Sharing a Common Language Affects Infants’ Pupillary Contagion

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ABSTRACT

From early in life, infants synchronize with others on a physiological level, a process thought to underlie social connections and group cohesion. This synchronization is seen, for example, when their pupils dilate in response to observing another person with dilated pupils – known as “pupillary contagion.” There is mixed evidence on whether arousal synchrony is modulated by interpersonal similarity factors, such as race, and even in studies that find such an effect, confounding visual factors could play a role. In the current study, language was used to manipulate interpersonal similarity for 10-month-old infants who saw speakers’ pupils dilate or constrict, while their own pupil size and gaze were assessed. Results from the first half of the study show that only own-language speakers elicited pupillary contagion and increased attention when their pupils dilated. While in the second half of the study, when infants’ level of attention was also decreasing, this effect did not hold. Together, the results indicate that infants’ sharing of arousal is modulated by shared language, though further research can help to clarify how these effects unfold over time.

A critical aspect of social group membership is being able to recognize and share the emotional arousal of others around us. This ability is thought to be a building block of empathy and caregiving relationships (Feldman, 2007) as well as being a way to coordinate group behavior (De Waal, 2008). Sharing of emotional arousal is seen when humans automatically mimic the facial muscular movements of others’ emotional expressions (Hess & Fischer, 2013). This effect is present in infants by 5 months of age for dynamic, multimodal expressions of crying and laughter (Isomura & Nakano, 2016), by 7 months of age for static happy expressions (Datyner, Henry, & Richmond, 2017), and by 6–7 years of age for dynamic happy, sad, fearful, and angry expressions (Deschamps, Schutte, Kenemans, Matthys, & Schutter, 2012). For adults, facial mimicry occurs even when observers are not aware of being shown the images (Dimberg, Thunberg, & Elmehed, 2000; Mathersul, McDonald, & Rushby, 2013).

Beyond facial expressions of emotion, dilation of one’s pupils can also be a signal of others’ increased arousal. Pupil dilation occurs as part of the sympathetic nervous system and is not under conscious control, making it a reliable signal of arousal responses (Laeng, Sirois, & Gredehäll, 2012; Loewenfeld, 1993). Thus, automatic reactions to subtle cues of others’ emotional arousal can also be observed via pupillary contagion: dilation of an...
observer’s pupils in response to viewing another person with dilated pupils. Pupillary contagion is documented in both adults (Harrison, Singer, Rotshtein, Dolan, & Critchley, 2006; Hess, 1975; Kret, Fischer, & De Dreu, 2015; Kret & De Dreu, 2017; van Breen, De Dreu, & Kret, 2018) and infants from as young as 4–6 months of age (Fawcett, Arslan, Falck-Ytter, Roeyers, & Gredebäck, 2017; Fawcett, Wesevich, & Gredebäck, 2016), and does not seem to vary over infant development from 6 to 18 months (Aktar, Rajmakers, & Kret, 2020). Whether people also mimic others’ pupil constriction is much less clear (Aktar et al., 2020; Kret, Tomonaga, & Matsuzawa, 2014) and when constriction mimicry does occur, it is not related to social processes (Kelsey, Krol, Kret, & Grossmann, 2019; Kret et al., 2015; Prochazkova et al., 2018). Given that pupil constriction is not a sign of arousal changes, there is less reason to propose that constriction mimicry is part of the same arousal sharing mechanism. Pupillary contagion to others’ dilation, however, is a robust effect in adults, which is modulated by other factors such as trust, and potentially race, though findings regarding race have been mixed. In one study with faces showing emotional expressions, there was variation in pupillary contagion across own- and other-race individuals (Kret et al., 2015), but in two studies using stimuli with neutral facial expressions, one with adult participants (Kret & De Dreu, 2017) and one with infants and their parents (Aktar et al., 2020), there was no such variation. It has also been proposed that pupillary contagion facilitates trust within one’s racial ingroup (Kret & De Dreu, 2017; Kret et al., 2015), yet the direction of this effect is not clear and it could be that we have greater pupillary contagion for those that we trust more.

