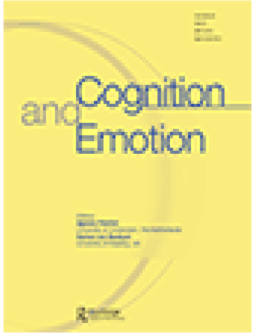

Cognition and Emotion

ISSN: 0269-9931 (Print) 1464-0600 (Online) Journal homepage: http://www.tandfonline.com/loi/pcem20

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To cite this article: Rosa M. Angulo-Barroso, Susana Peciña, Xu Lin, Mingyan Li, Julia Sturza, Jie Shao & Betsy Lozoff (2016): Implicit learning and emotional responses in nine-month-old infants, Cognition and Emotion, DOI: 10.1080/02699931.2016.1179624

To link to this article: http://dx.doi.org/10.1080/02699931.2016.1179624

COGNITION AND EMOTION, 2016
http://dx.doi.org/10.1080/02699931.2016.1179624

Implicit learning and emotional responses in nine-month-old infants

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ABSTRACT
To study the interplay between motor learning and emotional responses of young infants, we developed a contingent learning paradigm that included two related, difficult, operant tasks. We also coded facial expression to characterise emotional response to learning. In a sample of nine-month-old healthy Chinese infants, 44.7% achieved learning threshold during this challenging arm-conditioning test. Some evidence of learning was observed at the beginning of the second task. The lowest period of negative emotions coincided with the period of maximum movement responses after the initiation of the second task, and movement responses negatively correlated with the frequency of negative emotions. Positive emotions, while generally low throughout the task, increased during peak performance especially for learners. Peak frequency of movement responses was positively correlated with the frequency of positive emotions. Despite the weak evidence of learning this difficult task, our results from the learners would suggest that increasing positive emotions, and perhaps down-regulating negative emotional responses, may be important for improving performance and learning a complex operant task in infancy. Further studies are necessary to determine the role of emotions in learning difficult tasks in infancy.

ARTICLE HISTORY
Received 8 July 2015
Revised 18 December 2015
Accepted 14 April 2016

KEYWORDS
Motor learning; positive affect; negative affect; contingent learning; children

Young infants are capable of surprising implicit learning. Researchers on motor learning have exploited specific motor capacities of infants at different developmental stages. Spontaneous activities, like newborns' sucking or three-month-old leg movements, can quickly shift to instrumental activities when harnessed by the appropriate experimental arrangement. For instance, infants as young as one month of age can adjust their sucking rate to obtain an interesting visual display on a monitor (Milewski & Siqueland, 1975), three-month-old infants can increase the frequency of kicks to make an overhead mobile move (Angulo-Kinzler, 2001; Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980), and eight-month-old infants can learn to bounce on a Jolly-jumper by selecting the appropriate timing and amount of force generated by their legs (Goldfield, Kay, & Warren, 1993).

Although motor learning has been widely studied and demonstrated in infancy, there is less research on concurrent emotional responses. When infants learn a contingent response in tasks relatively easy, they display increases in positive emotional expression (Alessandri, Sullivan, & Lewis, 1990; Lewis, Sullivan, & Brooks-Gunn, 1985; Lewis, Sullivan, Ramsay, & Alessandri, 1992; Sullivan & Lewis, 1989). In contrast, when the contingency is taken away during the extinction phase and movement responses produce no reward (a brief extinction), infants display increased negative emotional expressions (Alessandri et al., 1990; Lewis, Alessandri, & Sullivan, 1990; Lewis et al., 1992; Sullivan & Lewis, 1989; Sullivan, Lewis, & Alessandri, 1992).

