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RESEARCH ARTICLE

High quality social environment buffers infants' cognitive development from poor maternal mental health: Evidence from a study in Bhutan

Joshua Juvrud[1] | Sara A. Haas[1] | Marcus Lindskog[1] | Kim Astor[1] | Sangay C. Namgyel[2] | Tshering Wangmo[2] | Wangchuk[2] | Sithar Dorjee[3] | Kinzang P. Tshering[3] | Gustaf Gredebäck[1]

[1] Uppsala Child and Baby Lab, Department of Psychology, Uppsala University, Uppsala, Sweden

[2] Faculty of Nursing and Public Health, Khesar Gyalpo University of Medical Sciences of Bhutan, Thimphu, Bhutan

[3] Khesar Gyalpo University of Medical Sciences of Bhutan, Thimphu, Bhutan

Correspondence
Joshua Juvrud, PhD, Games & Society Lab, Department of Game Design, Uppsala University, Campus Gotland, 62167 Visby, Sweden.
Email: Joshua.juvrud@speldesign.uu.se

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Abstract

Poor maternal mental health negatively impacts cognitive development from infancy to childhood, affecting both behavior and brain architecture. In a non-western context (Thimphu, Bhutan), we demonstrate that culturally-moderated factors such as family, community social support, and enrichment may buffer and scaffold the development of infant cognition when maternal mental health is poor. We used eye-tracking to measure early building blocks of cognition: attention regulation and social perception, in 9-month-old Bhutanese infants ($N = 121$). The cognitive development of Bhutanese infants in richer social environments was buffered from poor maternal mental health, while for infants in environments with lower rates of protective social environment factors, worse maternal mental health significantly predicted greater costs for infant attention, a fundamental building block cognition. International policies and interventions geared to improve maternal mental health and child health outcomes should incorporate each regions' unique family, cultural, and community support structures.

KEYWORDS
infant cognitive development, maternal mental health, protective factors, social environment

1 | INTRODUCTION

During infancy, the brain undergoes rapid change, and critical building blocks of cognition are established (Drury et al., 2016). Two early emerging abilities paramount for later cognitive development are attention regulation (Cuevas & Bell, 2014) and social perception (Aschersleben et al., 2008). These building blocks help infants structure their world, learn from others, and develop regulatory skills (Marciszko et al., 2020). While attention regulation in infancy has been related to later learning (Markant et al., 2016) and effortful control (Johansson et al., 2015), infants' social perception has been related to later pro-sociality (Juvrud et al., 2019), theory of mind (Aschersleben et al., 2008), and language development (Brooks & Meltzoff, 2008). Both attention regulation and social perception in infancy have been associated with later executive functioning (Marciszko et al., 2020; Veer et al., 2017) and quality of social interactions (Paulus et al., 2015; Perez-Edgar et al., 2010). For both abilities, proficiency in infancy is associated with better outcomes later in life.

During the first 2 years of life, cognitive development, in general, is highly context-dependent (Knudsen, 2004; Kuhl, 2004; Nelson III et al., 2019; Sheridan & Nelson, 2009), even foundational perceptual, and social processes can vary cross-culturally (Nisbett & Miyamoto, 2005; Segall et al., 1966). While primary caregivers universally play a central role in scaffolding their infants' learning (King et al., 2019), there is significant cross-cultural variation in child socialization, parent child-interaction, and time spent with caregivers and peers (Gaskins, 2006; Keller et al., 2004; Little et al., 2016). In spite of this variation, research has suggested that universally, high-quality maternal care is associated with strong cognitive development (Ronfani et al., 2015) and buffers from the adverse effects of stress (Ahun & Cote, 2019; Hibel et al., 2011). This is also the case for attention regulation and social perception, with low-quality maternal care negatively impacting both of these cognitive building blocks (Nelson III et al., 2019; Pollak & Sinha, 2002).

The quality of maternal care is coupled with maternal mental health. Mothers suffering from poor mental health (such as PTSD or depression) are often less able to provide learning and stimulation for infants, and less likely to respond to their infant's needs or engage in positive mother-infant interactions (Field, 2010). The absence of this critical maternal input, in turn, negatively impacts cognitive development from infancy (Bornstein et al., 2011, 2012) to childhood, affecting both behavior (Field, 2010) and brain architecture (Sandman et al., 2015).

Limited work has examined which culturally-moderated factors may act as protective buffers for infant attention regulation and social perception, indicators of cognitive development, when maternal mental health is poor (Ahun & Cote, 2019; Drury et al., 2016) or when other risk factors (e.g., low socioeconomic status [SES] or high allostatic load) are present. Likely candidates include social support and enrichment (Hostinar & Gunnar, 2015; King et al., 2019). This includes aspects of the infant's social contexts that promote rich experiences when the mother is unable to provide necessary stimulation for learning, including cultural participation in activities and social interaction that support and guide learning (Gauvain et al., 2011; Tomasello, 1999). For example, non-depressed fathers actively involved in caregiving may buffer infants from maternal depression by providing the necessary stimulation required for learning (Goodman & Gotlib, 1999; Kaplan et al., 2010). In low SES or high allostatic load households, supportive family members, teachers, mentors, and participation in organizations are associated with better psychological outcomes later in life (Werner, 2013). For attention regulation and social perception, more specifically, growing up in a home with more siblings is associated with better cognitive abilities (Amso et al., 2014). Thus, it is plausible that when mothers are impacted by poor mental health, social support and enrichment may compensate and support the development of cognition, attention regulation, and social perception.

Maternal mental health and SES are tightly coupled. Higher rates of poor maternal mental health are observed in low SES countries (Fisher et al., 2012; Husain et al., 2000; Wolf et al., 2002). Despite this, the effects of maternal mental health and SES on infant cognitive development are primarily studied in Western industrialized countries (Wachs et al., 2009). When resources are limited, and allostatic load is higher, such as in low- and middle-income regions of the world, it is arguably even more critical to provide infants with buffers from the negative effects of early life stress (Gunnar et al., 2015), and scaffold cognitive development (King et al., 2019). Accordingly, global efforts are needed to map out the impact of risk and protective factors on infant cognitive development and to inform governments and other stakeholders about how to cater to the needs of future generations.