The findings that pupillary contagion is both early-appearing in development and socially modulated, at least later in life, suggest that it is driven by a dual mechanism with both an automatic physiological process and one influenced by social factors. Yet exactly how social factors impact the physiological response is not clear. It could be that there are differences in attention to others based on interpersonal similarity that might impact whether pupillary contagion occurs, though previous studies on group effects have reported similar levels of attention to stimuli across conditions (Prochazkova et al., 2018). It could also be that social factors up- or down-regulate the automatic responses (Vaish, 2016). However, these different mechanisms are difficult to tease apart, and the first step toward understanding the social modulation of pupillary contagion is to examine more carefully the conditions under which it occurs.

The few studies that have examined the effect of interpersonal similarity on infants’ responses to others’ pupil dilation have used race (White vs. Asian) as the manipulation. In an fNIRS study, 9-month-olds showed greater sensitivity to pupil dilation in same-race (White) than other race (Asian) faces (Kelsey et al., 2019). A recent eye-tracking study showed that while there was overall greater pupil dilation to other race (Asian) faces, perhaps due to greater novelty, there was no difference in pupillary contagion across white and Asian faces for either 12-month-old infants or their parents (Aktar et al., 2020).

However, there are several reasons why race might not be the ideal manipulation to examine infants’ social modulation of pupillary contagion. From a methodological point of view, presenting race inherently means systematic variation in the visual stimuli and in the case of White vs. Asian faces which have been used in the previous studies in the area, potentially a difference in how visible the pupils are due to differences in eye shape. From a conceptual point of view, it has been shown that while infants show visual preferences for own-race faces by 3 months of age (Kelly et al., 2005), and may have preferences to follow the
gaze of own-race individuals by 7 months of age (Xiao et al., 2018), own-race preferences as measured by social behavior – such as giving and receiving toys – do not emerge until between 2.5 and 5 years (Kinzler & Spelke, 2011). In the case of social modulation of pupillary contagion, what is most critical to find are variations based on how infants think about others beyond perceptual familiarity and unfamiliarity.

Thus, if we want to examine social modulation of infants’ pupillary contagion, we need to manipulate a category that is meaningful for them: not only more familiar, but rather a category that leads to further social expectations about a person. Language is just such a category. Ten-month-olds preferentially select items endorsed by own-language speakers (Kinzler, Dupoux, & Spelke, 2012), 11-month-olds are more likely to mimic the facial actions of own-language speakers (de Klerk, Bulgarelli, Hamilton, & Southgate, 2019) and expect own-language speakers to provide them with information (Begus, Gliga, & Southgate, 2016), 12-month-olds select foods endorsed by an own-language speaker (Shutts, Kinzler, McKee, & Spelke, 2009), and 14-month-olds are more likely to imitate novel actions demonstrated by own-language speakers (Buttelmann, Zmyj, Daum, & Carpenter, 2013). Expectations about language are also seen in third-person contexts, such as expecting others who speak the same language to affiliate with each other (Liberman, Woodward, & Kinzler, 2017) and to share food preferences (Liberman, Woodward, Sullivan, & Kinzler, 2016). These behavioral indications of preference and social expectations, and not simply perceptual familiarity, are thus present in development already in infancy, which is not true for social preferences based on race (Kinzler & Spelke, 2011; Shutts, Pemberton, & Spelke, 2013).

In the current study, infants’ pupillary contagion to others varying in interpersonal similarity was examined with language as the manipulated social similarity factor. This allowed presentation of highly controlled visual stimuli to remove the possibility of confounding factors based on visual differences (e.g., visibility of iris and pupil in Asian eyes). Specifically, 10-month-olds first observed the eye region of a woman while either their native language (Swedish) or an unfamiliar language (Italian) was heard. Then, the woman’s pupils either dilated or constricted and the infant’s own pupil size change and gaze duration in response was examined. Pupillary contagion results in greater pupil dilation to others’ dilation, and the constriction condition was included as a control for a change of pupil size that should not lead to a shared arousal dilation response. That is, if infants show modulation of the pupillary contagion response based on common language, then they should show stronger pupillary contagion – greater dilation to another’s pupil dilation than constriction – for own-language than other-language speakers. Gaze duration could be an additional marker of infants’ differential responding. That is, gaze duration was assessed as a measure of attention and interest, which could be also modulated by social factors leading infants to pay more attention to own-language speakers who show an arousal response, similar to what has been shown for infants’ attention to pupil dilation in same-race individuals (Kelsey et al., 2019).

**Method**

**Participants**

Data from 66 10-month-olds (33 girls, M_{age} = 10 months 0 days, range = 9 months 17 days to 10 months 14 days) were included in the study. Participants who were familiar with the Italian language (here used as the “other language”) were screened out during the initial
recruitment phone call. Participants were recruited from a list of families who previously expressed interest in participating in research studies with their child. Participants lived in a mid-sized European city and were primarily white and from middle-class families.

