allocated to eyes for fearful faces and more attention allocated to mouth for happy faces reported in studies from infancy through adulthood (Johnels et al., 2017; Wagner et al., 2013; Wagner et al.,

2016). Studies that examined the relationship between attention to core features of faces and emotion recognition have found that greater attention to eyes is associated with faster recognition of fearful faces (Bal et al., 2010) and faster electrophysiological responses in face-sensitive components (Wagner et al., 2013).

Emotion processing has also been studied alongside physiological measures (e.g., Gaebler et al., 2013; Spapé et al., 2017; Yang et al., 2007), and many studies have been focused on the relationships between emotion processing and cardiac autonomic activity (e.g., Bradley et al., 2008; Buss et al., 2005; Herbert et al., 2010). Recent studies suggest that emotions are the result of multiple processes, including cognition, experience, behaviors, and physiology (for a review, see Lench et al., 2011). Other studies suggest that emotions involve patterns of peripheral autonomic activity that allow for the selection of a particular behavior in response to stimuli (for reviews, see Coppin & Sander, 2021; Critchley & Nagai, 2012; Keltner et al., 2019; Kreibig, 2010). For example, Harrison et al. (2010) showed that disgust elicited different physiological responses, measured through brain imaging and cardiac activity, as a function of the stimulus viewed.

The autonomic nervous system (ANS) regulates bodily responses, such as respiration and perspiration, and prepares the body to react appropriately to the environment. Heart rate (HR) is an indicator of autonomic activity and stimulus processing, and fluctuations in heart rate in response to emotionally charged stimuli can be described as part of a two-stage process (e.g., Lacey & Lacey, 1974). Initially, during the early stages of processing such stimuli, the cardiac response is characterized by deceleration, indicating a focus on orienting and attention, enhancing the organism's readiness for effective responses (e.g., Bradley et al., 2001; Lacey & Lacey, 1974; Messerotti Benvenuti et al., 2020). Subsequently, in the later stages of processing, the cardiac response shifts to acceleration, signifying preparation for action (e.g., Bradley et al., 2001).

Studies have found that changes in HR are dependent on the emotional content of images. For example, in young adults, negatively-valenced images (e.g., an injured dog) have been found to elicit greater HR deceleration compared with positive (e.g., a smiling baby) and neutral (e.g., buttons) images (e.g., Bradley et al., 2001, 2008; Messerotti Benvenuti et al., 2020; Soker-Elimaliah et al., 2020). Further, in adults, HR decelerated more in response to angry faces as compared to neutral, though HR responses to happy faces were not significantly different from either neutral or angry (Kolassa & Miltner, 2006). Related studies examined HR responses in infants to emotional faces and found greater HR deceleration to faces depicting negative emotions compared to positive or neutral faces (e.g., Leppänen et al., 2010; Peltola et al., 2011). Studies have

also examined different markers of cardiac activity (i.e., heart rate variability) in relation to emotional face processing, and more adaptive cardiac responding has been found to be associated with better emotion recognition (e.g., Bulut et al., 2018; Gaebler et al., 2013; Quintana et al., 2012).

In developmental studies, cardiac responses to social stimuli have been found to map onto general patterns of attention. Infant work has examined the relationship between visual attention and cardiac activity and found that longer sustained attention to novel social stimuli (i.e., faces) was associated with a greater decrease in heart rate, which reflects greater attention allocation (e.g., Brez & Colombo, 2012; Colombo et al., 2011; Colombo et al., 2001). Leppänen et al. (2010) examined correlations between heart rate responses during the first 1000 ms of emotional face viewing and subsequent attentional shifting away from the faces in 7-month-olds, and results showed that greater HR deceleration to fearful faces relative to neutral or happy faces predicted less sticky attention to fearful faces relative to the other faces.

While many studies with adults have examined how heart rate deceleration might differ based on the category of images being viewed (e.g., Bradley et al., 2008), to our knowledge no study with adults has explored how heart rate deceleration might directly correlate with more general aspects of attention allocation to social-emotional images, as has been looked at in infancy (e.g., Leppänen et al., 2010). This is an important area to consider, as it is possible that attention and physiological responses might interact in identifying and interpreting emotions; for example, initial attention patterns to a salient stimulus could lead to physiological responses that prepare the body to react appropriately, then, in turn, these might guide the subsequent allocation of attention (e.g., see Bradley & Lang, 2000).

The current study expands on past work to examine visual attention and heart rate responses to emotionally-expressive faces and houses (as a nonsocial control image) as they relate to emotion recognition in college students. The first aim of this work was to replicate findings in adults regarding differences in attention allocation to social compared to nonsocial stimuli. If faces, as social stimuli, are more salient than nonsocial stimuli (e.g., Ro et al., 2001), we expect participants to allocate more attention to faces overall and to have more visual exploration behaviors to faces than to houses, and we also expect attention allocation to core facial features to differ as a function of emotion (e.g., greater attention allocation to eyes for fearful faces and to mouth for happy faces; Johnels et al., 2017). The second aim of this study was to extend previous findings examining how visual attention and heart rate deceleration to faces might relate to emotion recognition (e.g., Bal et al., 2010; Van Hecke et al., 2009; Quintana et al., 2012).

The third and final aim of the present study was to explore the relationship between visual attention and heart rate deceleration, asking (a) whether greater differentiation between social and nonsocial images in visual attention is related to greater differentiation of social and nonsocial images in cardiac responses and (b) how greater social biases in attention and heart rate responses (i.e., more attention allocation and greater heart rate deceleration to social stimuli as compared to nonsocial stimuli) might relate to better emotion recognition. We expected that increased social bias in attention would be related to increased social bias in cardiac response, and that both would be related to better emotion recognition.

Method

Participants

A power analysis was conducted using G*Power (version 3.1.9.7; Faul et al., 2007, 2009) to compute the required sample size. Based on past work examining related questions, a power level was calculated and determined to be .8 (e.g., Bradley et al., 2008; Hunnius et al., 2011; Kolassa & Miltner, 2006). The effect size was calculated based on means and determined to be .42, and the suggested sample size was calculated at 66 participants. A total of 80 participants were recruited for the current study to ensure comparable statistical power given potential exclusions.