Research Highlights

- Cognitive development of Bhutanese infants in high quality social environments was buffered from poor maternal mental health.
- For infants in lower quality environments, poorer maternal mental health was related to poorer cognitive performance.
- Our findings suggests that policy makers globally should utilize community and family interventions to buffer infants from negative consequences of poor maternal mental health.
- We demonstrate the feasibility of utilizing eye-tracking to measure early infant cognitive development cross-culturally.

The present study aimed to fill this gap by examining whether familial differences in *intra*-cultural variables (such as cultural participation, and mother's self-perception of positivity) can scaffold and buffer 9-month-old infants' attention regulation and social perception from potentially negative effects of poor maternal mental health in a non-Western context (families living in Thimphu, Bhutan). The Kingdom of Bhutan is a democratic constitutional monarchy in the eastern Himalayas with a population of approximately 730.000 individuals. In a national survey 49% of the population were estimated to be illiterate and 48% of adults work with farming. Eighty-three percent identify themselves as Buddhists, 14% as Hindu (Gross National Happiness Commission, 2019).

The goal of this cross-sectional study is two-fold. First, we assessed attention regulation and social perception, known to vary cross-culturally, in 9-month-old infants in Bhutan, a population that has not been examined (Chavajay & Rogoff, 1999; Nisbett & Miyamoto, 2005; Segall et al., 1966). In the current study, we view attention regulation and social perception as indicative of general cognitive development. This is because both attention regulation and social perception have previously been tightly linked with later cognitive abilities (Aschersleben et al., 2008; Cuevas & Bell, 2014; Juvrud, et al., 2019; Marciszko et al., 2020).

Second, we examined the associative effect of poor maternal mental health on these abilities, and simultaneously assessed if culturally-moderated protective factors exist that buffers infants' cognitive development. It is important to note that, given the cross-sectional nature of the data, it is not possible to tease apart directions of effects. For example, it might be that strong/positive maternal mental health protects against (moderates) the negative impacts of impoverished social environments. However, prior work in both Western samples and immigrant samples examining the complex associations between mental health and social environment have suggested that various social environment factors, such as social cohesion, SES, and neighborhood components (Firdaus, 2017; McElroy et al., 2019), are influential in affecting mental health. In particular, mental health is in part driven by social conditions (Masi et al., 2011), and policies aimed at reducing disruptive social environment behavior have contributed to positive effects on mental health (McElroy et al., 2019). Our hypothesis is, therefore, that social environment moderates the effects of maternal mental health.

2 | METHODS

We relied on state-of-art eye tracking to get a detailed understanding of infants' attention regulation and social perception as indicators of general cognitive development. This technique allows for non-verbal, context-independent measures (Gredebäck et al., 2009) that we/researchers can easily adjust to local cultural contexts (Green et al., 2016). We used an eye-tracking based, visual-search task with two difficulty levels. On easy trials, a single target appears on the screen, and infants receive a reward when they fixate on the target. On difficult trials, the target is among four identical distractors, that are different from the target. Search efficiency, an index of attention regulation, was measured as the search time required to fixate on the target in the difficult compared to the easy trials.

Each visual search trial was preceded by the presentation of an emotional face (happy, angry, fear, and control). By measuring how social perception (i.e., the face) preceding the search, impacted search efficiency, the task thus allowed us to simultaneously assess social perception and attention regulation in the same paradigm. Prior work in US contexts with similar paradigms (Becker, 2009; Haas et al., 2016; Smith et al., 2020) has demonstrated that attention regulation, as measured by visual search efficiency, may be impacted by social perception (e.g., the emotional expression of the face) in children and adults. The present study thus takes advantage of this same paradigm, with modifications to optimize its' application for the infant age range.

2.1 | Participants

The present study presents data from a collaborative project between the Faculty of Nursing and Public Health at the Khesar Gyalpo University of Medical Sciences of Bhutan in Thimphu, Bhutan and the Department of Psychology, Uppsala University, Uppsala, Sweden. Families seeking vaccinations at the Jigme Dorji Wangchuck National Referral Hospital in Thimphu, as part of the national vaccination schedule program, were asked to participate in a study of infant development. Data were collected on 121 families prior to the routine visit for vaccinations for their 9-month-old infants (male = 62). Prematurely born infants (<37 weeks) were excluded from further analyses ($n = 8$ infants). Of the remaining 113 infants, 94 infants had usable eye-tracking data (50 male; mean age (days) = 277.96 days, $SD = 6.31$). Vaccinations were done on a voluntary basis, and families came in when they felt they had time. The vaccination program covers at least 90% of all children in the country. All participating infants were accompanied by their mother. In some cases, other family members (e.g., fathers, grandparents) also accompanied the mother, but only the mother was present during the interview process. Table 1 summarizes the demographic characteristics of the participating infants.

TABLE 1 Demographic characteristics of participants

	Demographic data	Eye tracking data
N	113	94
No. of males (%)	56 (51%)	51 (53%)
Ethnicity (%)	34 (31%) Ngalop	29 (31%) Ngalop
	45 (41%) Scharchop	39 (42%) Scharchop
	19 (17%) Lhotshampa	16 (17%) Lhotshampa
	12 (11%) Other	10 (11%) Other
Females: age in days (*SD*)	278.08 (6.64)	277.58 (5.63)
Males: age in days (*SD*)	277.72 (5.51)	278.36 (6.96)
Entire sample: age in days (*SD*)	277.91 (6.19)	277.96 (6.31)

2.2 | General procedure

Informed consent was obtained by trained Bhutanese facilitators, after which infancy researchers from Uppsala University conducted a 20-min assessment of infant cognitive development (both behavioral play and eye-tracking). Second, experienced Bhutanese family doctors and social workers at the Faculty of Nursing and Public Health at the Khesar Gyalpo University of Medical Sciences of Bhutan interviewed parents to gain an understanding of the social and emotional context surrounding the infant. The structured interview covered general background information as well as questions from standardized questionnaires. The total time of the interview, questionnaires, and the assessment was approximately 35 min, with some variation depending on the number of questions asked by parents and the complexity of the social and emotional context of the family. Study participation preceded actual vaccination with a nurse (local staff ensured that families understood that the choice to participate in the study or decline participation had no impact on future hospital care, including access to vaccination). Families were provided with a small wooden toy (Brio) for participating in the study. The study was conducted in accordance with the standards specified in the 1964 Declaration of Helsinki and approved by local ethics committees in Sweden and Bhutan (See Supplementary Information [SI] for further interview, and procedure detail).

