Twelve-month-old infants’ physiological responses to music are affected by others’ positive and negative reactions

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Abstract
Infants show remarkable skills for processing music in the first year of life. Such skills are believed to foster social and communicative development, yet little is known about how infants’ own preferences for music develop and whether social information plays a role. Here, we investigate whether the reactions of another person influence infants’ responses to music. Specifically, 12-month-olds (N = 33) saw an actor react positively or negatively after listening to clips of instrumental music. Arousal (measured via pupil dilation) and attention (measured via looking time) were assessed when infants later heard the clips without the actor visible. Results showed greater pupil dilation when listening to music clips that had previously been reacted to negatively than those that had been reacted to positively (Exp. 1). This effect was not replicated when a similar, rather than identical, clip from the piece of music was used in the test phase (Exp. 2, N = 35 12-month-olds). There were no effects of the actor’s positive or negative reaction on looking time. Together, our findings suggest that infants are sensitive to others’ positive and negative reactions not only for concrete objects, such as food or toys, but also for more abstract stimuli including music.
Music is a social form of art with both biological and cultural underpinnings (Trehub et al., 2015). From birth and throughout the first year, preverbal infants are believed to communicate with parents and caregivers by using musical cues to share affective and emotional needs (Malloch & Trevarthen, 2009; Thompson et al., 2014) and music is a tool for regulation of infants’ distress (Cirelli et al., 2020; Corbeil et al., 2016). Such forms of communicative musicality play important roles not only for musical development (Trehub, 2003), but also for social and emotional development (Trevarthen, 2020). Here, we expand work on infants’ developing musicality by asking how positive and negative social information affect infants’ responses to musical stimuli in a laboratory setting.

Infants begin to discriminate positive and negative emotions in the first months of life (e.g., Farroni et al., 2007) and social referencing paradigms have shown that infants from around 1 year of age make use of adults’ positive and negative emotional reactions to toys (e.g., Hornik et al., 1987), strangers (e.g., Feinman & Lewis, 1983), and the so-called ‘visual cliff’, an apparent drop-off in the floor (e.g., Sorce et al., 1985), to regulate their approach and avoidance behaviors. Interestingly, these social referencing studies also seem to show an overall negativity bias, in which negative reactions have a greater influence on infants’ behavior and own emotions than positive ones when comparing to a baseline or neutral reaction (Vaish et al., 2008). The greater impact of negative over positive social information is also seen at the neural level. Carver and Vaccaro (2007) recorded event-related potentials (ERP) from 12-month-olds who viewed pictures that had been associated with positive, neutral, or negative affect by adults in an earlier learning phase. They observed that infants engaged in more interaction with their caregiver and had larger ERP responses when viewing previously negatively associated pictures. The authors conclude that infants allocate increased neural resources to stimuli associated with negative adult emotion.

One suggestion for the origins of the negativity bias is that it is rooted in evolutionary survival needs, in that others’ negative emotions are likely to be more important for learning than positive ones since they can help in avoiding danger or unpleasant situations when exploring the environment (Vaish et al., 2008). While this is entirely plausible for learning about foods or objects, it is not clear whether such a pattern of negative reactions allocating greater attention (and evoking greater arousal) in infants might also transfer to more abstract, though culturally significant stimuli, such as music. A related explanation is that negative information is taken as a signal that we need to change course. That is, our natural tendency might be to explore novel situations—or to enjoy music—which would be in line with positive information from others, but negative information leads to a situation where we might need to change that tendency (Vaish et al., 2008).