The final sample consisted of 75 participants (45 female, 30 male), with a mean age of 19.49 years ($SD = 1.97$) from the College of Staten Island (CSI), City University of New York (CUNY). These 75 participants were part of a larger study with a battery of visual attention tasks (see Soker-Elimaliah et al., 2020). Participants were Psychology students taking an introductory course at CSI (PSY 100) who were recruited through an online system that listed available research including the current study. Participants received credit for their time in the lab completing the current study. Participation was voluntary, and participants could stop or withdraw from participation at any point and still receive credit for their time with no further consequences. All procedures were approved by the CSI/CUNY Institutional Review Board.

Of the original sample size of 80 participants, two participants did not contribute eye-tracking and cardiac data due to technical issues with recording the data (due to signal loss and calibration failure) and were therefore excluded from analysis. Three additional participants were excluded from subsequent analyses because they fell more than 3 SD above the mean for age, which has been found to have significant influences on cardiac activity (e.g., Heathers, 2014; see Statistical Analysis).

Demographic information showed that, of participants who reported their ethnicity information ($n = 73$), 23.3% self-identified as Hispanic or Latino ($n = 17$), and 76.7% self-identified as not Hispanic or Latino ($n = 56$); of participants who reported their racial information ($n = 74$), 37.8% self-identified as Caucasian ($n = 28$), 18.9% self-identified as African American ($n = 14$), 9.5% self-identified as Asian ($n = 7$), 4.1% self-identified as American Indian or Alaskan Native ($n = 3$), 2.7% self-identified as Native Hawaiian or Pacific Islander ($n = 2$), and 27% self-identified as multi-racial or other ($n = 20$).

Procedure

Participants completed the consent process in which all tasks and measures were explained and questions about the study were answered. Minor deception was used during consent to tell participants that this study would examine factors that influence memory for images and that they would be receiving a memory test at the end of the testing session. This was done to help ensure that participants were not influenced to view the images based on knowledge of participating in a study examining their social and emotional processing. After signing the consent form, participants were seated in the experimental testing room.

Experimenters attached three disposable electrodes to the participant (Biopac EL503 electrodes with Gel100 electrode gel for improved conductance) in lead 2 configuration (e.g., Berntson et al., 2007), with sensors on the right and left lateral portion of the clavicles (i.e., collar bones) and over the lower left ribcage, and this allowed for the recording of cardiac data. A respiration belt was also wrapped around the participants' chest in order to record respiration frequency. ECG and respiration were recorded using a Biopac MP150WSW system (Biopac Systems, Inc., Santa Barbara, CA) with a RSPEC-R BioNomadix Receiver and wireless transmitters at a sampling rate of 2 kHz. Data were filtered at acquisition, with a 1 Hz high pass filter and a 35 Hz low pass filter. After electrode placement and setup, the data recording was visually inspected to ensure that heart beats were successfully registered in the data collection software, Biopac AcqKnowledge (Version 4.4, Biopac Systems, Inc., Santa Barbara, CA), before the study began. Participants were seated in front of a SensoMotoric Instruments (SMI) RED 120 Hz eye-tracker in a dimly lit room with a partition between them and the researchers. The lights were turned off on the participant side of the partition during the entire duration of the experiment. A 5-point calibration routine with four validation points was used to ensure successful capture of participant gaze. As part of a battery of tasks (including heartbeat perception and an emotionally-valenced image viewing task; see Soker-Elimaliah et al., 2020), participants were presented with

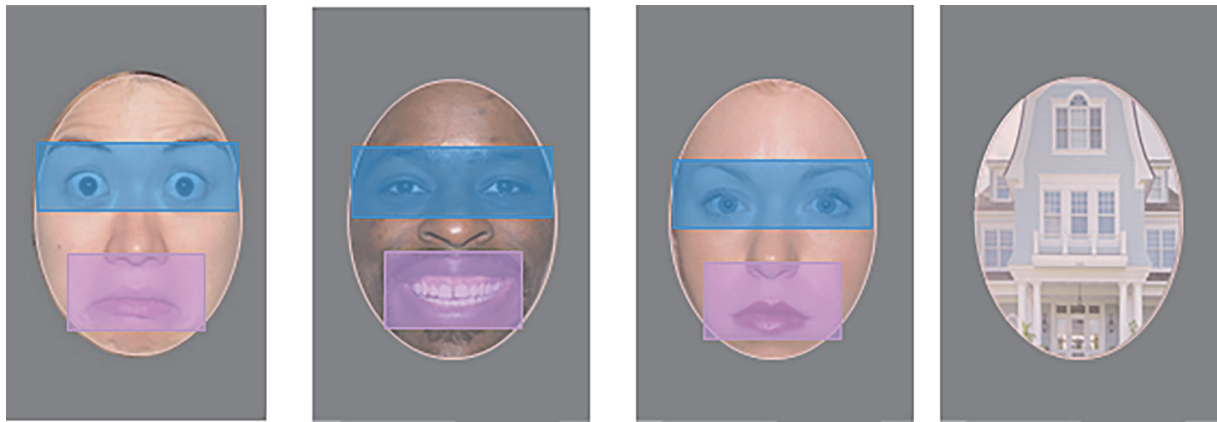


Figure 1. Sample stimuli displaying areas of interest (AOIs) used in the current study (from left to right: fearful, happy, neutral, house). AOIs were drawn for the face, eyes area, and mouth area for each emotional face, and a single AOI was drawn for houses that was equal in size to the face AOI.