2.3 | Interview measures

Families were asked to report on a variety of measures covering demographics (e.g., education, salary, ethnicity), infant health, personal health (e.g., alcohol use, maternal mental health), and family composition (persons in the household, marital status). From these measures, we only considered variables related to maternal mental health and the social environment of the infant and the mother (for more information about the other measures see SI).

2.3.1 | Maternal mental health

In our measure of maternal mental health, we included: (a) Postnatal depression symptoms using the Edinburgh Postnatal Depression Scale (Cox et al., 1987); (b) Post-traumatic stress symptoms using the PTSD Checklist-Civilian version (PCL-C) (Weathers et al., 1993); and (c) maternal negative mood states using the negative subscale of the Positive and Negative Affect Schedule (PANAS) (Watson et al., 1988). For descriptives, see Results and SI.

2.3.2 | Social environment

Prior work has demonstrated that supportive family members, teachers, mentors, participation in organizations, and siblings in the home lead to better outcomes (Werner, 2013). Accordingly, our measure of social environment included items closely related to these dimensions. In our measure, we included (a) total number of household members; (b) number of social gatherings attended monthly (Mott, 2004); (c) frequency of storytime reading/telling (Mott, 2004); (d) number of people can count on, loves me, and helps me (Mott, 2004); and (e) maternal positive mood states using the positive subscale PANAS (Watson et al., 1988). For descriptives, see Results and SI.

2.4 | Eye-tracking stimuli

2.4.1 | Social perception

Emotional facial expressions consisted of color images of adult female and male Bhutanese faces (~11 × 15 cm [~4.2 × 6.5 visual degrees]) with the emotional expressions happy, fearful, and anger, as well as an additional blurred neutral face. The pictures were taken of Bhutanese University students, and emotional sets of four female actors and four male actors were counterbalanced across all infants (see Figure 1; see SI for specifications). Photographs were taken in a room with standardized lighting before testing and included the hair and neck with a white sheet covering the shoulders by a researcher with experience creating similar stimuli in Western contexts. All individuals were asked to remove makeup, jewelry, and glasses. To standardize

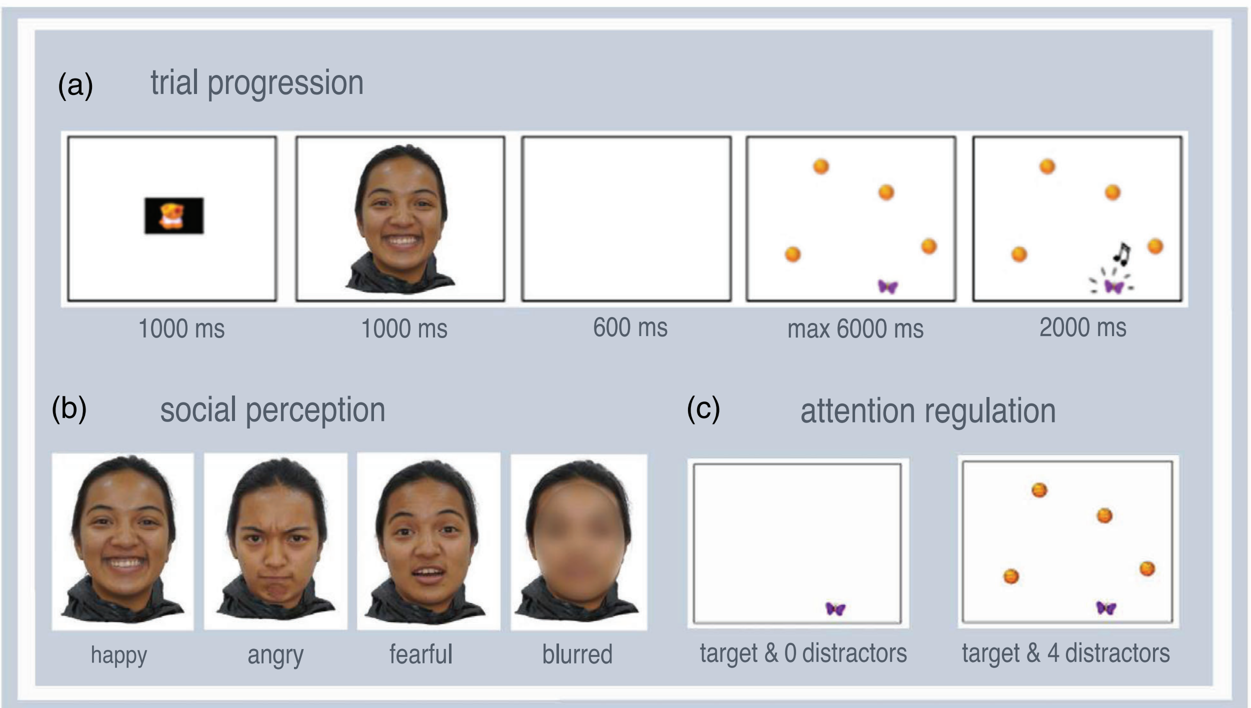

FIGURE 1 (a) Depicts average latency (ms) for infants to detect the target across all trials for zero distractor trials, and four distractor trials. (b) Depicts the moderation of social environment on the relation between maternal mental health and the estimated latent attention regulation cost (four distractor trials–zero distractor trials) at various levels of social environment: ±1, standard deviations and the mean. The color of the slop lines are associated with the color of the gradients on the *x*-axis shown as standard deviations, with red representing worse levels of social environment/maternal mental health and green being better

