



# Spatial working memory and attention skills are predicted by maternal stress during pregnancy<sup>☆</sup>



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## ARTICLE INFO

### Article history:

Received 18 May 2014

Received in revised form 7 August 2014

Accepted 7 November 2014

### Keywords:

Maternal stress during pregnancy

Spatial working memory

Attention skills

Postnatal care

## ABSTRACT

**Introduction:** Experimental evidence in rodents shows that maternal stress during pregnancy (MSDP) negatively impacts spatial learning and memory in the offspring. We aim to investigate the association between MSDP (i.e., life events) and spatial working memory, as well as attention skills (attention shifting and attention focusing), in humans. The moderating roles of child sex, maternal anxiety during pregnancy and postnatal care are also investigated.

**Methods:** Participants were 236 mother–child dyads that were followed from the second trimester of pregnancy until 4 years postpartum. Measurements included questionnaires and independent observations.

**Results:** MSDP was negatively associated with attention shifting at 18 months when concurrent maternal anxiety was low. MSDP was associated with poorer spatial working memory at 4 years of age, but only for boys who experienced poorer postnatal care.

**Conclusion:** Consistent with results observed in rodents, MSDP was found to be associated with spatial working memory and attention skills. These results point to postnatal care and maternal anxiety during pregnancy as potential targets for interventions that aim to buffer children from the detrimental effects of MSDP.

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## 1. Introduction

Spatial working memory and attention skills are predicted by maternal exposure to life events during pregnancy. Research in rodents provides direct evidence of a causal role of maternal stress during pregnancy (MSDP) in spatial learning and working memory deficits in offspring [1–3]. MSDP induces alterations in the orbitofrontal and

anterior cingulate cortices, two brain regions that are shared by attention and working memory [4,5]. In humans, questions remain about the involvement of MSDP in both attention and working memory. First, although some studies have found MSDP to be associated with general measures of attention [6–9], no study has yet investigated the specific aspects of attention skills that are affected, such as attention shifting and attention focusing. Second, only one study showed an association between retrospective reports of MSDP and performance in a verbal working memory task [10]. The nature of the working memory task may explain why their results are inconsistent with the observation that the spatial learning and memory deficits associated with MSDP are generally not observed in female rodents [4,11]. Whether the sex specificity of the effects of MSDP are observed in the case of spatial working memory remains to be tested.

Research in humans often investigates the mother's subjective reaction to stress (maternal anxiety during pregnancy; MADP) in addition to MSDP. In general, cognitive outcomes are more strongly associated with more objective measures of MSDP (e.g., recent life events) than MADP

<sup>☆</sup> We would like to thank all the women and their babies who participated in this study. We would also like to thank Patricia Szymkow, Carmen MacPherson and the entire Hamilton team and Vincent Jolivet, Helene Gaudreau, Lisa Barbosa and the entire Montreal team. This study was funded by a Canadian Institutes of Health Research (CIHR) trajectory grant for the MAVAN (PIs) to Michael J. Meaney and Stephen G. Matthews, by CIHR grants to Alison S. Fleming and Michael J. Meaney and by the Fraser Mustard Institute for Human Development (FMIHD) to André Plamondon to undertake postdoctoral work with Alison S. Fleming. The authors have no conflicts of interest to report.

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[12]. In the case of attention deficits, findings implicate both MSDP and MADP [7–9,13] while poorer working memory in offspring has only been associated with MSDP [10]. It may be the case, however, that maternal subjective anxiety modulates the association between MSDP and child outcomes. Indeed, discrepancies between objective and subjective measures of stress have been found to predict worse birth-related outcomes [15]. Moreover, MSDP is only related to poorer motor function at low levels of maternal subjective distress [14]. This raises the possibility that MADP modulates the link between MSDP and child cognitive outcomes.

Another factor that could alter the effect of MSDP on child cognitive outcome is postnatal care. Postnatal experience has been shown to moderate the association between prenatal stress and lower spatial memory performance in rodents [16]. In humans, child attachment at 18 months of age moderates the association between maternal prenatal cortisol and child cognitive development [17]. This result provides indirect evidence of the buffering role of maternal care as child attachment is strongly related to maternal care [18].