Less is known about how infants respond in challenging learning tasks. We were unable to identify

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Supplemental data for this article can be accessed here at 10.1080/02699931.2016.1179624.

prior studies of motor learning capacities and emotional responses in infants faced with difficult tasks. Infants' motor skills and motor control expand considerably by nine months of age, which allows for more complex motor-cognitive learning demands. In this study we developed a contingent learning paradigm that included two consecutive tasks that were difficult at nine months of age. This paradigm required one particular arm movement to be learned in the first task, and a different, but related, arm movement in the second task. Previous research demonstrated positive transfer when related tasks are practiced back-to-back (Angulo-Kinzler, Ulrich, & Thelen, 2002; Rosalie & Müller, 2012; Rovee-Collier, Morrongiello, Aron, & Kupersmidt, 1978; Stöckel & Wang, 2011; Weigelt, Williams, Wingrove, & Scott, 2000). To characterise emotional response to performance and learning we coded facial expressions. Given the difficulty of the tasks, we hypothesised that nine-month-old infants would demonstrate partial learning of both contingent tasks, but experience in the first task would enhance performance in the second task. We also expected high frequency of negative emotions. Based on previous literature, we predicted that infants would demonstrate positive emotional expressions during the acquisition phases but negative emotional expressions during the extinction phase. We also expected to see a relationship between learning and emotion such that better learning would correlate with positive emotions.

Method

Participants

This pilot study of motor learning and emotion was part of a larger project on iron deficiency in infancy. The project, conducted in southeastern China, was approved by the Institutional Review Board of the University of Michigan and the Children's Hospital of Zhejiang University. Signed informed consent was obtained from the families before infants were assessed.

Given the novelty of the experimental set-up presented here, we examined contingent learning and emotional responses at nine months of age for infants recruited in the initial enrolment period. We included all 38 infants for whom we had good video recording and output motor data. All infants were healthy, full-term singletons, weighing 3.3 Kg at birth on average and born to mothers ≥18 years. All infants were initially breast-fed. The average age of the infants was 9.3 ± 1.1 months and the sample included 36.8% males and 63.2 females and 31.6% of the fathers and 36.8% of the mothers had high school or higher education. We report how we determined our sample size, all data exclusions, all manipulations and all measures in the study.

Instrumentation

An arm-conditioning apparatus was designed and built for the purpose of this study. The apparatus consisted of a handle in T-form, an encoder, a data acquisition card (National Instruments, TDAQ744), a portable PC, a display screen and custom software. The T-handle was attached to the encoder, which was calibrated to measure degrees of angular displacement of the T-handle. The attachment structure permitted a maximum displacement limit of 150 degrees centred about the vertical position of the T-handle. In addition, the T-handle-encoder structure could be pivoted 90 degrees so that the handle could be moved either forward–backward or side-to-side. The T-handle structure was attached to a table via a custom-built clamping system (see Supplemental Figure 1). Customised software (Labview 2008, National Instruments) controlled the trajectory of the T-handle almost in real time via the input received from the encoder. In this way, the display on the screen (video display and sound of a cartoon) could be controlled depending on the decision criterion established (and programmed) to reinforce a given movement of the bar the infant made (see Figure 1 (S) and videos in the supplemental materials). A successful movement had to cover at least 20 degrees of range of motion centred on the vertical position in no more than 750 msec. If this criterion was met, the computed displayed a cartoon movie for 1.5 sec. If successive movements were produced that met criterion, the cartoon would seem to be displaying continuously. If the infant's movement at the bar did not meet criterion, the cartoon stopped. The still image of the last cartoon frame was displayed until a new successful movement was produced. To record emotional reactions to the task for future analysis, a video camera was placed such that the infant's face could be seen. The computer screen display that controlled the experiment and the video of the infant's face were simultaneously recorded in a separate computer using a multiple input frame grabbing board.

Procedures

At nine months, infants were brought to the Children's Hospital of Zhejiang University, Hangzhou (China) for a full assessment day. Infants were tested on the arm-conditioning task after having lunch and a nap. Infants were seated on the caregiver's lap in a quiet, semi-lit room in front of a 16-inch screen. The T-handle with two red grasping ends at each extreme of the top handle bar was located between the infant and the screen. The chair height was adjustable so that the chest of the infant was at the same height as the top bar of the T-handle.