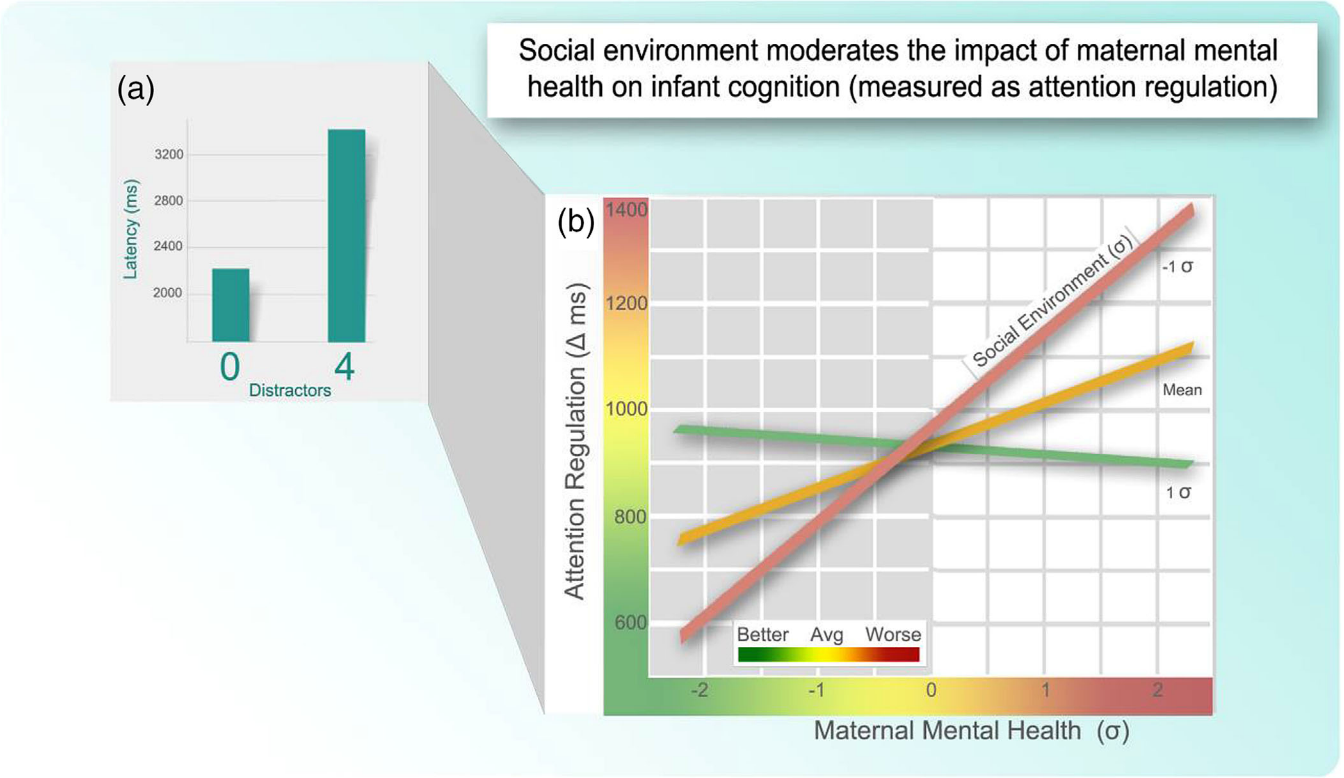

FIGURE 2 (a) Trial progression. (b) Social perception conditions. (c) Attention regulation conditions

emotional expressions, the individuals used a mirror and example photos of people expressing the different emotions from The Karolinska Directory of Emotional Faces (Lundqvist et al., 1998). The stimulus faces were shown with all facial features displayed (i.e., both internal and external facial features) and were standardized for brightness, contrast, color, and size using Adobe Photoshop CS5.

2.4.2 | Attention regulation

The visual search task was adapted for infants based on procedures from Juvrud et al. (2021) and Haas et al. (2016). Visual search targets consisted of static color cartoon objects (hat, butterfly, apple, cheese, pear, and sweater; ~3 × 2 cm; 1.2 × 1.0 visual degrees). Set sizes were either zero or four distractors (set size 1 and set size 5, respectively). Distractor pairings included: hat & banana, butterfly & basketball, apple & car, cheese & flower, pear & bow and sweater & planet (~3 × 2 cm; 1.2 × 1.0 visual degrees). Within and across infants, target location during visual search and the number and location of distractors was counterbalanced. All targets were of equal distance from the center of the screen (10 cm) and not overlapping with the location of the previously presented face stimulus. Reward stimuli were presented when the infant fixated on a target. These consisted of a short animation of the target moving up and down, accompanied by a chime sound. (See Figure 2).

2.5 | Eye-tracking apparatus and procedure

Infants sat on their parent's lap ~60 cm from the monitor (0.022 × 0.023 visual degrees per pixel). Prior to the experiment, a standard five-point infant calibration procedure (Gredebäck et al., 2009) was conducted using Tobii Lab Pro Eye Tracker Manager software on an external monitor (15.6 inches; 1920 × 1080), and a Tobii Pro Nano mobile eye tracker (0.1° precision, 0.3° accuracy, and 60 Hz sampling rate). Psychtoolbox (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997) in MATLAB (2019) was used for stimuli presentation, to measure infants' eye movements, as well as to record gaze-contingent area of interest (AOI) fixations.