## 2. The current study

The main goal of the current study was to investigate the association between an objective measure of MSDP and two executive function outcomes in the child, spatial working memory and attentional skills (attention shifting and attention focusing). We then explored the role of three potential moderators: child sex, MADP and maternal care.

For this purpose, we used a sample followed prospectively from early pregnancy to early childhood. MSDP was derived from maternal exposure to stressful life events. Attention skills were measured using maternal reports, and spatial working memory was measured using a computerized assessment battery. We statistically controlled for variables that could account for the link between prenatal stress and child cognitive outcomes such as family income and child birth weight. We also controlled for maternal depression to rule out the possibility that mothers' depression explains the link between MSDP and child cognitive outcomes [19]. Finally, we controlled for maternal ratings of infant attention orienting and regulation at 6 months post partum to rule out the possibility that our results are due to maternal perceptions of child attention functioning.

## 3. Methods

### 3.1. Sample

Participants were part of the Maternal Adversity, Vulnerability and Neurodevelopment (MAVAN) study, a longitudinal study following two cohorts of mothers and their infants. For this study, we used the Hamilton, Ontario cohort, which was originally composed of 241 mothers because these mothers were recruited during the second trimester of pregnancy (weeks 12–24), whereas participants in Montreal were recruited after birth. Subjects in Hamilton were referred from the St. Joseph's Health Center (SJHC) Women's Health Concerns Clinic and SJHC Ultrasound Department, Hamilton, Ontario, Canada. Recruited mothers were 18–45 years old, most of whom reported having a partner (94%). Ethnic descent in this sample was mostly Caucasian (90%), with 3% mixed ethnicity, 2% African, 1.5% Hispanic, and 1% East Indian; the remainder were unspecified. This ethnic distribution is typical of the greater Hamilton region. The current study is based on a subsample of 236 participants because some participants were lost due to stillbirth or termination ( $n = 3$ ) or were involved with Children's Aid Society ( $n = 2$ ).

### 3.2. Procedure

Subjects signed written consent to participate in the MAVAN project. Ethics approval for this study was obtained from the ethics review

boards at St Joseph's Healthcare, Hamilton, ON, and the University of Toronto, Toronto, ON. The mothers and their children started being followed during the second trimester of pregnancy (weeks 12–24). They were assessed through questionnaires, diagnostic tools and behavioral tasks. Participants received \$25 compensation after each visit.

### 3.3. Measures

#### 3.3.1. Demographics

Child sex, birth weight (in kilograms) and gestational age (in weeks) were used as covariates. Family income was obtained through participants reports prenatally and at 6 and 12 months postnatally. To obtain a more reliable estimate of family income, these measures were standardized and averaged ( $\alpha = .940$ ).

#### 3.3.2. Maternal stress, anxiety and depressive symptoms

To obtain a relatively objective measure of maternal stress exposure, mothers reported on the number of stressful life events experienced [17]. Stressful life events during pregnancy were derived from maternal reports of life events that occurred since the beginning of pregnancy among a list 27 possible life events, including one question that allowed mothers to mention an event that had not been covered (see Appendix A). This scale was filled out during the third trimester of pregnancy. The validity of this scale is supported by its association with the Interview for Recent Life Events (IRLE), which was administered during the second trimester of pregnancy,  $r = .560$ . The IRLE is widely used in both clinical and research settings and has acceptable psychometric qualities [20]. However, the IRLE could not be used as a measure of MSDP because participants report on events that occurred during the previous 6 months, which meant that event happening up to 3 months before pregnancy could be reported. At 18 months postnatal, participants were administered the IRLE. Anxiety was measured using the State-Trait Anxiety Inventory [21]. Internal consistency was excellent during pregnancy and at 6 months postnatally,  $\alpha = .955$  and .949, respectively. Maternal depressive symptoms were measured using the Edinburgh Postnatal Depression Scale [22]. This scale is sensitive to changes in depressive symptoms over time and can also be used in non-postnatal mothers [23]. Internal consistency was good during pregnancy and 6 months postnatally,  $\alpha = .883$  and .854, respectively.