Where do preferences for certain pieces of music originate? Music can have properties that can make it objectively more or less pleasant to listen to, at least within one’s own cultural experience. Infants in Western cultures have been shown to prefer music that is consonant (Trainor & Heinmiller, 1998; Trainor et al., 2002), higher in pitch (Trainor & Zacharias, 1998), and, at least for playful songs, quicker in tempo (Conrad et al., 2011). Importantly, music preferences are also largely influenced by culture and familiarity. For example, 4- to 8-month-old infants in the United States and Turkey prefer to listen to music in the meters that they had been exposed to in their culture (Soley & Hannon, 2010) and even infants’ preference for consonance and perhaps other musical properties is likely learned rather than innate (Plantinga & Trehub, 2014), with some research finding that even the preference for consonance is not found universally in adults (McDermott et al., 2016). Moreover, infants show enhanced responses and preferences for music and people who sing that music when the music was initially learned in meaningful social situations, such as if the music was learned from their parents (Mehr et al., 2016; Mehr & Spelke, 2018). This suggests
that sharing music is a meaningful social activity for infants and that music itself can acquire social value. Moreover, rhythmic song and recitation by an unfamiliar adult increase infant helping behavior, but this association is moderated by the infants’ familiarity with the song materials (Cirelli & Trehub, 2018). Together, these findings suggest that there are environmental influences on infants’ music preferences, yet little research has looked at these mechanisms when infants are first exposed to a certain piece of music, such as whether another person’s positive or negative reaction to it will shape infants’ later responses.

While many studies of infant music preference have used infant-controlled looking time paradigms (e.g., Soley & Hannon, 2010; Trainor & Heinmiller, 1998; Trainor et al., 2002; Trainor & Zacharias, 1998), another way of assessing infants’ responses to music could be through pupil dilation. Pupil dilation, which occurs not only due to changes in light, but also because of activation in the sympathetic nervous system, has been shown to be a marker for attention, cognitive processing (Krüger et al., 2019), and positive and negative physiological arousal (Bradley et al., 2008) in adults. Studies using pupillometry in infants have shown similar types of effects, for example, greater dilation responses to unusual manual actions (Gredebäck et al., 2018), unexpected sounds (Wetzel et al., 2016), remembered images (Hellmer et al., 2018), and others’ arousal (Fawcett et al., 2016, 2017).

Pupillometry has already been widely used in auditory research with adults (Zekveld et al., 2018), including music (Laeng et al., 2016; Weiss et al., 2016). These preliminary findings suggest that pupil dilation might reflect both cognitive (attention and memory) and affective (physiological arousal) processes for music, just as they do for visual stimuli. Zekveld et al., (2018) conclude from their review of 136 studies which used pupillometry to measure responses to auditory materials, that a complex set of perceptual, cognitive, and emotional components contribute to pupil dilation, which is also subject to individual variation. For example, increases in pupil dilation were found in adult non-musicians while listening to music which they liked and found easy to follow (Bianco et al., 2019). The authors suggest that music differentially affected physiological arousal as reflected in the ocular measure. Together these findings suggest that pupil dilation could shed light on infants’ developing responses to music.

The aim of the current study was to investigate whether infants’ changes in responses as a result of others’ positive and negative reactions toward concrete objects, such as toys, might extend to more abstract items which also have cultural relevance, specifically music. To this end, we chose pieces of fully orchestrated, instrumental Western music in a variety of genres (e.g., baroque, jazz, Celtic). Infants growing up in Western cultures appear sensitive to features of Western tonal music (Trainor & Trehub, 1992) and prefer the meters of Western music over those of other cultures (Soley & Hannon, 2010), and thus, we expect that they will be able to process and remember novel music excerpts representing typical structural features in the present study. Building on social referencing paradigms, we presented 12-month-old infants with an adult who reacted to different pieces of music positively or negatively, and then assessed infants’ responses to identical (Experiment 1) and similar (Experiment 2) pieces of music using looking time as a measure of attention and pupil dilation as a measure of arousal. We expected that infants’ own responses to the music would be affected by those of the actor and could potentially show a negativity bias, in line with other work on social learning (Vaish et al., 2008). That is, infants might show stronger physiological reactions (i.e., greater pupil dilation) to music that was reacted to negatively, as the negative emotional information would be more impactful or valuable and thus more likely to be shared by the infant. The predictions for looking time under negativity bias are less clear as greater attention could either indicate increased vigilance toward negative stimuli or increased interest in positive stimuli.
2 | EXPERIMENT 1

We individually tested a cohort of 12-month-old infants in a laboratory setting. The procedure entailed a learning phase (including positive or negative social information from an actor) and a test phase (without the actor). In both phases, infants were exposed to video clips of the same music clip that was chosen from a collection of music pieces while looking behavior and pupil dilation were measured using eye tracking. The method, sample size, and procedure were preregistered (https://aspredicted.org/ak2fp.pdf).