**Stimuli**

Stimuli included a series of four blocks of video clips which the infants viewed on a Tobii Pro Spectrum eye tracker at 120 Hz. The screen that measured 52.7 by 29.6 cm (23.8 inches diagonal, 1920 × 1080 resolution). Each block included 8 trials of the same language and same face/voice combination, but alternating between dilation and constriction. Language alternated across the four blocks and a different face was shown in each block. In each of the 32 trials, a different brief statement or question was presented to show the infant which language the model spoke (e.g. “Hi baby, how are you?,” “The summer is nice and warm”). Short attention-grabbing animations of one to two seconds were presented after every four trials.

The images used to make the videos were originally obtained from the Karolinska Directed Emotional Faces (Lundqvist, Flykt, & Öhman, 1998) (image IDs: AF06NES, BF19NES, BF13NES, BF01NES). All had neutral expressions. They were modified in Adobe Photoshop so that only the eyes and surrounding area including eye brows and upper part of nose were visible on a gray background (see Figure 1; mean width: 23.5 cm, mean height: 8.5 cm, 22.16° × 8.10° visual angle at 60 cm distance). In addition, their original irises were replaced with identical irises and pupils. Each individual face was presented in only one block.

The spoken sentences were recorded by two Swedish-Italian bilingual women. Each woman recorded each statement in both languages. In the videos, the faces and voices were counterbalanced across participants such that either face or either voice could be paired with each other and could be either the Swedish or the Italian example. The voices were presented in an ABBA or BAAB order across the blocks, such that each voice speaking each language was heard by each infant.

Each 8000 ms trial began with a 1000 ms fixation cross. Then the eye region of the woman appeared and the statement was heard (2500 ms, Speech Phase). There were 500 ms of no speech for the pupil baseline then for 1000 ms, the pupils of the woman either dilated (increased in size by 40%) or constricted (decreased in size by 40%). The acceleration curve of the pupil size change was based on actual recorded pupil data to ensure that it was as natural as possible. In the final part of the trial, for 3000 ms, her pupils remained the new size (Contagion Phase). All stimuli can be downloaded from the Open Science Framework (https://osf.io/h3wzd/).

**Procedure**

Parents received information about the study over the phone and then by e-mail if they agreed to schedule an appointment to participate. At the appointment, information was reviewed again and written consent was obtained. Infants sat on their parent’s lap approximately 60 cm from the monitor. After a successful 5-point calibration, the experiment began and infants viewed the video sequence as described above (approximately 4.5 minutes duration). Afterward, parents could hear more about the study and ask any questions. Ethical approval was obtained from the local ethical review board.
Figure 1. Sequence of events in each trial.

Figure 2. Infants’ responses to own-language (dark blue) and other-language (light blue) speakers’ pupil dilation and constriction as indexed by their pupil dilation (A and B) and looking time to the model (C and D) following the model’s pupil size change. Panels A and C show the results from the first experiment half (Blocks 1 and 2) and panels B and D show the results from the second experiment half (Blocks 3 and 4).
Data processing and analysis

The main dependent variable was change in participants’ pupil size in response to the model’s pupil size change. These values were calculated in TimeStudio (version 3.19, timestudioproject.org), an open-source, MATLAB-based program for processing time series data (Nyström, Falck-Ytter, & Gredebäck, 2016). The workflow used for the data processing can be downloaded from the Open Science Framework (https://osf.io/c3g8n/) and viewed in TimeStudio. Small gaps in the pupil series data of 5 samples or fewer were filled linearly and then the series was smoothed using a moving average of 20 samples. Finally, one pupil size change value was calculated for each trial by taking the average of the pupil size during the 3 s that the new pupil size was presented (Contagion Phase), minus a baseline of the average pupil size during 500 ms before the pupil size change occurred. A secondary dependent variable was looking time to the screen during the Contagion Phase which was also calculated in TimeStudio.