Before beginning each test, the encoder was calibrated so that the offset values were known and kept constant. The following instructions were given to the caregiver:

> Your baby will be tested on his/her ability to move this handle and control the display of a cartoon. Please make sure you give stable sitting support to your child but do not place his/her hands on the handle or make him/her rock. You may point to the screen if your baby is not interested in the screen display.

The test consisted of the following phases: (1) baseline (BA) of 2.30-seconds blocks (1 minute) where the infant could play with the handle but the cartoon would not start; (2) short contingency shaping phase (30 sec) where the experimenter demonstrated movement of the handle and the display and sound of the cartoon; (3) first acquisition phase (A1) of 8.30-second blocks (4 minutes) consisting of infant manipulation of the handle with the display of the cartoon if he/she moved the handle in the appropriate manner; (4) second acquisition phase (A2), 8.30-second blocks (4 minutes) where the infant manipulated the rotated handle so that a different arm movement was required for the cartoon to be displayed and (5) extinction phase (E), period similar to BA where the cartoon was not displayed but lasting 4.30-second blocks (2 minutes). Thus, infants were basically given two tasks under this procedure (forward–backward and side-to-side). In acquisition 1, infants received the reinforcement of the motion and sound of the cartoon if they produced a forward or backward movement of the T-handle. In acquisition 2, a movement left-to-right or right-to-left generated the cartoon. In both tasks, the movements had to be of a specific amplitude and velocity to be successful.

Data reduction

Counts of successful movements were recorded via the customised software for each testing phase in blocks of 30 sec (Figure 1(a). A mean was computed for BA and used to define a learning threshold and to control for BA level in subsequent blocks. Infants were considered to have learned the contingencies of arm movement to non-static movie display when they achieved 1.5 times BA values in at least four 30-second blocks of a given acquisition phase (Angulo-Kinzler et al., 2002; Fagen, Morrongiello, Rovee-Collier, & Gekoski, 1984). Infants were classified as learner or non-learners in each acquisition phase for further analyses. In addition, a statistically significant increase of successful arm movements during one block was considered as an indication of partial learning (Rovee & Rovee, 1969).

Because infants demonstrated large variability in spontaneous motor behaviours and rate of learning during these complex tasks, we focused on peak performance to assess optimal performance when limited ability to maintain a highly specific behaviour for a relatively long period of time exists. Peak performance was focused on the periods demonstrating some learning and on those infants who showed evidence of learning. We identified the 30-second block during A1, A2 and E in which each infant produced the highest frequency of movements that met criterion (Angulo-Kinzler, 2001). Peak performance was calculated by dividing the number of arm movements in the identified blocks by BA.

Video coding of emotional responses

Facial expressions were coded from videotape using the Affective Expressions Scoring System (AFFEX), (Izard, 1982). Positive affective responses included smiling and laughing. Negative affective responses included crying and fussing. In addition to coding facial expressions, we recorded instances in which infants actively pushed back from the equipment with either hands or feet. Pushing back generally co-occurred with crying or fussing and was integrated with the negative responses. Other negative emotional responses such as fear or disgust emotional responses occurred in such low frequency that their analysis was precluded.

Videos were coded for positive and negative emotional responses during the BA, first acquisition phase (A1), second acquisition phase (A2) and extinction phases (Figure 1(b)(c)). In further analyses, the emotional responses time blocks analysed coincided with those with peak performance for movements.

Video segments were identified by subject number only. Each segment was viewed with sound to score the occurrence of laughing and fussing/crying behaviour. Coders were trained until they achieved an inter-coder reliability of .85 or better (mean 89% agreement). A 20% random sample of records was then independently coded to check inter-rater reliability after training. Reliability exceeded .80 for each emotional expression scored.