2.1 | Method

2.1.1 | Participants

33 infants (15 girls) between 11.5 and 12.5 months of age ($M = 11$ months 29 days) participated in the study. An additional 3 infants were excluded for having insufficient data (see Data Preparation and Analysis). 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, educated families. The present study was conducted in accordance with the Declaration of Helsinki, with written informed consent obtained from parents or guardians for each participating child before any data collection. All procedures were approved by the local ethical review board (Uppsala Etikprövningsnämnden).

2.1.2 | Stimuli

Stimuli included a series of four blocks of video clips which the infants viewed on a Tobii TX300 eye tracker with a 23-inch diagonal monitor. There was a total of eight different music clips (8 seconds each), such that in each block, two music clips were compared. The music clips were selected from different Western culture genres and the pieces of music were not highly popular so that infants were unlikely to be familiar with the exact pieces of music. They were also selected to be fairly positive and engaging to infants to keep their attention during the study. Eight adults rated our initial selection of twenty possible clips on how positive to negative and how calm to exciting they were (0 to 7 scale for each response). From these ratings, we selected pairs of clips matched on how positive and exciting they were, as well as eliminating clips that were rated negatively. All of the music clips with a list of links are available for download on the Open Science Framework (OSF; https://osf.io/kxp8w/files/).

Each block consisted of a learning phase and a test phase (see Figure 1). In the learning phase, an actor sat at a table with two identical colored boxes on either side of her. She first said “now we will listen to music!”, then turned toward one box, pressed the top, and tilted her head to side to listen in its direction as the 8-second music clip played. When the music ended, she straightened her head, and either reacted positively, smiling and saying “oh, that was really good!” or negatively, frowning and saying “that was not very good!” Then, she turned to the box on the other side of her and repeated the pressing and listening actions for the second music clip. She reacted to the second clip in the opposite way (e.g., if she was positive toward the first, she was negative toward the second). She listened and reacted to each clip one more time, resulting in a total of four learning trials, two per clip.

In the test phase, which directly followed the learning phase in each block, the actor was no longer at the table but the two boxes were still present. An occluder slid in from one side to cover half of the
screen so that only one box was visible. This helped to direct infants’ attention to that box. Then, the same clip that had played from that box earlier played again. In the next test trial, the occluder slid in from the opposite side, leaving the other box visible and its music clip played. These trials were repeated for a total of four test trials (two per clip).

In each block, a new set of two music clips were used and a new color of boxes were shown. Between each block, there was a short (3 to 4 second) attention-grabbing animation to keep infants interested in the experiment. There were four different orders allowing counterbalancing across blocks for: the order of music box colors/music clip pairs, whether the clip that received a positive reaction played on the right or the left and first or second, and which of the clips in a pair was reacted to positively or negatively. Music clips were not counterbalanced across box colors, so each pair of clips was consistently matched to one color of music box (e.g., clips 1 and 2 were always played from the green boxes). Example stimuli video clips and the list of video orders can be downloaded from OSF (https://osf.io/kxp8w/files/).

2.1.3 | Procedure

Parents initially received information about the study over the phone and then by email 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 Tobii.
monitor. After a successful 5-point calibration, the experiment began and infants viewed the video sequence as described above. The total video sequence was 8.5 minutes in duration. After the experiment, parents had the opportunity to hear more about the study and ask any questions they might have.