The following exclusion criteria were set prior to running the study and preregistered (https://aspredicted.org/vc8s2.pdf). Trials in which fewer than 50% of gaze samples were recorded were excluded from pupil dilation analyses (1203/2112 trials, 60.0%) and trials in which the change in pupil size was more than 3 standard deviations from the grand mean for all trials were replaced with the next most extreme pupil value in the data set (i.e. Winsorization). Also preregistered was an exclusion criterion for participants who did not provide data for at least two trials per condition (e.g. own-language/dilated; \( n = 18 \) participants total). However, during the review process, this exclusion was suggested to be unnecessary and all participants are included in the analyses reported below, while the analyses for the preregistered smaller sample are reported as Supplementary results (https://osf.io/8mjyn/) and only briefly described below.

The regression analyses on the trial-level data were run using linear mixed-effects models in jamovi (version 1.2.22; Jamovi, 2020) with the GAMLj module 2.0.1 (Galluci, 2019), which was developed in R (R, 2019) and includes R’s lme4 package (Bates et al., 2015). Models included a random intercept for participant. In line with the preregistration, preliminary analyses individually examined the effects of participant sex, model voice (V1 or V2), model face (M1, M2, M3, or M4), and experiment half (first vs. second), by modeling each dependent variable using the predictors of model pupil size, language, the preliminary variable, and the interactions between them. These variables were examined because they could introduce effects that need to be controlled for (e.g. overall greater dilation to certain model faces or voices) or that could interact with the main effects of interest (e.g. the first vs. second exposure to someone speaking a new language could lead to different responses in infants due to contrast effects from the previous block or fatigue effects). Because including preliminary variables with significant effects or interactions can add power to the main models by explaining variance that would otherwise be error variance, or can add nuance to effects of interest, such as how responses might change over time, they were retained for the main analysis for each dependent variable, in line with the preregistered analysis plan.
Results

Pupil size change

Preliminary analyses on pupil size change revealed no effects or interactions for participant sex, model face, or model voice. However, there was a three-way interaction between model pupil size, language, and experiment half \((F(1, 872) = 5.25, p = .022)\). Full models for the preliminary analyses are available in the Supplementary Tables (S1-S4; https://osf.io/fykp3/).

An initial model with only the main predictors of model pupil size (dilated or constricted), language, and their interaction as fixed effects and participant as random intercept revealed no significant effects (see Table S5; https://osf.io/fykp3/). However, given that there was a significant interaction uncovered in the preliminary analyses and in line with the preregistered analysis plan, the main model examining infants’ pupil size changes included a random intercept for participant, fixed effects for model pupil size, language, experiment half, model pupil size by language, model pupil size by experiment half, language by experiment half, and model pupil size by language by experiment half (see Table 1). The three-way interaction between model pupil size, language, and experiment half was significant \((F(1, 872) = 5.25, p = .022)\). Simple effects analyses indicated that in the first experiment half, infants reacted to own-language speakers’ pupil dilation with greater pupil size change than to own-language speakers’ pupil constriction \((t(867) = 2.28, p = .023)\), but there was no comparable effect for other-language speakers \((t(866) = 0.12, p = .906)\). In addition, the estimated marginal means from the model indicate that infants’ pupil dilation was only significantly greater than baseline for own-language speakers with dilating pupils \((M = 0.05, SE = 0.02, 95\% CI [0.01–0.08])\). In the second experiment half, there were no significant effects for either own-language \((t(880) = −1.19, p = .235)\) or other-language \((t(872) = 1.20, p = .233)\) speakers (see Figure 2 A-B).

Looking duration

Preliminary analyses on looking duration revealed no effects for participant sex or model voice. However, there was a two-way interaction between model face and language \((F(3, 1259) = 4.58, p = .003)\) and a three-way interaction between model pupil size, language, and experiment half \((F(1, 1275) = 5.01, p = .025)\). Full models for the preliminary analyses are available in the Supplementary Tables (S6-S9; https://osf.io/fykp3/).

The main model for looking duration (see Table 2) included a random intercept for participant, fixed effects for model pupil size (dilated or constricted), language, experiment half, model face, model pupil size by language, model pupil size by experiment half, language by model face, language by experiment half, and model pupil size by language by experiment half. The three-way interaction between model pupil size, language, and experiment half was significant \((F(1, 1282) = 5.23, p = .022)\), as was the effect of experiment half, with less looking in the second experiment half \((F(1, 1291) = 31.41, p < .001)\). Simple effects analyses indicated that in the first experiment half, infants reacted to own-language speakers’ pupil dilation with longer looking time than to own-language speakers’ pupil constriction \((t(1279) = 2.40, p = .017)\), but there was no comparable effect for other-language speakers \((t(1278) = −0.87, p = .387)\). In the second experiment half, there were no significant differences for either own-language \((t(1285) = −0.93, p = .355)\) or other-language speakers \((t(1279) = 0.48, p = .632)\); see Figure 2C-D).
### Table 1. Main analysis model for pupil size change.