#### 3.3.3. Maternal care

Maternal care was assessed using an observation-based measure of mother-child interaction, the Maternal Behavior Q-Sort Short Form [24,25]. Consistent with the classical definition of maternal sensitivity, it measures a mother's capacity to detect a child's signal, interpret them appropriately, and respond to them promptly and adequately. Inter-rater agreement, based on 18 independent ratings by two raters, was excellent, ICC = .940.

#### 3.3.4. Attention skills

Early infant ability to orient their attention was measured using scales from the Infant Behavior Questionnaire at 6 months of age [26]. The global measure of attention orienting/regulation was based on a combination of 4 scales: duration of orientation, cuddliness, low intensity pleasure and soothability [26]. Internal consistency for each scale was excellent ( $\alpha = .805$ –.856). Based on these subscales, we created a global orienting scale. The item-total correlations were sufficiently high to justify this procedure ( $r_s = .338$ –.630). At 18 months, mothers completed a measure of toddler temperament, the Early Childhood Behavior Questionnaire [27]. We used two scales that specifically assess attention skills at 18 months of age: attention focusing and attention shifting. Attention focusing (12 items,  $\alpha = .798$ ) measures the extent to which children can sustain their attention in a task and resist to distractions. Attention shifting (12 items,  $\alpha = .631$ ) measures the extent to which children can be flexible in the deployment of their attention or divide their attention.

### 3.3.5. Spatial working memory

Children's spatial working memory was assessed at 48 months using the Cambridge Neuropsychological Test Automated Battery (CANTAB). The CANTAB was initially validated for use in samples of adults but its use was later extended to children [28]. It is a self-order search task in which participants need to find a token under a series of boxes. Participants need to keep track of the boxes under which there was a token because it is under a new box each time. A participant that selects a box that had contained a token during a previous search commits a between search error. In the current study, we used the number of between search errors (SWM errors) as the outcome, such that a higher score represents a worse performance.

### 3.4. Analyses

Descriptive analyses were done using SPSS version 18. Our main research goals were investigated using multiple linear regressions performed in Mplus 7.0 using an estimator that is robust to non-normality [29]. To deal with missing data, we performed multiple imputation (25 data sets) using MPlus 7.0 [30]. In preliminary analyses, we investigated all 2- and 3-way interactions between MSDP, MADP, child sex and postnatal care while entering our other covariates as well. For each of our main outcomes (attention shifting, attention focusing and spatial working memory), we report the final models that simultaneously contain all significant interactions found in the preliminary analyses as well as the other covariates. To interpret any potential significant interaction term, we performed simple slopes analyses on the multiply imputed data sets [31].

## 4. Results

Descriptive statistics appear in Table 1. Relatively few variables were associated with child attention focusing, attention shifting or spatial working memory. Females had slightly higher scores on attention shifting than males. MSDP was significantly associated with concurrent maternal well-being (MADP and maternal depressive symptoms during pregnancy), which is not surprising if we assume that psychosocial adversity impacts maternal well-being. MSDP was also associated negatively with income, in part because some life events referred to lacking money to pay for housing or food, for instance. It is noteworthy that MSDP was a stronger correlate of the quality of the postnatal environment that children are exposed to (maternal depressive symptoms, maternal anxiety, maternal stress and postnatal care) than the measure of income. No variable was related to spatial working memory errors at 48 months.

First, we investigated whether attention shifting at 18 months was predicted by MSDP and whether MADP, postnatal care or child sex moderated this association. In the final model (see Table 2), we found that most covariates were not significantly associated with attention shifting. We also found that the association between MSDP and child attention at 18 months was moderated by MADP. Data indicated that MADP was not associated with attention shifting,  $\beta = -.054$ , but that life events during pregnancy and the interaction between MSDP and MADP-predicted attention shifting  $\beta = -.491$  and  $\beta = .558$ , respectively. To interpret this interaction, we performed simple slope analyses. We found that MSDP was associated with worse attention shifting at 18 months at low levels of MADP,  $\beta = -.248$ ,  $p = .044$ , but not at high levels of MADP,  $\beta = .047$ ,  $p = .679$ .