48 images that included 24 faces and 24 houses for three seconds per image, with inter-trial intervals (ITI) ranging from 5.6 to 7 s to prevent anticipatory physiological responses. Participants were instructed to look to the center of the screen between trials, and after the experimenter confirmed attention following the ITI, the next image was presented. Face images were taken from the NimStim database (Tottenham et al., 2009) and included 8 fearful faces, 8 happy faces, and 8 neutral faces that were gender balanced and racially diverse. Based on past work, houses (obtained from a Google image search) were used as a neutral nonsocial stimulus (e.g., Kanwisher et al., 1997; Wagner et al., 2013), as they are stimuli with high complexity and a certain level of familiarity. Images were presented in a semi-randomized order, such that every block of six images included three images of houses and three images of faces (one of each emotion), with every pair of stimuli containing one house and one face. Participants viewed one image at a time, with a gray background (see Figure 1). After completing the experimental tasks, all sensors were removed and participants completed a series of self-report questionnaires, including demographics and brief health information as well as the RMET to assess emotion recognition. Participants were then told there would be no memory test and were debriefed about the true goals of the study.

Questionnaire Measures

Demographics and Health Information

A questionnaire gathering demographic information and assessing variables that could influence cardiac responses was given to participants (see Heathers, 2014, and Quintana & Heathers, 2014). In addition to age, ethnicity, and race, questions assessed height and weight (for calculation of body mass index, or BMI), exercise frequency, caffeine

intake before the study, smoking habits, diagnosis of cardiovascular disease, and medication use for depression or anxiety.

Emotion Recognition

The Reading the Mind in the Eyes Test (RMET; Baron-Cohen et al., 2001) was used to measure emotion recognition. Participants completed a paper-and-pencil version of the RMET in a room without distractions. They were presented with 36 pictures of eyes (one at a time), each with four choices of mental states, from which they were instructed to select the emotion they thought best described each set of eyes.

Data Processing

Eye-Tracking

For each face stimulus, areas of interest (AOIs) were defined for three regions, the face, eyes, and mouth, and the AOI size for each region was held constant across the three emotions. For house stimuli, one AOI that was identical in size to the face AOI was defined that included the full house image (see Figure 1 for sample face and house stimuli with AOIs drawn). Studies utilizing eye-tracking to study emotional face processing in adults have typically focused on overall attention metrics (e.g., Ebner et al., 2011; Wagner et al., 2013), however, work with children and adults has found that fixation metrics can provide additional valuable information about attention allocation (e.g., Parag & Vakil, 2018; Pishyareh et al., 2012; for a review see Lai et al., 2013). Therefore, for each AOI, eye-tracking data were exported for both total dwell time, a measure of overall attention, and for first fixation duration, a measure of initial attention. The overall attention metric indicates how much time the participant spent exploring each of

the AOIs, while the initial attention metric indicates to what extent the AOI grabbed the participant's attention. Data were also exported for total number of fixations, however, results with this metric were parallel to findings from total dwell time and therefore are not reported. For face and house stimuli, data were exported for each trial from SMI BeGaze software. Customized Java scripts (available through GitHub repository: <https://github.com/selimaliah/ETDataProcessing>) were run to flag trials with less than 50% gaze data to the face or house AOI (less than 1.5 s out of 3 s), and these trials were excluded from participants' averages. After trial exclusions, participants contributed eye-tracking data from, on average, 23.03 house trials ($SD = 1.98$) and 23.39 face trials ($SD = 1.43$), with an average of 7.77 fearful face trials ($SD = 0.60$), 7.80 happy face trials ($SD = 0.52$), and 7.81 neutral face trials ($SD = 0.56$).

With past work showing differences between attention to eyes and mouth (e.g., Johnels et al., 2017; Wagner et al., 2013; Wagner et al., 2016), an Eyes Bias score was calculated (using eyes and mouth variables averaged across emotions) for use in correlations as well. Based on Merin et al. (2007), Eyes Bias for dwell time was calculated as attention to eyes divided by attention to eyes plus mouth. For first fixation duration, Eyes Bias was calculated by subtracting average first fixation to mouth from average first fixation to eyes.

Heart Rate

Electrocardiography (ECG) data were analyzed in Biopac Acqknowledge (version 4.4) using the "Find Rate" and "Find Cycle" functions to export heart rate, in beats per minute (bpm) for 2 s of baseline (prior to stimulus onset) and for the 3 s of stimulus presentation. Data were manually inspected for artifacts (e.g., missed heartbeats, mislabeled heartbeats, or segments with noisy heart rate due to subject movement that prevented identification of heartbeats), and trials were excluded if an artifact appeared during the 2-s baseline period and/or the 3-s stimulus presentation. Based on past work (e.g., Bradley et al., 2008; Leppänen et al., 2010), change in HR was calculated by subtracting average HR during the baseline period (−2 to 0 s) from average HR during stimulus presentation (0–3 s), and this was averaged for each of the four stimulus categories. Based on the model of Lacey & Lacey (1974), because our stimuli were presented for 3 s, our study focuses on the first stage of cardiac responses to images – orienting and attention allocation.

Two participants were excluded from HR analyses, one due to technical issues that led to failure to record cardiac data, and one due to data that were too noisy to identify cardiac responses. The remaining 73 participants contributed HR data from, on average, 23.30 ($SD = 1.22$) house trials and 23.26 ($SD = 1.58$) face trials, with an average of

7.79 ($SD = 0.60$) fearful face trials, 7.70 ($SD = 0.66$) happy face trials, and 7.77 ($SD = 0.64$) neutral face trials.

Emotion Recognition

Based on previous studies, participants' responses on the RMET were scored as correct or incorrect. Scores were calculated as the proportion of correct answers out of the overall 36 possible RMET trials (e.g., Fertuck et al., 2009). For example, a participant with 26 correct answers was scored as 26/36 and received a score of .72. The mean proportion of correct responses was .69 ($SD = 0.13$, range: .36–.94). The reliability of the RMET in our sample was assessed for internal consistency, and Cronbach's alpha was .75, which is in line with reported alphas in the literature (for a review, see Vellante et al., 2013).

One participant did not complete the RMET due to time constraints and two participants completed less than half of the RMET, and this resulted in 72 participants included in RMET analyses.