Data analysis

Statistical analyses were performed using IBM SPSS Statistics 22.0. For motor and emotional outcomes, planned comparisons were conducted in the whole sample across phases. In addition, Pearson correlations were conducted between movement, and positive and negative emotional responses for the time blocks where learning was demonstrated. To further examine changes in motor and emotional responses across phases, peak movement performance during acquisition phase 2 (when partial learning occurred) and extinction blocks were selected to conduct One-way ANOVAs with repeated measures in Phase. In addition, and to explore the behaviour of those infants who learned in the acquisition phase where significant improvement was observed, mixed ANOVAs were also conducted for learners versus non-learners in acquisition 2 to test for group (learners, non-learners) and phase (B, Pk_A1, Pk_A2, Pk_E) and group by phase interactions. *Post-hoc* comparisons were conducted with least significant difference corrections. Level of significance was set to $p < .05$.

Results

Contingent learning

Successful arm movements for each 30-second block by phase (B, A1, A2 and E) are shown in Figure 1(a) for all infants together. There was a significant increase in successful movement at the initiation of acquisition 2 (A2–60) when the task changed from forward–backward movements to side-to-side movements ($t = -1.99$, $p < .05$) compared to average BA performance. Eight infants (21%) were able to increase their BA successful motor responses by 50% in both acquisition phases. An additional four infants learned in acquisition 1, and five others did so during acquisition 2. Therefore, 31% and 34% of the infants showed evidence of learning in the initial forward–backward and the side-to-side task, respectively. A total of 17 infants (44.7%) achieved learning threshold in either or both arm-conditioning tasks.

Positive and negative emotional responses are shown in Figure 1(b)(c), respectively. The overall frequency of negative emotions across the entire test was higher than that of positive emotional responses. Negative emotions followed a bimodal distribution with the two lowest periods overlapping with BA and maximum movement responses in acquisition 2 (shaded zone in Figure 1). Negative emotional responses in the shaded area were lower than mid-acquisition 1 and mid-acquisition 2 ($t = 2.54$, $p < .02$ and $t = 2.78$, $p < .01$, respectively).

Correlation between movement and emotional responses

Arm movements were negatively associated with negative emotional responses at block A2–60 (within the first minute of acquisition 2) ($r = -0.333$, $p = .041$), and showed a similar suggestive trend for A2–30 ($r = -0.302$, $p = .065$). Positive emotional responses were not significantly correlated with movement responses.

Movement and emotional responses at peak response: all subjects

See Figure 2S in the supplemental materials for a representation of group mean values for peak movement responses and for corresponding positive and negative emotional responses. On average, peak movement responses in A2 occurred during the third block. There were significant phase differences for peak movement responses ($F(3, 36) = 17.5$, $p < .001$, $p\eta^2 = 0.49$). *Post-hoc* analyses confirmed that BA was different from Pk_A2 and Pk_E, while these last two phases were similar. There was also a significant phase effect for peak positive responses ($F(3, 36) = 5.0$, $p = .012$, $p\eta^2 = 0.22$), where only Pk_A2 was greater from BA. Finally, peak negative responses were different across phases ($F(3, 36) = 24.5$, $p < .001$, $p\eta^2 = 0.58$). Specifically, BA was different from other phases and Pk_A2 was different from Pk_E. The Pearson correlation was significant only between