**Table 1**  
Descriptive statistics of the main study variables.

|                                                    | 1      | 2      | 3     | 4      | 5      | 6     | 7     | 8      | 9      | 10    | 11     | 12     | 13    | 14    | Mean   | SD     | n   |
|----------------------------------------------------|--------|--------|-------|--------|--------|-------|-------|--------|--------|-------|--------|--------|-------|-------|--------|--------|-----|
| 1. Female                                          |        |        |       |        |        |       |       |        |        |       |        |        |       |       | 0.419  | 0.495  | 236 |
| 2. Birth weight (kg)                               | -.134* |        |       |        |        |       |       |        |        |       |        |        |       |       | 3.415  | 0.521  | 236 |
| 3. Gestational Age (weeks)                         | -.031  | .555*  |       |        |        |       |       |        |        |       |        |        |       |       | 38.725 | 1.615  | 236 |
| 4. Income until 1 year postnatal                   | .049   | -.048  | -.068 |        |        |       |       |        |        |       |        |        |       |       | -.067  | 0.993  | 218 |
| 5. MSDP                                            | -.039  | -.041  | -.006 | -.426* |        |       |       |        |        |       |        |        |       |       | 2.863  | 2.659  | 211 |
| 6. Maternal stress (18 months postnatal)           | .013   | -.109  | -.025 | -.173* | .306*  |       |       |        |        |       |        |        |       |       | 2.461  | 1.937  | 154 |
| 7. MADP                                            | -.026  | .046   | -.076 | -.147† | .416*  | .124  |       |        |        |       |        |        |       |       | 36.221 | 13.076 | 172 |
| 8. State anxiety (6 months postnatal)              | -.079  | .122   | -.028 | -.086  | .252*  | .100  | .558* |        |        |       |        |        |       |       | 35.327 | 12.381 | 150 |
| 9. Depression (pregnancy)                          | -.086  | -.025  | -.097 | -.218* | .499*  | .027  | .752* | .487*  |        |       |        |        |       |       | 7.853  | 5.863  | 170 |
| 10. Depression (6 months postnatal)                | -.025  | .050   | -.073 | -.174* | .285*  | .063  | .480* | .745*  | .607*  |       |        |        |       |       | 6.981  | 5.212  | 158 |
| 11. Maternal care (18 months postnatal)            | -.034  | .012   | -.085 | .217*  | -.217* | -.090 | -.135 | -.119* | -.194* | -.106 |        |        |       |       | 0.441  | 0.412  | 154 |
| 12. Att. orienting/regulation (6 months postnatal) | .084   | -.052  | -.024 | -.134† | -.040  | .074  | -.078 | -.108  | -.119  | -.134 | -.183* |        |       |       | 5.060  | 0.562  | 165 |
| 13. Attention focusing (18 months postnatal)       | .007   | -.141† | -.032 | .059   | .104   | -.034 | .114  | -.167† | .132   | -.074 | -.118  | .152†  |       |       | 4.151  | 0.792  | 150 |
| 14. Attention shifting (18 months postnatal)       | .197*  | .010   | .084  | -.104  | -.042  | .005  | .066  | .068   | .024   | .042  | -.063  | -.380* | .247* |       | 4.655  | 0.680  | 150 |
| 15. SWM errors (48 months postnatal)               | -.003  | .150   | .055  | -.111  | .132   | -.131 | -.083 | -.036  | -.156  | -.073 | -.013  | -.011  | .001  | -.113 | 29.366 | 8.704  | 112 |

Note. † $p < .10$ . \* $p < .05$ . MSDP = maternal stress during pregnancy. MADP = maternal anxiety during pregnancy. Att. orienting/regulation = attention orienting and regulation. SWM = spatial working memory