Social Bias Scores

For eye-tracking and change in HR metrics, Social Bias scores were calculated for exploratory analyses examining (1) whether increased responding to faces relative to houses in visual attention was related to increased responding to faces relative to houses in cardiac responses, and (2) whether increased Social Bias scores were related to better emotion recognition. The Social Bias scores were calculated as the difference between social and nonsocial responding, with average response to houses (nonsocial stimuli) subtracted from average response to faces (social stimuli; averaged across the three face categories) for total time and first fixation duration, as well as change in HR. For visual attention, greater social bias was reflected by more positive values, and for HR, greater social bias was reflected by more negative values. Social Bias scores were calculated only for participants contributing data for each of the four stimulus categories (see Statistical Analysis for inclusion criteria).

Statistical Analysis

All statistical analyses were conducted using IBM SPSS software (Version 25.0, IBM Corp., Armonk, NY). An initial set of analyses first examined the skew and kurtosis of the variables of interest to confirm the use of parametric testing, and age was also examined, as this variable has been found to influence cardiac activity (e.g., Heathers, 2014; Kuo et al., 1999; O'Brien et al., 1986). For age, when the total sample of participants with eye-tracking or heart rate data collected were included ($n = 78$), the distribution for age was found to be highly skewed (skew of 3.93) and leptokurtic (kurtosis of 16.99), and an examination of outliers

revealed three participants who fell 3 *SD* above the mean. These three age outliers were subsequently excluded from the final sample, leaving 75 participants.

Analyses were then performed for skew and kurtosis for visual attention metrics, change in HR responses, Social Bias scores, and RMET. No evidence was found for skew or kurtosis for HR to the different stimuli (skewness ranged between -0.47 and -0.15 , kurtosis ranged between 0.21 and 1.81) nor for RMET (skewness of -0.55 , kurtosis of -0.18).

Analysis of skew and kurtosis for visual attention variables looked at total dwell time and first fixation duration for each area of interest for each stimulus category (e.g., fearful eyes, neutral mouth, house image). First fixation duration on house images had skewness of 1.38 and kurtosis of 2.62 , which is above the acceptable skew and kurtosis limit values (larger than 2 and smaller than -2 ; George & Mallery, 2016). Additionally, the Social Bias score of first fixation duration was found to have skewness of -1.50 and kurtosis of 3.71 .

Following assessment of skew and kurtosis, all variables were then checked for outliers, and participants who had data falling at least 3 *SD* outside the mean were eliminated for that variable. Elimination of outlier values per variable allowed inclusion of participants in a subset of analyses even if they were excluded from one or more other analyses (e.g., a participant with outlier data only for first fixation duration to fearful mouth could be included in analyses for total dwell time, first fixation duration to overall image, change in HR, and RMET). No outlier values were found for RMET. For eye-tracking variables, after removing outliers, one participant was excluded from analyses of total dwell time to the eyes versus mouth (and total dwell time Eyes Bias) and five participants were excluded from analyses of first fixation to the eyes versus mouth (and first fixation Eyes Bias), with one of these five also excluded from analyses of first fixation duration to the overall image (and therefore also the Social Bias score for first fixation duration). An additional participant was excluded as an outlier for total dwell time Social Bias score based on the calculated mean of this variable. Lastly, five participants were excluded from analyses using change in HR (including Social Bias scores for HR), due to an outlier variable in at least one of the four stimulus categories. Table 1 shows mean, standard deviation, skew, and kurtosis values for variables after the exclusion of outlier values.

Because past work has found gender differences in cardiac activity (Agelink et al., 2001; Rossy & Thayer, 1998) and visual attention to faces (Sargezeh et al., 2019), and because mixed results have been found regarding gender differences in RMET (for a review see Kirkland et al., 2013), preliminary analyses also examined gender effects in the current sample for change in HR, visual attention

measures, and emotion recognition on the RMET. Male and female participants did not significantly differ on visual attention measures ($ps > .11$, $ds < .39$), or RMET ($p = .61$, $d = .12$; see similar findings by Hoffmann et al., 2010). Change in HR, averaged across all stimuli, did significantly differ by gender, with male participants showing overall greater HR deceleration ($M = -1.03$, $SD = 0.76$) than females ($M = -.42$, $SD = 1.01$; $t(71) = -2.80$, $p = .007$, $d = .68$). Based on this group difference, gender was included as a factor in subsequent analyses that examined effects of stimulus on change in HR.

To examine the effects of stimulus (house, fearful face, happy face, neutral face) on total dwell time and first fixation duration, repeated-measures ANOVAs were conducted with stimulus as the only factor. Next, patterns of visual attention to the eyes and mouth while viewing emotional faces were examined for each eye-tracking variable using a 3 (Emotion: fearful, happy, neutral) $\times 2$ (AOI: mouth, eyes) repeated-measures ANOVA. A set of correlations was then conducted between RMET accuracy and visual attention metrics (total dwell time and first fixation duration), including attention to faces and Eyes Bias averaged across emotion (social category), and attention to houses (nonsocial category).

A repeated-measures ANOVA was also used to examine the effect of stimulus (house, fearful face, happy face, neutral face) on heart rate deceleration. Based on preliminary analyses above, gender was included as a between-subjects factor. A series of correlations were then conducted to examine RMET accuracy in relation to average change in HR to faces across emotion (social category) and average change in HR to houses (nonsocial category).

Finally, a set of exploratory correlational analyses examined the relationship between Social Bias scores for visual attention and cardiac responses, as well as between these Social Bias scores and emotion recognition.