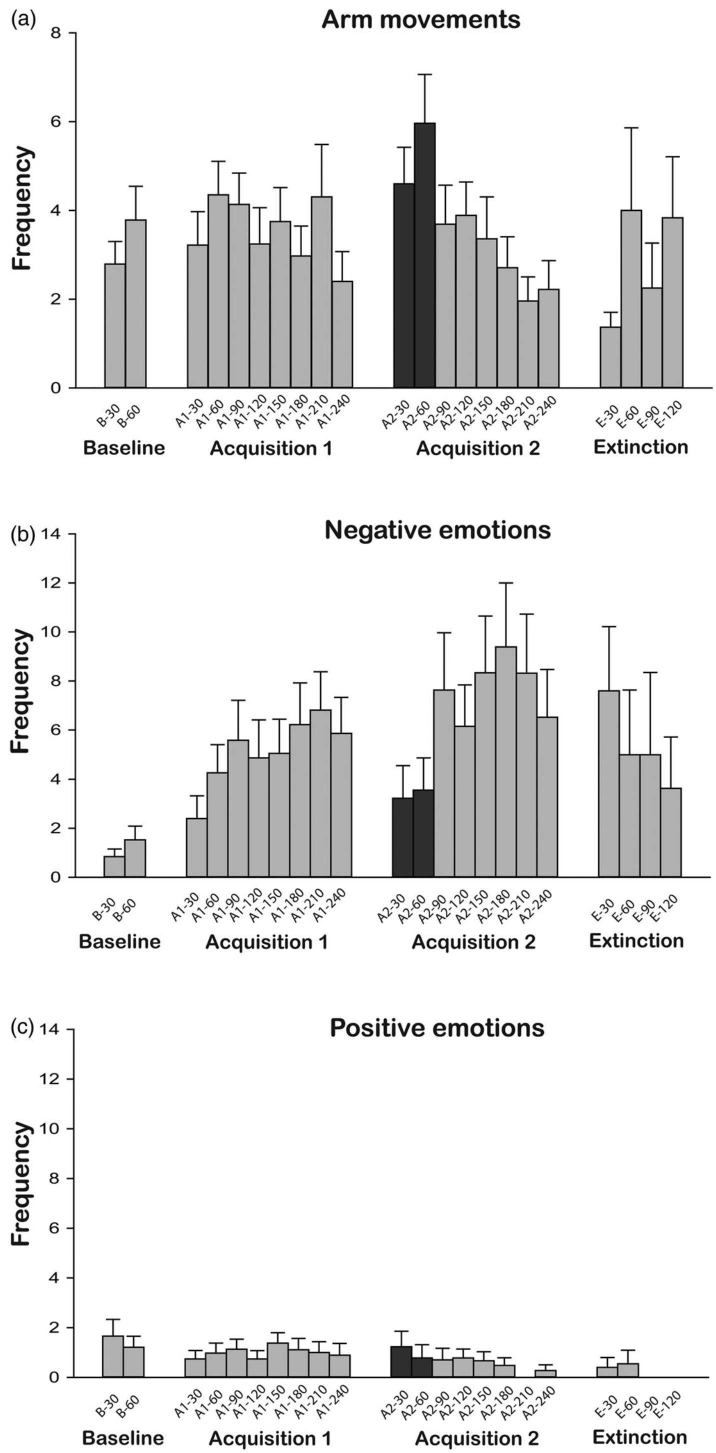

Figure 1. Mean and standard errors of appropriate arm movements (a), positive emotions (b), and negative emotions (c) across all phases and blocks for all infants. Values in acquisition 1, acquisition 2 and extinction are not adjusted for BA.