**Table 2**  
Regression predicting attention skills at 18 months.

|                           | Attentional shifting |      |         | Attentional focusing |      |         |
|---------------------------|----------------------|------|---------|----------------------|------|---------|
|                           | Std. Est.            | SE   | P-value | Std. Est.            | SE   | P-value |
| Female                    | .172*                | .078 | .026    | -.053                | .080 | .508    |
| Birth weight              | -.065                | .087 | .453    | -.196*               | .092 | .034    |
| Gestational age           | .138                 | .094 | .142    | .054                 | .099 | .584    |
| Income                    | -.081                | .081 | .316    | .209*                | .090 | .020    |
| (pregnancy to 12 months)  |                      |      |         |                      |      |         |
| Att. orienting/regulation | .374*                | .078 | .000    | .207*                | .076 | .007    |
| (6 months postnatal)      |                      |      |         |                      |      |         |
| MADP                      | -.054                | .167 | .748    | .167                 | .152 | .272    |
| Maternal anxiety          | .082                 | .133 | .535    | -.251†               | .137 | .066    |
| (6 months postnatal)      |                      |      |         |                      |      |         |
| MSDP                      | -.491*               | .223 | .028    | .223†                | .116 | .055    |
| Maternal stress           | -.015                | .096 | .872    | -.097                | .101 | .339    |
| (18 months postnatal)     |                      |      |         |                      |      |         |
| Depression                | -.080                | .128 | .531    | -.059                | .160 | .711    |
| (pregnancy)               |                      |      |         |                      |      |         |
| Depression                | .028                 | .125 | .824    | .086                 | .143 | .545    |
| (6 months postnatal)      |                      |      |         |                      |      |         |
| Postnatal care            | .039                 | .103 | .703    | -.110                | .102 | .281    |
| (18 months postnatal)     |                      |      |         |                      |      |         |
| MSDP × MADP               | .558*                | .274 | .042    | –                    | –    | –       |

Note. †  $p < .10$ . \*  $p < .05$ . Att. orienting/regulation = attention orienting and regulation. MSDP = maternal stress during pregnancy. MADP = maternal anxiety during pregnancy. Std. Est. = standardized parameter estimate.

We then investigated whether attention focusing at 18 months was predicted by MSDP and whether MADP, postnatal care or child sex moderated this association. Family income was the only demographic covariate associated with attention focusing. Family income was associated with greater attention focusing. Early maternal perception of attention/orienting also predicted greater attention focusing at 18 months. Maternal anxiety at 6 months was associated with lower levels of attention focusing,  $\beta = -.350$ ,  $p = .008$ . No other variable-predicted attention focusing and no interaction term was significant.

Finally, we looked at spatial working memory errors (see Table 3). We found that maternal depressive symptoms during pregnancy as well as maternal stress (as indicated by the number of recent life events) at 18 months were associated with a better performance (i.e., fewer errors),  $\beta = -.345$  and  $\beta = -.198$ , respectively. We also found a three-way interaction implicating MSDP, maternal care and child sex. Although this interaction was only marginally significant, the power to detect a three-way interaction is small, especially when one predictor is dichotomous, which is the case for child sex [32]. We

therefore decided to further investigate this three-way interaction by looking at the two-way interactions between MSDP and postnatal care in girls and boys separately. In girls, the effect of MSDP was significant,  $\beta = .436$ ,  $p = .022$ , but the effects of postnatal care and the interaction term between MSDP and postnatal care were not significant  $\beta = -.122$ ,  $p = .489$  and  $\beta = .059$ ,  $p = .674$ , respectively. In boys, those three parameters were significant; for postnatal care,  $\beta = .296$ ,  $p = .025$ , for life events during pregnancy,  $\beta = .472$ ,  $p = .001$  and for their interaction,  $\beta = -.294$ ,  $p = .046$ . A simple slope analysis indicated that life events during pregnancy were associated with more spatial working memory errors among boys that received poorer postnatal care,  $\beta = .504$ ,  $p = .001$ , but that life events during pregnancy were not associated with spatial working memory errors among boys who had received high levels of maternal care,  $\beta = .136$ ,  $p = .466$ . Thus, MSDP predicted more errors on the spatial working memory task in boys and girls, but boys who also experienced high levels of postnatal care in toddlerhood were protected from the detrimental effects of MSDP.