Results

Visual Attention

Attention to Faces Versus Houses

Repeated-measures ANOVAs were conducted to examine the effects of stimulus (house, fearful face, happy face, neutral face) on total dwell time and first fixation duration. For both analyses, a main effect of stimulus was found ($F_s > 23.45$, $ps < .001$, $\eta_p^2 > .24$; see Figures 2a and 2b). For total dwell time, pairwise comparisons showed significantly less attention allocated to houses than each of the three faces ($ps < .001$, $ds > .56$), but the three faces did not differ from each other ($ps > .32$, $ds < .12$; see Table 1 for descriptive

Table 1. Sample means (SDs) of visual attention metrics and change in heart rate

	House	Fearful	Happy	Neutral	Summary
Total Dwell Time					
Overall Image					
Mean (SD)	2762.48 (144.88)	2856.71 (116.06)	2843.75 (131.59)	2850.68 (118.30)	Fearful = Neutral = Happy > House
Skew; Kurtosis	−0.44; −0.75	−0.78; −0.03	−0.92; 0.37	−0.56; −0.87	
Eyes					
Mean (SD)		1737.79 (357.90)	1645.19 (356.65)	1905.67 (365.55)	Neutral > Fearful > Happy
Skew; Kurtosis		−0.21; −0.45	−0.31; 0.31	−0.26; 0.05	
Mouth					
Mean (SD)		462.57 (185.59)	666.26 (254.01)	446.83 (212.79)	Happy > Fearful, Neutral; Fearful = Neutral
Skew; Kurtosis		0.01; −0.81	0.07; −0.05	0.53; 0.19	
First Fixation Duration					
Overall Image					
Mean (SD)	362.42 (107.29)	317.78 (80.34)	283.79 (63.51)	295.31 (69.41)	House > Fearful > Happy > Neutral
Skew; Kurtosis	1.38; 2.62	0.55; 0.09	0.96; 0.92	1.13; 1.86	
Eyes					
Mean (SD)		283.15 (76.58)	265.97 (66.25)	273.41 (64.20)	Fearful > Happy; Neutral = Fearful, Happy
Skew; Kurtosis		0.91; 1.23	0.53; 0.20	0.63; 0.60	
Mouth					
Mean (SD)		200.48 (82.63)	254.40 (92.39)	196.83 (83.60)	Happy > Fearful, Neutral; Fearful = Neutral
Skew; Kurtosis		0.54; 0.56	0.09; 0.43	0.01; −0.63	
HR Change from Baseline					
Mean (SD)	−0.38 (1.16)	−0.96 (1.16)	−1.00 (1.77)	−0.30 (1.67)	Happy < Neutral < House; Happy = Fearful
Skew; Kurtosis	−0.30; 1.81	−0.19; 0.21	−0.47; 0.30	−0.15; 1.01	

Note: HR = Heart Rate; Reported means, standard deviations, skeweness, and kurtosis are after outliers exclusion. Summary based on paired sample *t*-tests with differences indicating $p < .05$.

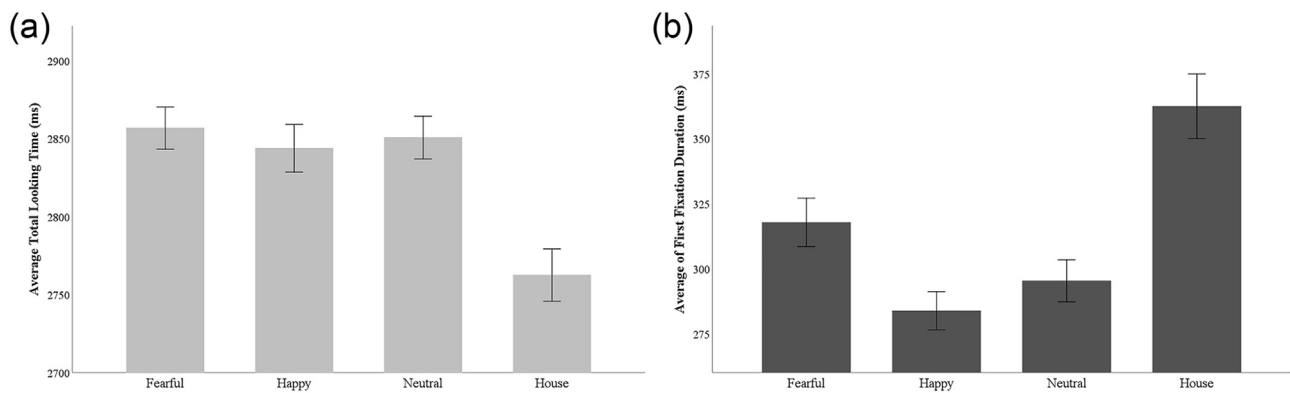


Figure 2. (a) Average total dwell time on faces and houses. A main effect of stimulus was found ($p < .001$), with significantly less attention allocated to houses than each of the three faces ($ps < .001$), but the three faces did not differ from each other ($ps > .32$). (b) Average first fixation duration on faces and houses. A main effect of stimulus was found ($p < .001$), with significantly longer durations to houses than each of the three faces ($ps < .001$). The first fixation duration for fearful faces was significantly longer than for happy and neutral faces ($ps < .01$), though happy and neutral faces did not differ ($p = .15$). Error bars reflect $\pm$ SEM.

statistics). For first fixation duration, pairwise comparisons showed significantly longer durations to houses than each of the three faces ($ps < .001$, $ds > .48$). Further, first fixation duration for fearful faces was significantly longer than for

happy faces ($t(73) = 3.81$, $p < .001$, $d = .47$) and neutral faces ($t(73) = 2.75$, $p = .008$, $d = .30$), though neutral and happy faces did not significantly differ from each other ($p = .15$, $d = .17$; see Table 1).