**Fixed Effect Omnibus tests**

| Effect                     | F     | Num df | Den df | p     |
|----------------------------|-------|--------|--------|-------|
| Model Pupil Size (MPS)     | 1.099 | 1      | 877    | 0.295 |
| Language                   | 0.686 | 1      | 886    | 0.408 |
| Experiment half            | 4.723 | 1      | 902    | 0.030*|
| MPS * Language             | 0.120 | 1      | 876    | 0.729 |
| MPS * Experiment half      | 1.214 | 1      | 866    | 0.271 |
| Language * Experiment half | 1.559 | 1      | 883    | 0.212 |
| MPS * Language * Experiment half | 5.247 | 1 | 872 | 0.022* |

**Fixed Effects Parameter Estimates**

| Names                      | Effect                                   | Estimate | SE   | Lower | Upper | df  | t    | p     |
|----------------------------|------------------------------------------|----------|------|-------|-------|-----|------|-------|
| (Intercept)                | (Intercept)                              | 0.01921  | 0.0107 | -0.00185 | 0.0403 | 64.5 | 1.788 | 0.078 |
| Model Pupil Size (MPS)     | dilated - constricted                    | 0.01442  | 0.0138 | -0.01253 | 0.0414 | 877.0 | 1.049 | 0.295 |
| Language                   | own - other                              | 0.01145  | 0.0138 | -0.01565 | 0.0386 | 885.5 | 0.828 | 0.408 |
| Experiment half            | 02-Jan                                   | 0.03045  | 0.0140 | 0.00299  | 0.0579 | 902.4 | 2.173 | 0.030*|
| MPS * Language             | dilated - constricted * own - other      | -0.00953 | 0.0275 | -0.06346 | 0.0444 | 875.7 | -0.346 | 0.729 |
| MPS * Experiment half      | dilated - constricted * 2 - 1           | -0.03018 | 0.0274 | -0.08386 | 0.0235 | 865.8 | -1.102 | 0.271 |
| Language * Experiment half | own - other * 2 - 1                      | -0.03448 | 0.0276 | -0.08860 | 0.0196 | 882.6 | -1.248 | 0.212 |
| MPS * Language * Experiment half | dilated - constricted * own - other * 2 - 1 | -0.12593 | 0.0550 | -0.23368 | -0.0182 | 872.4 | -2.291 | 0.022* |

**Random Components**

| Groups | Name     | SD     | Variance | ICC   |
|--------|----------|--------|----------|-------|
| ID     | (Intercept) | 0.0619 | 0.00384  | 0.0875 |
| Residual |          | 0.2001 | 0.04006  |       |

*Note.* Satterthwaite method for degrees of freedom

*Note.* Number of Obs: 909, groups: ID 65
Table 2. Main analysis model for looking duration.

| Fixed Effect Omnibus tests | F   | Num df | Den df | p     |
|---------------------------|-----|--------|--------|-------|
| Model Pupil Size (MPS)    | 0.261 | 1 | 1280 | 0.609 |
| Language                  | 2.289 | 1 | 1289 | 0.131 |
| Experiment half           | 31.409 | 1 | 1293 | <.001* |
| Model face                | 1.872 | 3 | 1289 | 0.132 |
| MPS * Experiment half     | 0.986 | 1 | 1280 | 0.321 |
| MPS * Language            | 0.633 | 1 | 1280 | 0.426 |
| Language * Experiment half| 1.242 | 1 | 1285 | 0.265 |
| Language * Model face     | 0.662 | 3 | 1280 | 0.576 |
| MPS * Language * Experiment half | 5.226 | 1 | 1282 | 0.022* |