2.1.4 | Data preparation and analysis

Raw data were exported from Tobii Studio and processed in TimeStudio, a MATLAB-based, open-source program for processing of time series data (TimeStudio version 3.21, timestudioproject.com, Nyström et al., 2016). The analysis tools and processing sequence for the current study are described below and can be downloaded from OSF (https://osf.io/7gbtm/).

Data for pupil size were first processed by linearly filling gaps that were 5 samples or shorter and by smoothing using a moving average over 20 samples. Then, target time periods were identified and their pupil reaction scores were calculated using the average pupil size during the target time window minus the average pupil size during a baseline time window. Specifically, for the music segment of the learning phase, the baseline was from 5 to 6 seconds and the analysis phase was from 6 to 14 seconds. For the reaction segment of the learning phase, the baseline was from 13 to 14 seconds and the analysis period was from 14 to 19 seconds. For the test phase, the baseline was from 5 to 1 second and the analysis period was from 2 to 10 seconds (the time during which the music clip played). Data for looking time were calculated by taking the duration of gaze toward the screen during these same target time periods (music segment of learning trial, 8s; reaction segment of learning trial, 5s; and music segment of test trial, 8s) as well as for the entire learning trial (20s) to check whether infants attended to a sufficient percentage of it.

Data exclusions were carried out as described in the preregistration. Entire blocks were excluded if they did not have at least 25% of gaze recorded during the learning phase, to help ensure that infants observed the actor's reactions. For the analyses on pupil dilation, individual test trials were excluded if there was not at least 50% of gaze samples recorded, to be able to obtain an accurate pupil size measurement. If the pupil change value was more than 3 standard deviations from the grand mean for all trials, it was replaced with the next most extreme value (.019% of learning trials and .008% of test trials were replaced in this manner). Participants were excluded if they did not have at least 2 included test trials per music type (positive and negative).

Data analyses were carried out in jamovi (The jamovi project, 2020) using the GAMLj module (Gallucci, 2019). Data were analyzed using linear mixed-effects models which allow data to be analyzed trial by trial, accounting for individual variability across participants which provides a more accurate analysis than methods that use aggregation over trials (Baayen et al., 2008). Preliminary analyses determined whether extraneous variables (participant sex, presentation order, trial, color of music box, or side of music box) affected each of the dependent variables: pupil size and looking duration during test trials. F-scores for the fixed effect omnibus test for these analyses are presented below. For the main analyses, we examined the effect of the actor's reaction to the music clips on the infants' responses (pupil dilation or looking time) by including fixed effects for our main variable of interest: reaction, and a control variable: the infant's response (pupil dilation or looking time) to the clip during the learning trials. The main analyses also included random intercepts for participant and any of the extraneous variables which had a significant effect on that dependent variable in the preliminary analyses. For these analyses, each model is presented in a table including parameter estimates. Based on feedback from reviewers, the analyses presented in the manuscript deviate slightly from our preregistered analysis plan. The results from the preregistered analyses are available on OSF (https://osf.io/x2j7h/), and importantly, none of the main findings differed between the two analysis plans.
Results and discussion

2.2.1 Pupil dilation

Preliminary analyses showed that the variables side of box ($F(1,377) = 11.84, p < 0.001$), and trial ($F(1,390) = 4.32, p = 0.038$) had significant effects on pupil dilation during test trials. The predictors of presentation order, color of box, and participant sex were non-significant (all $p$'s > 0.05). In the main analysis, our main predictor of interest: the actor's reaction, and the control variable of pupil dilation to the particular music clip during the learning phase were included as fixed effects and side of box and trial were included as random intercepts. In this model (see Table 1), there was a significant effect of reaction, such that infants dilated their pupils more in response to music clips that the actor had previously reacted negatively toward. Infants’ pupil response during music learning was also a significant predictor, with greater dilation to music which infants responded to with greater dilation during the learning phase. Together, this reveals that infants’ own physiological arousal to the music clips when they were heard in the test trials was influenced by the actor's earlier reaction to those clips, even when adjusting for infants’ own earlier arousal response to the clip (see Figure 2).