Attention to Emotional Faces

To examine patterns of attention to the eyes and mouth while viewing emotional faces, two 3 (Emotion: fearful, happy, neutral) $\times$ 2 (AOI: mouth, eyes) repeated-measures ANOVAs were conducted. For total dwell time, a significant main effect of emotion was found ($F(2, 146) = 16.89, p < .001, \eta_p^2 = .19$), showing shorter looking time on core features for fearful faces than happy and neutral faces ($ps < .001$), but neutral and happy faces were not significantly different from each other ($p = .15$). A significant main effect of AOI was also found ($F(1, 73) = 551.98, p < .001, \eta_p^2 = .88$), with greater attention to eyes. Additionally, a significant interaction between emotion and AOI was found for total dwell time ($F(2, 146) = 48.43, p < .001, \eta_p^2 = .40$). Follow-up t -tests showed that for eyes, more time was spent on neutral eyes than fearful ($t(74) = -5.75, p < .001, d = .47$) and happy ($t(74) = -8.14, p < .001, d = .73$). Total time spent on fearful eyes was also significantly longer than happy eyes ($t(74) = 3.21, p = .002, d = .26$). For mouth, total time spent on happy mouth was significantly greater than fearful ($t(73) = -8.25, p < .001, d = .90$) and neutral ($t(74) = 7.71, p < .001, d = .94$), but total time spent on fearful mouth did not significantly differ from neutral mouth ($p = .27, d = .12$; see Table 1).

The ANOVA examining first fixation duration also found a main effect of emotion ($F(2, 138) = 4.46, p = .015, \eta_p^2 = .06$), with longer first fixation durations when examining core features of happy faces than fearful and neutral faces ($ps < .18$), however, fearful and neutral faces did not significantly differ ($p = .58$). A main effect of AOI was again found ($F(1, 69) = 37.79, p < .001, \eta_p^2 = .35$), with longer first fixation durations to the eyes than the mouth. The interaction between emotion and AOI was also significant ($F(2, 138) = 15.72, p < .001, \eta_p^2 = .19$). Follow-up t -tests revealed that, for eyes, first fixation durations were significantly longer while viewing fearful eyes as compared to happy eyes ($t(73) = 2.184, p = .032, d = .27$), but neutral eyes did not differ from the other emotions ($ps > .17, ds < .19$). For mouth, longer first fixation durations were seen when viewing happy faces as compared to fearful ($t(73) = -4.69, p < .001, d = .60$) and neutral faces ($t(72) = 4.70, p < .001, d = .64$), but fearful and neutral faces did not differ ($p = .75, d = .35$; see Table 1).

Relations With Emotion Recognition

A series of correlations was conducted in order to examine relations between emotion recognition on the RMET and six metrics of visual attention: (1) total dwell time on faces, (2) total dwell time on houses, (3) first fixation duration on faces, (4) first fixation duration on houses, (5) Eyes Bias for total dwell time, and (6) Eyes Bias for first fixation duration.

Significant positive correlations were found between RMET score and total dwell time on faces ($r(70) = .27$,

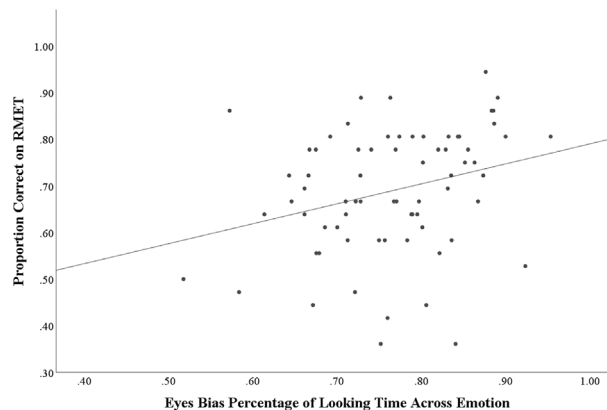


Figure 3. Correlation between Eyes Bias percentage for total dwell time and emotion recognition as measured by the RMET. More time spent on eyes relative to the mouth was correlated with better emotion recognition ($p = .016$).

$p = .024$), and between RMET and Eyes Bias for total dwell time ($r(69) = .28, p = .016$; see Figure 3). RMET was also found to be significantly and positively related to total time spent on houses ($r(70) = .27, p = .023$), suggesting better emotion recognition relates to more attention allocation overall in the current study, including both social and nonsocial stimuli. No significant correlations were found when examining RMET and first fixation duration variables ($rs < .06, ps > .60$).

Cardiac Response to Faces and Houses

Heart Rate

A repeated-measures ANOVA was conducted to examine the effect of stimulus (house, fearful face, happy face, neutral face) on heart rate deceleration, and included gender (male, female) as a between-subjects factor based on preliminary analyses. A main effect of stimulus was found ($F(3,198) = 4.48, p = .007, \eta_p^2 = .06$; see Figure 4), and follow-up t -tests showed that change in HR for happy faces was not significantly different from fearful faces ($t(69) = .32, p = .75, d = .05$), but both were significantly greater (i.e., greater deceleration) than neutral faces ($ps < .03, ds > .33$) and houses ($ps < .014, ds > .36$). Change in HR for neutral faces and for houses was not significantly different ($p > .75$; see Table 1). A main effect of gender was also found ($F(1, 66) = 7.75, p = .007, \eta_p^2 = .10$), with greater HR deceleration in males than in females, but no interaction between stimulus and gender was found ($F(3, 198) = 1.79, p = .16, \eta_p^2 = .03$).

Relations With Emotion Recognition

A series of correlations was conducted in order to examine relations between emotion recognition on the RMET and two metrics of cardiac activity, average change in HR to faces (across emotion) and average change in HR to



Figure 4. Average change in heart rate (HR) to faces (fearful, happy, and neutral) and to images of houses. Heart rate deceleration to happy faces was not significantly different from fearful faces ($p = .75$), but both showed significantly greater negative change as compared to neutral faces and houses ($p < .014$). Error bars reflect $\pm$ SEM.

houses. No significant associations were found between RMET and change in HR to faces ($p = .46$), but a significant positive correlation was found between RMET and HR deceleration to houses ($r(67) = .35, p = .003$), indicating that less HR deceleration (e.g., less physiological responsiveness) to nonsocial stimuli was related to better emotion recognition.

Exploratory Analyses – Relations With Social Bias Scores

An exploratory set of correlations was conducted in order to examine associations between Social Bias scores in visual attention (total looking time and first fixation duration) and Social Bias scores in cardiac response (change in HR), as well as between each of the three Social Bias scores and emotion recognition.