## 5. Discussion

Previous studies in humans have found MSDP to be related to general measures of child cognitive development [12,33,34] as well as in attention difficulties [7–9,13]. Fewer studies identified more specific impairments related to MSDP, for instance, in verbal working memory [10]. We extend these studies by showing an association with spatial working memory, which is conceptually closer to the spatial learning and memory deficits previously observed in rodents [35]. We also found evidence that MSDP predicts attention shifting but not attention focusing, possibly pointing to more specific attention difficulties that are related to MSDP. Importantly, our results were found when controlling for maternal anxiety, depressive symptoms and family income. Failing to control for these constructs might lead to erroneous conclusions about the predictive power of MSDP since they were found to be correlated with MSDP.

We also explored if the predictive significance of MSDP would be moderated by the child's sex, by MADP and by postnatal care. We did find a moderating role for child sex, but only in the case of spatial working memory. Moreover, differences between females and males did not pertain to the effect of MSDP but rather to the moderating role of postnatal care. Indeed, for both males and females, spatial working memory was negatively affected by MSDP, although postnatal care moderated this association in males. Results indicating that both males and females' attention and spatial working memory can be affected by MSDP are consistent with a previous study showing a link between MSDP and working memory in young women [10]. These results, however, are inconsistent with the findings that females spatial learning and memory is unaffected by MSDP in rodents [4,11]. It is possible that the working memory tasks that have been used in human studies do not require enough spatial skills to demonstrate the spatial learning deficits associated with MSDP. Another possibility is that MSDP does not affect spatial learning and memory in a sex-specific way in humans. It will be necessary to investigate the effects of MSDP on a wider range of spatial tasks to differentiate these possibilities.

We also found that MADP modulates the effect of MSDP on attention shifting, and that MSDP still had a significant contribution even after accounting for this interaction. Thus, MSDP was harmful for attention shifting, and this detrimental effect was stronger when a mother was less anxious. The moderating role of maternal anxiety is consistent with previous studies showing that the link between an objective measure of MSDP and child birth and motor outcomes was only observed when mothers experienced low levels of subjective distress [14,15]. This result might be explained by a ceiling effect: mothers exposed to stressful life events have an elevated level of cortisol, which explains the link between MSDP and lower attention shifting. However, MSDP may not contribute to a further increase in cortisol when it is already elevated, whereas mothers that are less anxious can show such an

**Table 3**  
Regression predicting spatial working memory (between errors) at 48 months.

|                                       | Std. Est. | SE   | P-value |
|---------------------------------------|-----------|------|---------|
| Female                                | .177      | .139 | .204    |
| Birth weight                          | .152†     | .078 | .051    |
| Gestational age                       | .010      | .087 | .904    |
| Income (pregnancy to 12 months)       | -.083     | .085 | .326    |
| Att. orienting/regulation (6 months)  | .019      | .076 | .808    |
| MADP                                  | .046      | .116 | .690    |
| Maternal anxiety (6 months postnatal) | .083      | .113 | .464    |
| MSDP                                  | .420*     | .098 | .000    |
| Maternal stress (18 months postnatal) | -.198*    | .085 | .020    |
| Depression (pregnancy)                | -.345*    | .152 | .023    |
| Depression (6 months postnatal)       | -.062     | .131 | .635    |
| Postnatal care (18 months)            | .274*     | .116 | .018    |
| Postnatal care × MSDP                 | -.282*    | .126 | .025    |
| Female × MSDP                         | -.034     | .148 | .821    |
| Postnatal care × Female               | -.299*    | .140 | .033    |
| Postnatal care × Female × MSDP        | .219†     | .113 | .052    |

Note. †  $p < .10$ . \*  $p < .05$ . Att. orienting/regulation = attention orienting and regulation. MSDP = maternal stress during pregnancy. MADP = maternal anxiety during pregnancy. Std. Est. = standardized parameter estimate.



increase because their cortisol level is not already elevated. This hypothesis is consistent with results showing an association between stressful life events and cortisol [36], and that current or past internalizing difficulties are associated with a blunted cortisol reactivity to stress [37]. The interaction between stress and anxiety during pregnancy may also explain why studies often show little to no association between maternal cortisol and life events [17,38,39]. Further studies investigating the mechanism accounting for the interaction between life events and anxiety are needed.