Each experiment test trial was initiated with an attention grabber and automatically advanced after 1000 ms. This was followed by an emotional face for 1000 ms (emotion and sex of the face were counterbalanced). Next, a blank screen appeared (600 ms), followed by a visual search stimulus (max. 6000 ms). When the infant fixated anywhere within the target in each visual search (100 ms) (Wass et al., 2013), a short gaze-contingent reward animation and chime played (2000 ms). Only latency (ms) to fixate on visual search target for successful trials were further analyzed (usable trials per infant: $M = 22.87$, $SD = 13.01$, $Range = 1–55$ trials). Trials automatically advanced without a reward if the infant failed to fixate on the target within 6 s. The infants viewed a total of 64 trials (32 per set size, eight per emotion), and the task was approximately 10 min long (See Figure 1 for task schematic).

2.6 | Eye-tracking apparatus, procedure, data extraction

2.6.1 | Eye-movement data

Eye movement data were recorded and trials were labeled using Psych-Toolbox extensions (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). A custom script in the open-source analysis program TimeStudio version 3.03 (Nyström et al., 2016) in MATLAB (2019) extracted successful trials (as described above) during which the infant fixated on the target for at least 100 ms.

2.7 | Data analysis

2.7.1 | Step 1

First, we conducted an exploratory analysis to examine latent predictors of the Maternal Mental Health and Social Environment variables using PCA (Principal Component Analysis, conducted in SPSS 25 using the full dataset of 113 infants; see SI Table S1 for descriptives). Each of the relevant variables were standardized. Based on work from western contexts, we anticipated that there would be clusters of related measurements (see SI for more information). We expected that there would be distinct factors for Maternal Mental Health (Edinburgh, PTSD, and PANAS Neg), Social Environment variables (household members, social gatherings, story reading/telling, supportive people, and positive subscale of PANAS). As expected, factor scores were normally distributed around a mean of zero, both with standard deviations of 1. Scores ranged from −2.15 to 2.37 for the Maternal Mental Health factor score and −2.2 to 2.63 for the Social Environment factor score (see Table S3 for rotated component matrix). The purpose of Step 1 was to use a data-driven approach to inform which combination of background variables were most appropriate to assess in relation to infant attention regulation and social perception in subsequence analytic steps (see Table S2 for correlations). We believe a data-driven exploratory approach is the most culturally sensitive way to examine these data. We specifically chose a PCA (as opposed to factor analysis) because a PCA seeks to identify variables that are composites of the observed variables without the explicit assumption that latent factors exist underlying the observed data.

2.7.2 | Step 2

We were next interested in how the observed variables would relate to our dependent variables, including complex interactions. We were, therefore, careful to appropriately take into account the nature of our data in our analyses and preserve power. We used the MSEM framework, as it is an appropriate analysis when simultaneously estimating categorical repeated measures (e.g., the repeated social perception categorical conditions) and continuous variables (e.g., number of distractors and trial order effects). MSEM is also appropriate to reduce cross-product measurement error associated with interaction terms, a confound that often results in underestimation and Type 2 errors. We used Linear Mixed-Effects Modeling (LMM), as such latent variable approaches produce estimates of interactions that are not reduced by measurement error. This was important to increase our study's power and reduce the likelihood of possible biased estimates (Maslowsky et al., 2015). We conducted a preliminary analysis using LMM to examine if Step 1 aggregate scores of mothers' maternal mental health and the infant's social environment impacted social perception and attention regulation (*Step 2*). This preliminary analysis did not suggest that social perception was impacted by mothers' maternal mental health nor the infant's social environment. Thus, we simplified our final model using the MSEM framework to focus solely on attention regulation (See SI for detailed information on Step 2; SI Tables S4–S6 show latency descriptives).

2.7.3 | Step 3

In our final model, we estimated a succinct MSEM. This model simultaneously confirmed our exploratory factor scores from Step 1, demonstrating the same patterns of significant factor loadings for the Maternal Mental Health and Social Environment factors. Moreover, this model simultaneously estimated our two factors of interest and their interactive effects to predict infant attention regulation. In the SEM framework, power is most commonly assessed via model fit indices during the modeling stage. Therefore, we assessed model adequacy using the chi-squared parameter by statistically probing the fit of our model of interest compared to alternative models (Asparouhov & Muthén, 2010; Satorra & Bentler, 2010).

Level 1 of the model (within-subjects effects) was estimated from individual infant trial-level data. Trial-level effects on overall latency were controlled for, and random or "latent" intercepts (analogous to Set Size 1) and slopes (Δ*Attention Regulation)* were estimated for each infant. This allowed us to statistically assess whether Δ*Attention Regulation*, the cost in selective attention as a function of the amount of distracting visual information (e.g., set size-related cost or "slope" in latency to detect the target: Set Size 5-Set Size 1; See Haas et al., 2016 for further explanation of visual search paradigm "slope" calculations). Estimating a latent slope for Δ*Attention Regulation* is superior to averaging across trial-level data for each infant, as manually calculating Δ*Attention Regulation* could result in biased estimates due to loss in variance related to trail-order effects, set size conditions, as well as missing data. Thus, we opted to estimate a 2-level MSEM analysis and used full information maximum likelihood estimation with robust estimators (MLR) Mplus 8 to handle missing data (Muthén & Muthén, 2018).

Level 2 (between-subject effects) of the model was analogous to a traditional SEM analysis. The latent terms, Maternal Mental Health, Social Environment, from our exploratory analysis in Step 1 were re-estimated as an additional confirmatory step. To reduce cross-product measurement error associated with interaction terms, the latent interaction of both latent variables, Maternal Mental Health × Social

Environment, was estimated (Klein & Moosbrugger, 2000). We examined paths between these latent variables and the latency intercept and Δ*Attention Regulation* from Level 1. Within this same model, we specified simple slopes analyses to statistically probe Social Environment moderation effects on the relation between Maternal Mental Health and Δ*Attention Regulation* at low, average, and high levels of social-environmental support (±1 standard deviations & mean). Note that results from Step 2 indicated that Social Perception did not vary as a function of Attention Difficulty, Maternal Mental Health, nor Social Environment, and thus was not included in Step 3. See SI for complete *Step 2* model results.