No significant correlations were found between Social Bias scores for visual attention metrics and change in HR ($p > .20$), nor between Social Bias scores in visual attention and RMET ($p > .22$). A significant negative correlation was found, however, between Social Bias score for change in HR and RMET ($r(63) = -.31, p = .011$; see Figure 5), suggesting that greater cardiac responding to social images relative to nonsocial images is associated with better emotion recognition ability.

Discussion

The present study examined visual attention and cardiac response to social and nonsocial stimuli in adults and asked how these responses are associated with emotion recognition. This study expands on past work that focused on either the differences in the allocation of visual attention

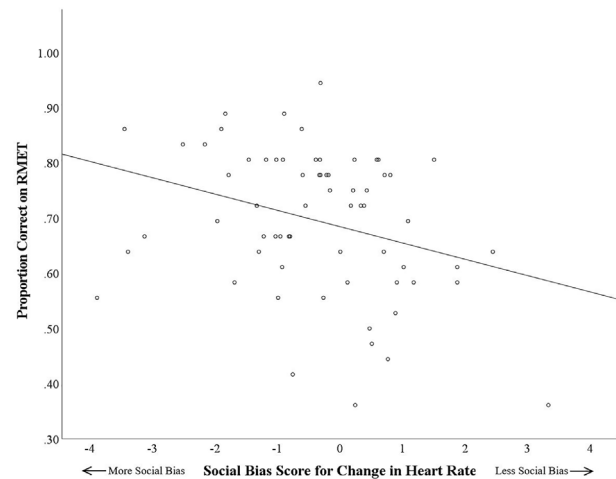


Figure 5. Correlation between Social Bias score for change in HR and emotion recognition as measured by the RMET. Greater HR deceleration to faces relative to houses was associated with better emotion recognition ability ($r(63) = -.31, p = .011$).

or in cardiac response while viewing emotionally-expressive faces (e.g., Bannerman et al., 2009, Kolassa & Miltner, 2006, respectively), to examine attentional and cardiac responses in a single group of participants alongside emotion recognition. The main findings of the current study were: (1) more attention was allocated to social (faces) than nonsocial stimuli (houses), (2) within social stimuli, more time and longer first fixations were allocated to the eye region than to the mouth, and these attentional patterns varied based on the emotion viewed, (3) HR deceleration to happy and fearful faces was greater than to neutral faces and houses, (4) better emotion recognition was correlated with more time attending to faces, less HR deceleration to nonsocial stimuli, and greater Social Bias in HR deceleration, and (5) no relations were found between visual attention metrics and HR for biases to social stimuli relative to nonsocial stimuli.

With regards to visual attention, analyses revealed that even in a passive viewing context, attention is biased towards social stimuli compared to nonsocial stimuli in adults. Total dwell time analyses revealed that participants spent more time looking at faces than houses, and first fixation duration revealed longer first fixation durations to houses than faces. Work by McPartland et al. (2011) examined visual attention patterns measured by total fixation duration and proportion of fixation counts to faces and objects in adults and found similar patterns, with more visual attention allocated to faces compared with objects in adults. More overall time on faces along with shorter first fixation durations suggests greater engagement and more exploratory eye movements during social stimuli as compared with nonsocial stimuli.

When looking at differences in attention between the three emotional faces, total time did not differ; however,

first fixation duration to fearful faces was longer than to happy and neutral faces. This finding is consistent with past work across development that finds attentional capture in response to fearful faces, illustrated in many studies by a difficulty disengaging attention from these stimuli (e.g., Holmes et al., 2005; Peltola et al., 2008), a response that could reflect the evolutionary importance of this type of salient and informative cue (for a review, see Leppänen & Nelson, 2012).

Further examination of attention to the eyes and mouth while viewing faces revealed that participants allocated more time and longer first fixation durations to eyes than mouth, which is consistent with findings from past work using static images of faces with adults (e.g., Johnels et al., 2017; Rutherford & Towns, 2008). Attention to core features was also found to vary based on the emotion viewed, with, for example, happy faces drawing the most attention to the mouth and the least attention to the eyes for total dwell time (see also Hanawalt, 1944; Ross et al., 2007; Wagner et al., 2013). These findings suggest that different features of the face might be more important depending on the emotion viewed, and that individuals might adjust their attention to parts of the face that might be more informative for emotion processing. In the current study, for first fixation duration, attention to eyes was greater to fearful eyes than to happy eyes, but no differences were seen with neutral eyes. For total time on eyes, while fear was greater than happy, time on neutral eyes was the greatest of all three faces. Future work is needed to better understand how neutral faces are processed as compared to positive and negative emotional faces, as well as why different patterns of visual attention to core facial features might vary based on emotion and how this could facilitate emotion processing and recognition.

Past work that examined HR responses to emotionally-salient images has found greater HR deceleration to negative stimuli as compared to positive or neutral (e.g., Bradley et al., 2008), and some similarities have been found in studies with emotionally-expressive faces (Kolassa & Miltner, 2006; Leppänen et al., 2010). Kolassa and Miltner (2006) found significantly more pronounced HR deceleration to angry faces than to neutral faces, but HR deceleration to angry and happy faces did not differ. Consistent with this, the current study also found more pronounced HR deceleration to fearful faces than neutral faces and houses, and no differences between HR responses to fearful and happy faces. However, unlike Kolassa and Miltner (2006), HR deceleration to happy faces in the current study was also significantly greater than the neutral stimuli presented. Greater HR deceleration is thought to indicate the allocation of greater attentional resources (e.g., for discussion, see Bradley et al., 2008), therefore, our results suggest that in this study, both the happy and fearful faces were

highly salient, requiring more attentional resources as compared to both neutral social stimuli and neutral nonsocial stimuli. More work is needed to understand the different physiological response patterns to different emotionally-salient stimuli and to better understand the unique impact of emotional faces on attentional resources.