2.2.2 Looking time

Preliminary analyses showed that test trial ($F(1,458) = 144.60, p < 0.001$) had a significant effect on looking time during test. The predictors of presentation order, side of box, color of box, and participant sex were non-significant (all $p$'s > .05). For the main analysis, we included fixed effects for our main predictor of interest: actor's reaction, and the control variable of duration of looking to the music clip during learning trials. Random intercepts for participant and test trial were also included. In this model (see Table 2), only looking duration during learning was significant, with infants looking more during music clips that they looked at more in the learning phase. This suggests that the actor's reaction did not influence infants’ visual attention to the music clips when they heard them later but that infants’ own level of attention to the music clips carried over from learning to test trials.

3 EXPERIMENT 2

In Experiment 1, infants’ physiological responses revealed increased arousal to music clips that had been followed by negative reactions from another person. Although this finding is in line with our hypothesis, it is unclear whether infants memorized the music clips in more relative or more absolute terms. In other words, we do not know whether exposure to clips of similar musical structure might suffice to elicit physiological reactions through generalization. It has been shown that infants may encode pitch patterns, that is, the patterns of ups and downs in tonal melodies, with greater accuracy.

| Effect                        | Estimate | SE  | 95% Confidence interval | df | t    | p     |
|-------------------------------|----------|-----|-------------------------|----|------|-------|
| (Intercept)                   | 0.09     | 0.04| 0.006 – 0.18            | 3.8| 2.10 | 0.107 |
| Reaction (Negative - Positive)| 0.05     | 0.03| 0.004 – 0.10            | 344.2| 2.12 | 0.034 |
| Pupil response to learning music | 0.17     | 0.05| 0.06 – 0.27            | 382.4| 3.19 | 0.002 |
than adults (Trainor & Trehub, 1992). However, whether such accuracy of memory representation would be required for music to elicit differential physiological reactions in response to associated social information is a question we sought to answer in Experiment 2.

3.1 | Method

3.1.1 | Participants

35 infants (16 girls) between 11.5 and 12.5 months of age ($M = 11$ months 28 days) participated in the study. An additional 6 were excluded for having insufficient data (see Data Preparation and Analysis). Participants were recruited, and ethical approval and consent were obtained as in Experiment 1.

3.1.2 | Stimuli

The stimuli were identical to those used in Experiment 1 with the exception that the clips played during the test trials were not the exact same clips that were played during the learning trials. That is, for each learning phase clip, a new generalization clip was obtained from the original piece of music. The process for selecting the generalization clips was that for each original clip, three potential generalization clips were first identified by research assistants. These clips were then rated by eight adults as to how similar they were to the original clips (from not at all similar (0) to very similar (5)). From the ratings, the overall average was calculated (3.14) and the clip from each set that was closest to the overall average was selected as the generalization clip for the stimuli (range = 2.71 to 3.43). A full list of clips is available on OSF (https://osf.io/94qp8/).
3.1.3 | Procedure

The procedure was identical to that of Experiment 1.

3.1.4 | Data preparation and analysis

Data preparation and analysis were carried out as in Experiment 1 and can be downloaded from OSF (https://osf.io/zqp2d/). When outliers were replaced as in Experiment 1, .007% of learning trials and .011% of test trials were affected.

3.2 | Results and discussion

3.2.1 | Pupil dilation

Preliminary analyses showed that the predictors of presentation order, side of box, color of box, test trial, and participant sex were non-significant (all $p$’s > 0.05). In the main analysis, we included reaction and pupil dilation during learning as fixed effects and a random intercept for participant. In this model (see Table 3), there were no significant predictors, suggesting that the actor’s reaction to the original music clips did not influence infants’ later physiological arousal to similar music clips.