3 | RESULTS

3.1 | Maternal mental health and social environment—Descriptive results

Based on our exploratory analysis, our latent factors of interest, Maternal Mental Health and Social Environment variables, were defined in our model as (a) maternal mental health (Edinburgh, PTSD, and PANAS Neg) and (b) social environment variables (household members, social gatherings, story reading/telling, and positive subscale of PANAS).

3.1.1 | Maternal mental health

Mothers' reported post-partum depression symptoms (M = 11.38, SD = 4.18, range = 2:21) indicated probable post-partum depression in 49% of our sample (scores of 13 or higher on the Edinburgh PDS) (Cox et al., 1987). The observed PPD prevalence is similar to that of low- and middle-income countries (estimated PPD prevalence 15%–50% of mothers) (Husain et al., 2000; Wolf et al., 2002).

Maternal report of post-traumatic stress symptoms on the PCL-C (M = 15.62, SD = 10.20, range 0:37) suggested DSM-qualifying PTSD sample prevalence of 16.5% (Weathers et al., 1993). These rates are higher than general population estimates in countries free from war (e.g., USA has a prevalence of 6.8%) (Kessler et al., 2012) but consistent with post-partum estimates from international community samples, with clinically significant symptoms estimated affecting up to 16.8% of mothers (Dekel et al., 2017).

Maternal negative mood scores (M = 10.5, SD = 3.53, range = 5:20) on the negative subscale of PANAS (Watson et al., 1988) were comparable to average scores across a range of countries (e.g. Australia: M = 10.76, SD = 3.36; India: M = 11.72, SD = 3.02; USA: M = 11.27, SD = 2.66; Vietnam: M = 12.06, SD = 2.37) (Thompson, 2007).

3.1.2 | Social environment

On average, each household included 4.74 members (SD = 1.65, range 2:14) and families attended 1.44 social gatherings per month (SD = 1.73, range 0:7). Mothers read or told stories to their infant on average several times per month (Average of scale 1 = less than several times per month to 4 = everyday, M = 1.77, SD = 1.05, range 1:4). The reported number of household members in our sample is consistent with the average in Thimphu, Bhutan of 4.2 persons per household (Bhutan, 2017). There was variability in responses on each of the other items. Notably, however, 43% of mothers had not attended any social gatherings in 30 days, and 56% of mothers engaged in storytelling or reading with their infant less than several times per month. On average, mothers' positive mood scores, assessed with the positive subscale of PANAS (Watson et al., 1988), equaled 16.22 (SD = 5.69, range 5:25) and were comparable to those reported from several other countries (e.g. Australia: M = 19.16, SD = 3.39; India: M = 19.56, SD = 2.85; USA: M = 19.73 SD = 2.58; Vietnam: M = 18.26 SD = 2.44) (Thompson, 2007).

3.2 | Infant cognition—Descriptive results

Attention regulation was assessed via a visual search task. The exploratory Linear Mixed-Effects Model in *Step 2*, suggested that the number of distractors significantly impacted search times (F(1, 2108.02) = 271.08, p < 0.001). On average, target detection latency was 921 ms (SE = 56.00) slower for trials with four distractors (M = 3036.40 ms, SE = 50.84) compared to trials with zero distractors (M = 2115.49 ms, SE = 40.41).

Social perception was assessed in *Step 2* as well, by analyzing how a preceding emotional facial expression affected search times in the visual search task. The main effect of social perception (F(3, 2068.71) = 2.85, p = 0.04) was driven by fear condition. Infants were significantly faster by 215.95 ms (SE = 75) to detect the target after viewing fearful faces (M = 2469.03 ms, SE = 59.59) compared to control stimuli (blurred faces, t(2069.45) = −2.875, p < 0.001; M = 2684.99 ms, SE = 57.63). There were no additional effects for the other social perception, nor did social perception interact with any of the other variables. (See SI for full *Step 2* model results).

3.3 | Step 2: Linear mixed effects modeling

We used LMM with restricted estimation maximum likelihood (REML) criterion in SPSS 25 to analyze relations among maternal mental health, Social Environment, and Visual Attention. There were no direct effects of maternal mental health (as a risk factor) and social environment (as a protective factor) on search times. The number of distractors significantly impacted search times (F(1, 2108.02) = 271.08, p < 0.001). On average, target detection latency was 921 ms (SE = 56.00) slower for trials with four distractors (M = 3036.40 ms, SE = 50.84) compared to trials with zero distractors (M = 2115.49 ms, SE = 40.41).

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There were no additional effects for the other social perception (e.g., happy or angry conditions), nor did social perception interact with any other variable. While there was not a significant interaction between maternal mental health and social environment factors, there was a three-way interaction between attention regulation (infant cognition), maternal mental health, and social environment ($F(1, 2112.25) = 4.82$, $p = 0.03$) indicated an impact of risk and protective factors on search efficiency. Additional descriptions of the LMM can be found in the SI.

3.4 | *Step 3*: Infant cognition—Impact of risk and protective factors

Results from *Step 2* indicated that there were no direct effects of maternal mental health (as a risk factor) and social environment (as a protective factor) on social perception, nor on search times as a function of difficulty level. However, a significant three-way interaction in *Step 2* of attention difficulty level (Set Size), maternal mental health, and social environment ($F(1, 2112.25) = 4.82$, $p = 0.03$) indicated an impact of risk and protective factors on attention regulation. The latent interaction of Maternal Mental Health × Social Environment was statistically probed using MSEM in *Step 3*, and revealed that Δ*Attention Regulation* (Set Size 5 – Set Size 1) is significantly predicted by the 2-way interaction of maternal mental health, and social environment (estimate: −1939 ms, SE = 69.5, $p < 0.001$, [CI: −2053, −1825]). Simple slopes moderation analyses showed that for infants in environments with lowest rates of protective social environment factors, worse maternal mental health significantly predicted greater costs in latency to find the target when surrounded by four distractors as opposed to none (See Table 2 and Figure 1).