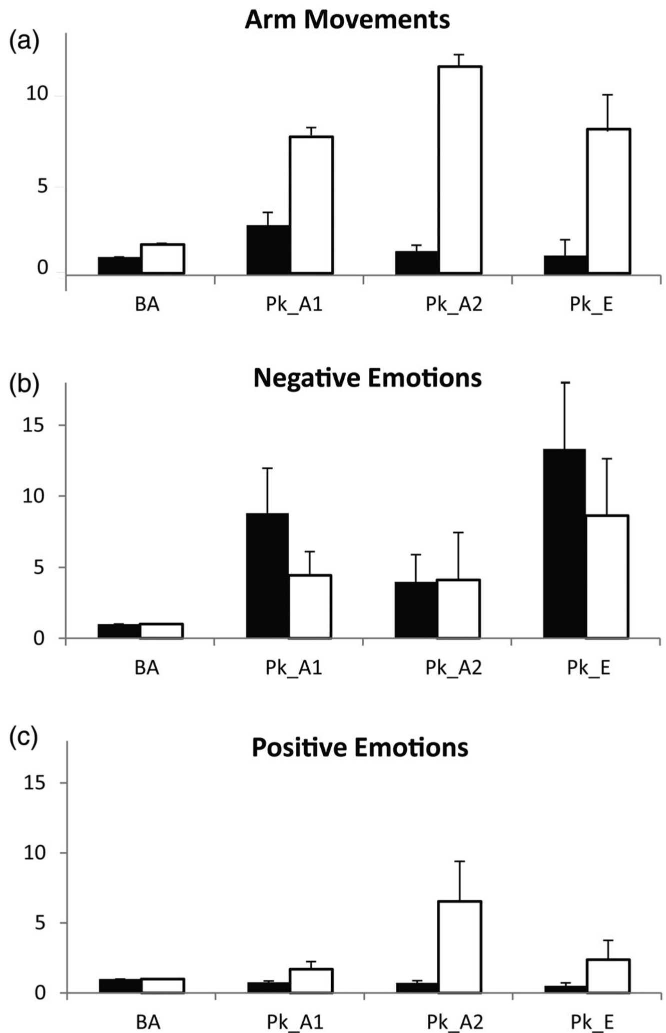

Figure 2. Average peak movement responses and positive and negative emotional responses adjusted for BA across phases for learners and non-learners in acquisition 2.

peak movement response and positive emotional responses during acquisition 2 ($r = 0.356$, $p = .028$).

Movement and emotional responses at peak response: learners versus non-learners in acquisition 2

The 13 infants who learned in acquisition 2 (34%) increased movement counts from BA to acquisition 2, while the non-learners maintained the same BA level (a significant group by phase interaction ($F(3, 34) = 18.97$, $p = .001$, $p\eta^2 = 0.63$). An additional significant group main effect was found ($F(1, 36) = 16.06$, $p < .001$, $p\eta^2 = 0.31$). The main effect of phase ($F(3, 34) = 40.39$, $p < .001$, $p\eta^2 = 0.78$) was also significant with an increase from BA to acquisition 2 and a significant decrease from acquisition 2 to extinction (Figure 2(a), top).

The results indicated that the learners produced more positives responses than non-learners ($F(1, 36) = 7.44$, $p = .01$, $p\eta^2 = 0.17$). In addition, there was a significant group by phase interaction for positive emotional responses ($F(3, 34) = 2.95$, $p < .05$, $p\eta^2 = 0.21$) suggesting that learners increased positive emotional responses from BA to acquisition 2, while the non-learners decreased their levels (Figure 2(b), middle).

Negative emotional responses showed a significant phase effect ($F(3, 34) = 15.3.0$, $p < .001$, $p\eta^2 = 0.57$) with overall increases from BA to acquisition 1 and extinction and a significant increase from acquisition 2 to extinction (Figure 2(c), bottom). Thus, negative emotional responses were kept closer to BA level during peak response in acquisition 2.

Person correlations were not conducted given the small sample.

Discussion

We expected that nine-month-old infants could learn the relationship between arm movement and cartoon display with some degree of difficulty. Indeed, learning rates defined by 1.5 BA threshold were clearly below 50%. Nevertheless, our overall results suggest some level of learning since a significant increase in the frequency of appropriate responses was observed during the initial part of acquisition 2. In contrast, the expected increase of motor responses in the extinction phase was not observed. The observed learning in acquisition 2 may be due to sufficient practice time, transfer of learning, a positive effect of an easier task, or a combination of these factors.

Instead of the expected increase in positive emotional responses during the learning (acquisition) and the expected increase in negative emotional responses during the extinction phase, we found an overall increase in negative responses. In essence, this task seemed to generate a certain level of frustration (negative emotion) in the infants. However, these negative emotions were reduced when evidence of partial learning occurred. Furthermore, peaks of performance were associated with positive emotional responses and learners showed an increase of positive emotional responses. These findings will be considered in relation to prior research.