3.2.2 | Looking time

Preliminary analyses showed that test trial ($F(1,502)=95.44, p<0.001$) had a significant effect on looking time during test. The predictors of presentation order, side of box, color of box, and participant sex were non-significant (all $p$’s > 0.05). For the main analysis, we included fixed effects for reaction and looking time during learning music and random intercepts for test trial and participant. In this model (see Table 4), only looking time during learning music was significant, with more looking in learning predicting more looking during test as well. As with the pupil results, this suggests that the actor’s reaction to the original music clips did not influence infants’ visual attention to the similar clips. However, the predictive value of infants’ earlier looking duration from the learning trials and their later looking duration in the test suggests that they did at least associate the two clips or have similar levels of attention to them, even though they were not identical.

| Effect                               | Estimate | SE  | 95% Confidence interval | df    | t    | p     |
|--------------------------------------|----------|-----|-------------------------|-------|------|-------|
| (Intercept)                          | 0.13     | 0.02| 0.09 – 0.17             | 35.8  | 5.74 | <0.001|
| Reaction (Negative - Positive)       | 0.02     | 0.03| −0.04 – 0.08            | 370.4 | 0.74 | 0.458 |
| Pupil response to learning music     | −0.01    | 0.07| −0.15 – 0.12            | 377.2 | −0.19| 0.850 |
We conducted two experiments to answer the question of whether 12-month-old infants show differential responses to music based on an adult’s positive or negative reactions to it. Our findings revealed that when the same music clips were presented in the learning and the test phases, music that had received a negative reaction led to greater pupil dilation than music that had received a positive reaction. Moreover, this finding was not replicated when the learning and test phases presented similar, rather than identical, clips from the pieces of music, suggesting that infants’ learning might be fairly specific in this context.

Previous work has confirmed a high degree of musical competences in infants that have both learned and genetic origins (Stefanics et al., 2009; Tan et al., 2014). These competences include memory for complex music from the age of seven months (Saffran et al., 2000; Volkova et al., 2006) and preferences based on musical features (Conrad et al., 2011; Trainor & Heinmiller, 1998; Trainor et al., 2002). Infants’ exposure to music in their culture (Soley & Hannon, 2010) and from their caregivers specifically (Mehr et al., 2016; Mehr & Spelke, 2018) also influences their preferences and now we have evidence suggesting that—beyond mere exposure—observing other individuals’ reactions to music could further shape infants’ preferences. This finding is in line with research on older children, adolescents, and adults showing that the opinions of others influence individuals’ music preferences in conformity paradigms (Finnäs, 1989).

Our study adapted a social referencing style of paradigm in order to explore whether infants’ responses to music would be affected by others’ positive and negative reactions, just as they are for more concrete objects, such as toys. The current findings show that infants are susceptible to others’ reactions to music and the influence is evident on a physiological level. This apparent transfer of response from adult to infant could be seen as evidence for the social importance of music and its ability to be culturally transmitted (Mehr et al., 2016; Mehr & Spelke, 2018). Further, the pupil dilation in response to a stimulus that had been negatively tagged by an adult might indicate learning to be wary of the stimulus or of sharing the adult’s negative arousal and in this way, our findings align with the negativity bias demonstrated in infants’ attention and responses to others’ emotions. Explanations for the negativity bias are often rooted in evolutionary and ecological accounts, suggesting that the bias is based on functional survival needs. Thus, given that we have evidence for a negativity bias for music, several possibilities arise. First, it could be that the negativity bias is more based on the salience or novelty of negative emotions, rather than survival-related evolutionary processes. On the other hand, it could be argued that given the social bonding potential of music, learning to like and dislike music along with your group members is indeed an aspect of survival that could be subject to evolutionary pressures just as foods and other concrete items in the world are. Finally, it could also be that the negativity bias is a domain-general one which applies to any stimuli. That is, while music might not be directly related to survival, the same mechanisms that shape our exploration and interest in the world around us might generalize to music as well. That is, our default response to music might be to enjoy

| Effect                             | Estimate | SE  | 95% Confidence interval | df | t    | p     |
|-----------------------------------|----------|-----|-------------------------|----|------|-------|
| (Intercept)                       | 4.07     | 0.24| 3.61 – 4.54             | 31.1| 17.13| <0.001|
| Reaction (Negative - Positive)    | −0.23    | 0.14| −0.51 – 0.06            | 476.0| 1.57 | 0.117 |
| Looking duration during music learning | 0.14     | 0.04| 0.05 – 0.22             | 524.7| 3.24 | 0.001 |