Thus, for these infants, there are larger costs on visual attention as a function of more distractors. For infants living in rich social environments, there was no significant effect of poor maternal mental health. Put differently, a better social environment provided a buffer and fostered normative levels of cognitive development despite the presence of risk factors. Table 2 and Figure 1 summarize the significant interaction. See Table 3 for model comparisons.

4 | GENERAL DISCUSSION

Our findings extend previous related work, and uniquely highlight that family, community social support and enrichment may buffer and support attention regulation and social perception when maternal mental health is poor. In the present study, we measured attention regulation and social perception, interpreted as indicative of infant cognition, using portable, non-verbal eye-tracking technology in a cross-cultural context. Our work suggests that practitioners and policy makers globally should utilize tools at their disposal in the form of community (e.g., social gatherings, public pre-school programs) and family (e.g., parent education) interventions, that may buffer against the negative consequences of poor maternal mental health on infant and child cognitive development. As well, we demonstrate the cross-cultural feasibility of mobile eye-tracking technology to assess early infant cognitive development, particularly attention, and social perception, as a cost-effective alternative to conventional checklists and time-consuming assessments (e.g., the Bayley Scales of Infant and Toddler Development) requiring trained clinical staff.

The findings are represented in Figure 1, where the red slope and red gradients on the x- and y-axis show worse social environment and maternal mental health, and green is better. The way to interpret these findings is that maternal mental health appears to affect the development of critical cognitive processes in a worse, more impoverished social environment. Maternal mental health might affect the development of critical cognitive processes in an impoverished social environment. At the same time, in a more rich social environment, maternal mental health had little influence on the same development and may buffer from the negative consequences observed in more impoverished social environments. These findings are in line with previous studies showing that when mothers are unable to provide critical learning and stimulation for infants, it has negative consequences for development in general (Bornstein et al., 2011, 2012; Field, 2010; Sandman et al., 2015), and cognitive development in particular (Bornstein et al., 2011, 2012). While our findings are cross-sectional, and lack the same predictive power as in a longitudinal study, these results echo previous work showing that growing up in a rich social environment can buffer from risk factors such as low SES or high allostatic load (Amso et al., 2014; Werner, 2013).

Our findings extend previous work by uniquely showing that when mothers are impacted by poor mental health, social support and enrichment have the potential to compensate and support the development of cognition. That is, when infants receive more social input and exposure from the environment, it appears to counteract potential negative consequences of poor maternal mental health. Our results indicate that when infants grow up in a rich social environment, including a rich family context, positive maternal affect, and a strong community, the effects of maternal mental health diminish. These findings highlight that both community (e.g., meeting places, sports clubs, public preschools programs, etc.) and family (e.g., positive parenting programs;) (De Graaf et al., 2008; Salari et al., 2013) interventions might be effective in minimizing the impact of poor maternal mental health on cognitive development. Life and culture in Bhutan are heavily guided by extended family structures and religious gatherings (included in our social gatherings measure) inherent in Bhutanese society. It might be that it is precisely such cultural contexts that can buffer infants' cognitive development when maternal mental health is poor.

Let us unpack our effect of maternal mental health and social environment, and why we believe it may influence infants' cognitive development, in a bit more detail. We used eye-tracking to get a detailed understanding of infants' cognitive development, specifically focusing on the abilities of attention regulation and social perception, known to vary cross-culturally (Segall et al., 1966; Nisbett & Miyamoto, 2005). Our visual-search task was designed to reveal possible effects on both of these abilities. We found an effect with respect to attention

TABLE 2 Step 3: MSEM model results

Parameter	Estimate (*SE*)	− 95% CI	+ 95% CI	*p*
Level-1 (Within-Subjects)				
Trial → attention regulation	7.8 (1.6)	5.1	10.5	<0.001
ΔAttention regulation (set size → attention regulation)	933 (79)	801.8	1063.8	<0.001
Level-2 (Between-subjects)				
Maternal mental health factor				
Edinburgh total score	9.66 (3.37)	4.12	15.21	0.004
Post-traumatic stress total score	1.36 (.66)	0.288	2.45	0.037
[a]*PANAS negative subscale*	0.39 (2.28)	−3.35	4.155	0.861
Social environment factor				
PANAS positive subscale	0.80 (0.38)	0.17	1.43	0.037
[a]*Total household numbers*	2.59 (1.88)	−0.49	5.69	0.167
Social gatherings (30 Days)	4.12 (1.83)	1.11	7.133	0.024
Story telling/reading	1.41 (.493)	0.61	2.23	0.004
Intercept (Latency$_{\text{Set Size 1}}$)	1902.7 (63.4)	1798	2007	<0.001
Social environment → ΔAttention regulation	−71.1 (260)	−49.87	356.5	0.785
Maternal mental health → ΔAttention regulation	336.7 (230)	−42.5	716	0.144
Social Environment × Maternal mental health → ΔAttention regulation	−1939 (69.5)	−2053	−1825	<0.001
Simple slopes moderation tests				
Maternal mental health → ΔAttention regulation				
Social environment = −1 σ^2	726.4 (223)	358.4	1094.4	<0.001
Social environment = 0 σ^2	336.7 (230)	−42.5	716	0.144
Social environment = + 1 σ^2	−53.00 (238)	−444.4	338.4	0.824

Note. The MSEM was estimated in Mplus using Maximum Likelihood Robust (MLR) Estimation to handle missing data and nonnormal distributions of count and Likert scale questionnaire data. Unstandardized estimates are given (scale is latency in ms).
[a]While not significant in the full MSEM model, these two items were kept to remain consistent with the proposed theoretical constructs and initial significant loadings in analyses in *Step 1*.