| Fixed Effects Parameter Estimates | Estimate | SE | 95% Confidence Interval | df | t | p     |
|-----------------------------------|----------|----|-------------------------|----|----|-------|
| (Intercept)                       | 1.3826   | 0.0690 | 1.2474 - 1.5178 | 63.9 | 20.041 | <.001 |
| MPS                               | 0.0247   | 0.0483 | −0.0700 - 0.1194 | 1279.9 | 0.511 | 0.609 |
| Language                          | −0.0739  | 0.0488 | −0.1696 - 0.0218 | 1288.8 | −1.513 | 0.131 |
| Experiment half                   | −0.3031  | 0.0541 | −0.4091 - −0.1971 | 1291.5 | −5.604 | <.001* |
| Model face                        | 0.0467   | 0.0723 | −0.0950 - 0.1885 | 1288.0 | 0.647 | 0.518 |
| MPS * Experiment half             | −0.0960  | 0.0966 | −0.2854 - 0.0934 | 1280.6 | −2.286 | 0.022* |
| MPS * Language                    | 0.0768   | 0.0966 | −0.1124 - 0.2661 | 1279.6 | −0.796 | 0.426 |
| Language * Experiment half        | −0.1193  | 0.1070 | −0.3290 - 0.0905 | 1285.0 | −1.115 | 0.265 |
| Language * Model face             | −0.1730  | 0.1714 | −0.5090 - 0.1630 | 1317.5 | −1.009 | 0.313 |
| MPS * Language * Experiment half  | −0.8423  | 0.1935 | −0.8215 - 0.0631 | 1281.9 | −4.423 | <.001* |

| Random Components | Name                 | SD  | Variance | ICC  |
|-------------------|----------------------|-----|----------|------|
| Groups            | (Intercept)          | 0.520 | 0.270   | 0.262 |
|                   | Residual             | 0.872 | 0.760   |      |

Note. Satterthwaite method for degrees of freedom
Note. Number of Obs: 1342, groups: ID 66
Looking duration and pupil dilation

As an exploratory analysis to assess whether differences in pupil dilation responses might be driven by attention, participants’ pupil dilation was predicted by their looking time on a trial-by-trial basis. This model showed no effect of looking duration ($F(1, 815) = 0.60, p = .440$; see Table S10 for the full model, https://osf.io/fykp3/).

Preregistered analyses

The results from the preregistered analyses with the smaller sample due to exclusions of participants with fewer than two trials per condition (e.g. own-language dilation) were for the most part identical to those presented above. One difference in the pupil dilation analyses was that in the initial model with only language, model pupil size, and their interaction, there was a significant effect of model pupil size overall with greater dilation when the model’s pupils dilated than constricted. A second difference in the pupil dilation analyses was that in the second experiment half, there was a significant effect of model pupil size for other-language speakers, suggesting possible pupillary contagion to other-language speakers in the second experiment half. None of the looking time results differed significantly. Details are presented in the Supplementary results (https://osf.io/8mjyn/).

Discussion

Do infants show social modulation of pupillary contagion responses based on interpersonal similarities? In the current study, language was manipulated to indicate interpersonal similarity and 10-month-old infants’ pupillary contagion responses to speakers was examined. The findings from the first half of the study – that is, infants’ first block of exposure to each language in the study – gave evidence for selective pupillary contagion for own-language speakers, with dilation greater than baseline only when own-language speakers’ pupils dilated; as well as an attentional bias with longer looking time when own-language speakers’ pupils dilated rather than constricted. This suggests that at 10 months of age, infants are modulating their pupillary contagion responses based on sharing a common language with another person.

The current findings are in line with literature on infants at this age beginning to show preferential behavior and responses toward those who speak their native language (Buttelmann et al., 2013; de Klerk et al., 2019; Kinzler et al., 2012; Shotts et al., 2009). The findings are also in line with one recent study that examined 9-month-old infants’ brain responses to others’ pupil dilation and constriction and found more brain activation for the pupil dilation of own-race than other-race individuals, suggesting that infants might only be sensitive to pupil size changes for individuals similar to themselves in race (Kelsey et al., 2019). However, another recent study that directly examined pupillary contagion responses to own- and other-race faces in 6-, 12- and 18-month-old infants and their parents found no differentiation of pupillary contagion across race for either infants or their parents (Aktar et al., 2020). Studies examining infants’ gaze following for own- and other-race individuals have shown some variation in responses. For example, 7-month-old infants showed a bias to follow the gaze of own-race individuals only when the individuals were somewhat unreliable in gazing toward the displayed object (Xiao et al., 2018) and 18- to 20-month-
old infants being raised bilingually were less likely to show an own-race bias in gaze following than monolingual infants (Singh, Quinn, Xiao, & Lee, 2019). These studies suggest that there may be additional factors that help explain when and why infants will show biases toward attending to and learning from those who are similar to them.