Learning

Within the first year of life, infants can modulate their sucking, head turning, gaze, legs and arm movements to receive a reward (Lewis et al., 1990; Rovee-Collier et al., 1980; Tiernan & Angulo-Barroso, 2008). In almost all of these studies, infants increased the appropriate motor responses during the acquisition phase as a demonstration that the contingent relationship between response and reward was learned. Our results demonstrated some learning but only in acquisition 2. The task requirements were demanding in both range and speed of movement. Furthermore, increases in the motor response in the retention phase, that is, when the reinforcement is not available, have been seen in most prior studies. However, we did not observe this increase in the extinction phase, perhaps because two tasks were involved, and tasks were difficult. In studies that examined individual differences (Sullivan & Lewis, 2003; Tiernan & Angulo-Barroso, 2008; Watanabe et al., 2013), not all infants demonstrated learning; those who did, typically showed lower levels of motor responses during the BA. Our results are in agreement with these findings. It is possible that there is an inverted *U*-shaped relationship between frequency of motor responses and learning, but confirmation will require further investigation.

The ability to transfer learning to new situations is one critical aspect of learning. Positive transfer of learning between two similar tasks has been previously demonstrated in the literature (Ben-Tov, Levy-Tzedek, & Karniel, 2012; Kitazawa, Kimura, & Uka, 1997). Although our task was not designed as a transfer test, it is likely that some transfer of learning occurred because our two consecutive tasks shared identical reward (movie display on the monitor) and included common aspects of movement requirements (holding a T-handle, arm movement). In fact, the two tasks shared all contextual and task demand variables except for movement direction. Little is known about transfer of learning between two different but related motor responses in infancy. In contrast, transfer of learning in infancy has been more widely demonstrated in the symbolic-language and visual-auditory domains (Barr, 2010; Hupp & Sloutsky, 2011; Zack, Gerhardstein, Meltzoff, & Barr, 2013). In the motor domain, Rovee-Collier et al. (1978) showed transfer of learning from one leg to the other via a mobile response-reversal procedure in three-month-old infants. A more recent study by Angulo-Kinzler (2001) demonstrated that three-month-old infants who learned an intralimb coordination task with one leg were able to transfer this learning to the other leg using a contingent reinforcement paradigm. In our study, transfer of learning required a change in movement direction. Infants could use a strategy based on movement corrections, guided by sensory feedback, and/or in cognitive representation that better suits the task-goal (McNay & Willingham, 1998). Our data may be the consequence of nine-month-old infants demonstrating some, but limited, ability to transfer learning under such experimental conditions. Alternatively, enhanced learning may be seen during the second acquisition, because more practice accumulated, and/or the task requirements were easier in the side-to-side than in the forward–backward arm movement. Perhaps holding and moving the T-handle side-to-side may require less effort. Nevertheless, future research should examine these possibilities.

Emotional responses

The contingent learning paradigm elicited positive and negative emotions and thus provided a tool to examine the interplay between emotions and learning in a highly demanding and frustrating task in infants. Negative emotions were high throughout the contingency task and more frequent than positive emotions, indicating the challenging nature of the task at this age. Positive emotions arise in contexts appraised as safe and familiar (Izard, 1997) and as requiring low efforts (Ellsworth & Smith, 1988). However, a close examination of the emotions elicited throughout the contingent learning paradigm revealed that the partial learning of appropriate motor responses, evident at the beginning of the second task, was accompanied by an initial decrease of negative emotions and a subsequent increase in positive emotions concurrent with peak performance.

Negative emotions, though high throughout the contingent learning test, decreased during peak performance. Most importantly, the decrease in negative emotions was also observed in the time block previous to peak response. While peak arm movement responses occurred on average during the third block of acquisition 2 (i.e. 60–90), a significant decrease in negative emotions was observed during the first two blocks of acquisition 2 (i.e. 0–60). These findings suggest that a reduction in negative emotionality allowed improvements in performance and partial learning. However, whether learning a difficult and somehow frustrating task may require down-regulation of negative emotions needs future examination.