4 | GENERAL DISCUSSION

We conducted two experiments to answer the question of whether 12-month-old infants show differential responses to music based on an adult’s positive or negative reactions to it. Our findings revealed that when the same music clips were presented in the learning and the test phases, music that had received a negative reaction led to greater pupil dilation than music that had received a positive reaction. Moreover, this finding was not replicated when the learning and test phases presented similar, rather than identical, clips from the pieces of music, suggesting that infants’ learning might be fairly specific in this context.

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and be interested in it and it is only after negative social information that we internalize a negative reaction and alter our response.

The findings from Experiment 2, in which infants did not react with significantly increased arousal based on the actor's reactions when presented with music clips similar to the previously disliked ones, raises questions about the strength and perseverance of the effect. It is possible that infants did not perceive the clips as sufficiently similar to generalize the actor's reaction from one to the other and that they may need more experience with complex music to develop these skills, for example to interpret the reaction as applying to the entire song or genre, rather than a specific musical feature present in the particular clip. However, the finding that looking time to music clips during the learning phase was predictive of looking time to the paired similar clips during the test phase in both experiments suggests that infants did associate them on some level, resulting in similar levels of attention. Based on our current data, it appears that the precise information upon which an evaluation takes place is important and that similar music of the same type may not fall under the regime of (negative) evaluation, at least for this age of infants. Importantly, the null result from Experiment 2 also helps to rule out a potential alternate explanation that infants interpreted the actor's reactions as being directed to the boxes themselves rather than the music that played, since if that had been the case, the same effect should be apparent across both studies.

One strength of this study was the application of a robust measure of physiological reactions, namely pupil dilation, which has also been interpreted as a proxy for the activity of norepinephrine in studies on music listening in adults (Laeng et al., 2016). However, this measure also reflects a complex set of cognitive and affective processes and the relative contribution of each is uncertain. Therefore, our results could, for example, point to processes of expectancy violation, heightened attention, or a combination of those. Thus, while we can only speculate at this point about the exact mechanisms underlying our findings, the overall finding remains the same: that infants react more strongly—whether in attention, cognitive processing, or arousal—to music excerpts to which they observed another person react negatively. Future studies could build on this work by including additional outcome measures that will help to disentangle the social, cognitive, and affective components that underlie the current observations.

Several limitations of the study should be noted. First, there may not have been sufficient exposure to the actor's reactions in order for the familiarization and preference behaviors that have been documented in other studies with much more extensive learning phases (e.g., Mehr & Spelke, 2018) to emerge. Another limitation is that parents did not wear noise-canceling headphones or blindfolds, and thus, it is possible that their own reactions to the stimuli could have been subtly communicated to their infant through touch, influencing infants' responses. Finally, we did not include objective measures of similarity between the sets of stimuli in Experiment 2, only ratings from non-expert adults. Therefore, our finding of a lack of generalization across similar items must be treated with some caution. Subjective and objective measures of similarity in music has been a topic of extensive research efforts (e.g., Bello, 2011; Berenzweig et al., 2004), and it is possible that we did not have sufficient precision in selecting pairs of excerpts that were both distinguishable from each other and sufficiently similar to the infants' ears to evoke a generalization response.

5 | CONCLUSIONS

In sum, our findings corroborate and extend previous work on the influences of others’ positive and negative reactions on 12-month-old infants’ responses to stimuli. Infants are sensitive to others’ positive and negative expressions toward external stimuli and use this information to build up their own
knowledge and impressions of the world around them, underlining the importance of social learning not only for concrete objects, but also for more abstract and artistic experiences.

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