From a theoretical standpoint, these results provide support for the proposal that pupillary contagion is based on dual processes of arousal sharing. While there may be an automatic response mechanism of sharing arousal that results in pupil dilation to others’ pupil dilation even for young infants (Aktar et al., 2020; Fawcett et al., 2017, 2016), there also appears to be social modulation in which infants’ responses vary depending on individual characteristics of the observed person that the infants interpret as meaningful. Such selectivity in responding based on interpersonal similarity could have a functional aspect in that it may be more important for infants to be socially and emotionally in tune with those who are in their social group. That is, sharing of arousal has been suggested to be a way to build caregiving relationships (Feldman, 2007) and to coordinate group behavior (De Waal, 2008), thus being able to selectively share arousal with those close to us would facilitate these processes.

When it comes to the looking duration results in which infants looked longer at own-language speakers with dilated than constricted pupils, the findings are not consistent with one earlier report that adults did not vary in looking time to individuals with dilating versus constricting pupils (Prochazkova et al., 2018). However, it is important to note that infants may vary more than adults in their looking time based on task compliance differences, with infants being much more prone to gaze away from the screen. It has also been suggested that attention might be a main driver behind pupillary contagion responses via the pupillary light reflex (Mathôt & Naber, 2018); however, given that an exploratory analysis did not find a relation between looking time and pupil response in the current data, this seems unlikely at least in the current task.

In the second experiment half, the pattern of results with selective pupillary contagion and increased gaze duration for own-language speakers did not hold and in fact in the preregistered analysis on the more selective sample, there even appeared to be a switch in responses with infants beginning to show pupillary contagion with greater dilation in response to the other-language speaker’s dilation than constriction. It’s important to note that infants’ looking time decreased significantly from the first to the second experiment half, indicating that they were less attentive over time and it’s possible that these later trials are less reliable than the earlier ones. For infants’ own language, it could be that fatigue or over-familiarity contributed to the fading out of their pupillary contagion. While for the other language, which was unfamiliar to the infants previous to the participating in the study, it could be that increasing familiarity via the earlier block’s exposure facilitated the emergence of a pupillary contagion response in the later block, particularly in infants who were able to sustain their attention until the end of the study. Though given that the other-language result did not hold with more participants included, it could potentially be a spurious effect. Future studies could examine how responses to own- and other-language speakers shift over time.

A key strength of the study is that using language as the manipulation for interpersonal similarity allowed for high control over visual features of the stimuli, allowing reliable measurement of pupillary contagion without concern for confounding effects based on factors such as visibility of the pupil due to eye shape differences across races. Another strength is that pupil size changes were dynamic, rather than static as in several previous
studies on infants’ pupillary contagion (Fawcett et al., 2017, 2016). However, one possible weakness of the stimuli is that in order to maximize control over the visual images of the faces, they were not animated during speaking, potentially decreasing their realism and ecological validity. Specifically, the eye region was visible as a static image while the speaker’s voice was heard and then the pupil size changed dynamically within the image. Future studies could consider using actual videos of different language speakers paired with images in which pupils could be manipulated dynamically.

Another potential weakness of the study is that only one language combination was tested and which language was the own vs. other language was not counterbalanced. While it would be beneficial to have participants from both language groups included in the study to achieve this level of counterbalancing in future research, it is not uncommon to have imperfect counterbalancing in similar studies. For example, studies that have examined pupillary contagion across own- and other-race individuals have tested White participants who viewed White and Asian faces (Kelsey et al., 2019; Kret & De Dreu, 2017; Kret et al., 2015).

Together, the results from the current study show that infants’ sharing of arousal, as indicated by their pupillary contagion, is affected by the language that others speak. Language, more so than race, is an early-recognized social factor for infants. Whether someone shares a common language or not affects infants’ behavior, preferences, and social expectations (de Klerk et al., 2019; Kinzler et al., 2012; Liberman et al., 2017, 2016; Shutts et al., 2009) and now there is evidence that it may affect their social connections with others on a physiological level as well, adding to our understanding of infants’ social development as well as the origins and development of physiological synchrony.

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**Data availability statement**

The data that support the findings of this study are available on request from the author.
Open scholarship

This article has earned the Center for Open Science badges for Open Materials and Preregistered. The materials are openly accessible at https://osf.io/h3wzd and https://aspredicted.org/vc8s2.pdf.

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