Several studies have investigated negative emotionality associated with goal blockade during contingency learning in infants. These studies show that when an infant's access to a positive reward is blocked, facial expressions predominantly of anger emerge (Alessandri et al., 1990; Lewis et al., 1992; Sullivan & Lewis, 2003). The negative emotionality in these studies has been interpreted as a natural reaction to the blockage of the reward and as the disruption of the infant's expected control over the contingent stimulus (Lewis et al., 1990). Our study is, to our knowledge, the first to examine the link between emotionality and learning during the acquisition phase of complex/difficult operant tasks that elicit negative emotions in the absence of goal blockade.

Our initial analysis did not reveal an increase of positive emotions during learning in the initial phase in acquisition 2. However, positive emotions correlated with peak arm movements and learners demonstrated an increase of positive responses from BA to acquisition 2. These results support previous findings that contingency learning in infants is often associated with positive emotional expression (Alessandri et al., 1990; Lewis et al., 1992). Our results do not allow us to infer the direction of causality between positive emotions and learning. While it is possible that the increase of positive emotions might have facilitated learning, it is also possible that learning of the task at hand might have resulted in an increase in positive emotions.

Taken together, our findings indicate that emotional processes are dynamically linked to performance enhancement and potentially learning processes even in young infants. Specifically, our results support the notion that up-regulation of positive emotions, and perhaps down-regulation of negative emotional responses, might be necessary for the learning of complex/difficult operant tasks in infants.

Limitations

Our results should be considered cautiously since the study has several limitations. Our sample size was relatively small, though similar in size to many infancy studies of contingent learning. Whether one task was harder than the other cannot be experimentally tested because task order presentation was not randomised. Results from healthy, full-term infants in China may not generalise to other populations. Furthermore, evidence of learning was limited since only about one third of infants achieved learning criteria in acquisition 2. Emotions were evaluated via subjective assessment of facial expressions and we did not assess attention. Finally, we assessed only one type of learning, that is, learning that depends on a reward or reinforcement. Transfer of learning and its relation to emotional responses should be examined in a different experimental setting that includes counterbalanced presentation of the two tasks, and in other learning paradigms, such those that consider statistical-learning (Aslin, 2014).

Conclusions

The main contributions of this study are its demonstration of motor-perceptual learning of a difficult task in nine-month-old infants and plausible interactions between enhanced performance, learning and emotion at this age. Overall, some nine-month-old infants were capable of learning a relatively difficult arm movement task if given practice and a subsequent related task. However, there were large individual differences: BA levels of movement responses varied across infants, not all infants at this age demonstrated an increase in appropriate arm movements sufficient to control the cartoon display, and peak responses occurred at different times.

Increasing positive emotional responses in the face of a difficult task and perhaps limiting levels of negative emotional responses in a rewarding situation may facilitate learning, particularly of a subsequent related task in nine-month-old infants. However, further research is necessary to support the idea that strategies to constrain negative emotions and reinforce positive emotional responses may be important in parental and educational programs to enhance infant learning.

Acknowledgements

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health. The National Institutes of Health had no role in study design; the collection, analysis, and interpretation of data; the writing of the report; and the decision to submit the manuscript for publication. The authors thank the infants and families who participated in the study and all team members in Children's Hospital Zhejiang University School of Medicine and at the Center for Human Growth and Development for their assistance with data collection and data reduction.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was part of a National Institutes of Health-supported cross-species program project (Brain and Behavior in Early Iron Deficiency [No. P01 HD039386], Betsy Lozoff, Principal Investigator), and supported as well by the National Natural Science Foundation of China grant (Effects of early iron deficiency on brain and behavior in infants [No. 30671773], Jie Shao, PI).

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