TABLE 3 Step 3: MSEM model comparisons

Model comparison		Parameters	Log-likelihood	MLR correction	$\Delta\chi^2$	*df*	*p*
1.	H_0: Main model (Table 2)	33	−9535.47	1.09			
	H_1: Saturated Model (See SI)	37	−9526.51	1.26	6.83	4	0.144
2.	H_0: Restricted model (See SI)	32	−9536.38	1.17			
	H_1: Main model (Table 2)	33	−9535.47	[b]1.15	8.56	1	0.003[a]

Note. Appropriate model fit was statistically probed via the Positive Satorra-Bentler Chi-Square Difference Test (Asparouhov & Muthén, 2010; Satorra & Bentler, 2010).
[a]Significant results indicate a statistically superior fitting H_1 model compared to the H_0 model.
[b]See supplemental materials for detailed model selection and $\Delta\chi^2$ computation.

regulation; visual search efficiency, an indicator of infants' attention regulation, was impaired in infants whose mothers had poor mental health when little social support was present. Early attention regulation is related to both later learning (Markant et al., 2016) and effortful control (Johansson et al., 2015). In general, good attention regulation skills in infancy are associated with better outcomes later in life (McClelland et al., 2013). Accordingly, a diminished ability to regulate attention might hinder children from reaching their full potential in school and beyond.

While we were initially surprised to see maternal positive affect as an indicator of the social environment, this finding is consistent with prior literature showing a differential effect of positive and negative maternal affect on infant behavior (Hornik et al., 1987; Juvrud et al., 2021). Prior work suggests that negative maternal affect has a more immediate effect on infant behavior than positive affect, which may be more reflective of a social environment indicator (consistent with the social referencing hypothesis). In addition, since our approach was data-driven without explicit assumptions, and considering the non-Western sample that has thus far not been sufficiently represented in the literature, we were careful to let the data guide the present factors.

Our results indicated no effect of maternal mental health or social environment on social perception, in contrast to previous work (Bornstein et al., 2011). It might be that some effects are present in one culture (Bornstein, 2017) but not another (current results) are cultural dependent, for a further elaboration about cultural specificity and context specificity see: (Elfenbein & Ambady, 2002). Another alternative is that the relation between maternal mental health and social perception is not as strong as previously assumed (Bornstein et al., 2011). From our data, it is not possible to distinguish between these possibilities, and further studies are needed to tease them apart.

In addition to the reported effects, the current study demonstrates the feasibility of mobile eye-tracking technology to assess infant cognitive development as a cost-effective alternative to conventional checklists and time-consuming assessment (e.g., the Bayley Scales of Infant and Toddler Development) requiring trained clinical staff. In line with several recent studies and critiques, we (Ballieux et al., 2016; Brito et al., 2019; Forssman et al., 2017; Hernik & Broesch, 2019) suggest that future work assessing early infant cognition, particularly attention, and social perception, use mobile eye-tracking technology in cross-cultural contexts instead of more crude behavioral assessment batteries that cost both extra time and resources (Brito et al., 2019).

In the present study, we did not operationalize the social environment construct to be independent of maternal behavior. For example, we included both maternal activities (e.g., storytelling) and factors independent of the mothers' behavior (e.g., number of household members) in it. Therefore, we cannot isolate the effect of infants' environment from that of maternal behavior. As such, we take our findings to suggest a reciprocal influence between infants' social environment and maternal behavior, and that this dynamic social system as a whole buffers infants from the negative consequences of poor maternal mental health. This idea is supported by our initial confirmatory factor analysis, used to create our social environment composite score: factor loadings suggested that the infants' social environment and maternal behaviors are tightly linked. Future work should also carefully examine to what extent the proximal influence of maternal behaviors on infant development could have relative to the more distal impact of the social environment, and whether there is any evidence that positive maternal mental health could protect against the negative impacts of impoverished social environments.

An inherent challenge in cross-cultural research is the translation and interpretation of interview data. In all interviews, the researcher verbally explained each question/item and then prompted the mother for an answer. Often, additional examples of circumstances or feelings were needed for a response to be given. Although necessary for data collection, such practices might influence both the validity and reliability of measurements. Furthermore, although very different from a Western sample, our participants likely represent a subset of Bhutan's population that has the most access to resources, such as healthcare, education, and technology. Future research efforts are therefore needed further to validate our findings in a broader Bhutanese and global context. Nevertheless, our sample draws from a region that remains markedly under-represented in the developmental psychology literature (Henrich et al., 2010; Nielsen et al., 2017).

To conclude, we found that a rich social environment may buffer against the adverse effects of poor maternal mental health on critical cognitive development in infancy. These results have far-reaching practical implications in that they suggest that practitioners and stakeholders now have several cultural tools in the form of community (e.g., social gatherings, public pre-school programs) and family (e.g., parent education) interventions at their disposal to buffer against the negative consequences of poor maternal mental health on cognitive development.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

The data in this manuscript came from a larger project collaboration conceived by G.G. and M.L. at Uppsala University, Sweden, W. from the Faculty of Nursing and Public Health, Bhutan and S.D. and K.P.T. from Khesar Gyalpo University of Medical Sciences of Bhutan. S.A.H, J.J. and K.A. additionally contributed to the conception and planning of the eye tracking experiments. S.C.N., T.W., and W. were involved in the planning, logistics and administration of the questionnaire measures. The project experiments were carried out in Bhutan by J.J., K.A., S.C.N., and T.W. S.A.H. conducted the analyses. The final figure in the text was created by J.J.. J.J and S.A.H. wrote the manuscript in consultation with G.G. and M.L. and K.A. All authors provided critical feedback on the manuscript for submission.

DATA AVAILABILITY STATEMENT

The data and analyses reported in this article were not formally preregistered. Neither the data nor the materials have been made available on a permanent third-party archive; requests for the data or materials can be sent via email to the Gustaf Gredebäck gustaf.gredeback@psyk.uu.se .

ORCID

Marcus Lindskog https://orcid.org/0000-0003-1326-6177

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