The relationship between visual attention during the eye-tracking task and emotion recognition on the RMET was also examined, and results showed that participants who spent more time on faces, particularly in the eye region, were more accurate at recognizing emotional expressions conveyed through the eyes in a separate assessment. This is consistent with developmental work showing that increased attention to eyes relates to faster emotion recognition in children (Bal et al., 2010) and faster neural processing of emotions in adolescents (Wagner et al., 2013). Additionally, participants who spent more time on houses were also more accurate at emotion recognition, suggesting that overall attention in the current task related to successful understanding of emotions. This, however, leaves open questions of whether attention to nonsocial stimuli outside of a socially-relevant task would also show associations with emotion recognition, or whether this relationship was driven by overall interest in the task due to the inclusion of images displaying emotionally-expressive faces.

When looking at cardiac responses in relation to emotion recognition, the current study found associations with change in HR as a response to nonsocial stimuli (houses) and Social Bias score (change in HR to faces relative to houses). This suggests that both lower responsiveness to nonsocial stimuli overall and greater HR response to social as compared to nonsocial stimuli were related to better skill in identifying emotions. Responses to social stimuli overall were not related to emotion recognition, though Social Bias scores indicate prioritization of social stimuli relative to nonsocial stimuli. More work is needed to understand why responses to nonsocial stimuli might be a more informative marker of successful social-emotional processing skill than responses to social stimuli alone.

Finally, the current study also examined potential relations between social biases in visual attention and social biases in HR, but no associations were found. This is especially surprising given that both attentional and cardiac measures showed differences based on the emotion being viewed, and that both visual attention and cardiac activity showed relations with emotion recognition. Infant work has found relations between attention and changes in HR (e.g., Brez & Colombo, 2012; Colombo et al., 2011; Colombo et al., 2001), but the current study suggests that these relations are less clear in adulthood. To better understand the developmental trajectories of these changes in the associations between visual attention and cardiac response, especially for emotionally-salient stimuli, further research is

needed. Past work by Hunnius et al. (2011) examined similarities and differences in attention to faces from infancy through adulthood and found that although infants at 7 months of age might have scanning patterns similar to adults, there are still major differences in visual attention to faces. For example, adults looked less (i.e., shorter time and fewer number of fixations) at threat-related emotional faces than infants. These differences in visual attention to faces between infants and adults might lead to differential relations between social attention and cardiac responses across development and should be further examined.

The current study had several important limitations. First, emotion recognition was measured using a task separate from the image-viewing eye-tracking task. Studies should examine the relationships between visual attention and emotion recognition within a single task, preferably using images of more natural and complex social and nonsocial scenes. Our emotion recognition task was also limited, as it focused only on emotion recognition from the eye region and could be easier for participants who attend more naturally to the eye region as compared to other participants who might have different preferences in scanning emotional faces. With findings that biases in looking to the eyes relative to the mouth were positively related to emotion recognition, future studies should investigate whether this relationship would hold if the emotion recognition task required identification from the whole face or from a different region (e.g., the mouth).

A second limitation was that our social stimuli included 8 trials of each emotional expression, which is fewer than has been used in past work studying heart rate responses, so work with a greater number of trials will help to minimize potential noise in cardiac responding. Furthermore, the emotional stimuli were simple images of faces, which were static and decontextualized. This could reduce the emotional and physiological responses of our participants (for a review see Risko et al., 2016), so in addition to increasing the number of trials, follow-up studies would benefit from the use of naturalistic, more complex, emotional stimuli to examine whether attention patterns and autonomic activity are linked. Moreover, more complex stimuli will allow for the examination of the effects of more general emotional valence (i.e., pleasant or unpleasant) on visual attention and cardiac activity, such as comparing social-emotional, social-neutral, and nonsocial emotional pictures (using stimuli as in Catalano et al., 2021).

Another potential limitation relates to participants being told the current study was focused on memory and that they would be tested for their memory of images viewed later in the testing session. This could have influenced attentional and physiological processing of the images, and their responses may therefore not reflect what would have happened spontaneously during the task. Future

studies would benefit from a more naturalistic viewing context to examine these responses further.

One final limitation to consider is that heart rate, the physiological measurement included in this study, is a marker that can reflect both the parasympathetic and sympathetic branches of the ANS. Future work would benefit from the inclusion of additional ANS measures, such as including measures of parasympathetic activity from cardiac responses (e.g., respiratory sinus arrhythmia; RSA), as these measures have previously been linked to social and emotional processing (e.g., Quintana et al., 2012; for a review, see Kreibitz, 2010; see also Porges, 2003, 2007). For example, the Polyvagal Theory supports this relationship between parasympathetic activity and social interactions and states that better parasympathetic control allows for bodily regulation that supports and promotes social behaviors (Porges, 2003). The measurement of RSA for each stimulus category was not possible based on the current study design (e.g., see Berntson et al., 1997), but future studies with a blocked design, for example, would allow for the examination of this physiological marker.

In summary, the current study looked at visual attention and cardiac response to emotionally-expressive faces and houses and relations to emotion recognition in adults. Findings showed that overall attention to social stimuli (faces) was greater than to nonsocial stimuli (houses), and that face scanning varied depending on the emotion displayed. Cardiac deceleration was also found to be greater to happy and fearful faces as compared to neutral faces and houses. Finally, more overall attention to the face and eyes, less cardiac deceleration to nonsocial images, and greater social bias in cardiac response were all related to better emotion recognition skills, though social biases in visual attention and cardiac response were not related to each other. This work contributes to an understanding of how attention and cardiac responses to relevant emotional cues could play a role in emotion processing. The current study also provides support for using methods that combine both behavioral and physiological measures in order to receive a more comprehensive picture of emotion processing and its underlying mechanisms. Continued work in this area is needed to examine how visual attention and physiological responses are integrated with emotion recognition, and to ask how this might change at different points across development.

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Sapir Soker-Elimaliah

Chan Division of Occupational Science and Occupational Therapy,
University of Southern California
1540 Alcazar St., CHP-133
Los Angeles, CA, 90089-9003
USA
elm.sapir@gmail.com