The moderating role of maternal care in the association between MSDP and spatial working memory is consistent with another study showing that maternal prenatal cortisol was associated with child cognitive development, but only for children whose attachment was insecure [17]. Because attachment insecurity is associated with poorer maternal care [18], these results suggest that maternal care serves as a buffer from MSDP. The consistency of these results with ours despite conceptually related, yet different measures of stress during pregnancy, maternal care as well as different child cognitive outcomes support the buffering role of postnatal care in the association between prenatal stress and child cognitive outcomes. It is unclear, however, why females did not benefit from the protective role of maternal care. It is possible that the combination of supportive postnatal care with sex-stereotyped differences in the postnatal environment, including toys and activities, is more supportive of boys' visuospatial skills than girls' [40]. These results suggest that children who are exposed to stress prenatally may constitute a group for whom interventions that target mother-child interactions may be helpful, but it may be necessary to understand why postnatal care did not protect girls' spatial working memory from the effects of MSDP.

Contrary to our expectations, the detrimental effects of stressful life events during pregnancy were not observed in the case of attention focusing. The fact that attention shifting and attention focusing were predicted by a different set of variables suggests that they are associated with distinct risk factors. It is possible that MSDP induces alterations in the medial prefrontal cortex [41], which has been associated specifically with attention shifting and not attention focusing. It will be necessary to investigate whether MSDP is indeed only associated with attention shifting and not attention focusing before interpreting the discrepant results further.

Four findings that did not pertain to our main hypotheses merit mention. First, there was a trend for MSDP to predict greater attentional focusing at 18 months whereas there was a trend for post-natal anxiety to predict worse attentional focusing (see Table 2). This may be explained by the fact that MSDP is associated with anxiety in offspring, which has in turn been associated with attention being driven by stimuli rather than voluntary control (Eysenck et al., 2007). Consequently, MSDP may predict attentional focusing because this scale also measures the extent to which children are taken by specific stimuli (e.g., books and toys). With regards to postnatal anxiety, it may predict worse

attentional focusing via its association with parenting behaviors that are detrimental for children's cognitive development such as restrictiveness [42]. Second, there was a trend for birth weight to predict worse attention focusing (see Table 2) and worse SWM scores (see Table 3). This result may be explained by findings showing that the association between birth weight and cognitive factors is nonlinear [43,46], such that both higher and lower birth weights are risks for impaired cognitive development. The current results may therefore be due to some heavier babies with slightly less favorable cognitive outcomes. Third, attentional focusing was associated with income whereas attentional shifting was not (see Table 2). There is evidence that children's attention focusing is influenced by postnatal experiences in the home and in childcare whereas this is not the case for attention shifting [47]. The current study suggests that biological mechanism may be more prominent in the explanation of attentional shifting. Fourth, we found maternal depression during pregnancy and postnatal stress to predict fewer SWM errors. These results are surprising since they were both associated with MSDP, which had a detrimental effect on SWM performance. It is possible that children exposed to MSDP have better cognitive functioning in slightly more adverse environments marked by factors such as maternal depression and postnatal stress. This would be consistent with a goodness of fit model whereby the influence of MSDP on prenatal development prepares children to be exposed to greater adversity [43]. However, more work is needed to investigate this hypothesis.

This study is not without limitations. First, this study is only based on correlational data. This prevents us from making any inferences regarding the causal links between prenatal stress and child cognitive outcomes. However, we statistically controlled for other factors that could account for the association between MSDP and child outcomes. Another limitation is that we mostly relied on information given by mothers. However, one of our outcomes was obtained via a computerized assessment, thereby ruling-out the hypothesis that the current results are only due to shared rater bias.

## 6. Conclusion

In sum, our results indicate that MSDP in the form of life events during pregnancy is associated with both attention skills and spatial working memory during early childhood. Our results also showed that these associations varied as a function of child sex, MADP and/or maternal care. It is notable that MSDP was also related to MADP and poorer postnatal care, which suggests that MSDP places some children at risk both biologically and environmentally. Our results may have implications for the prevention of academic difficulties because attention skills and spatial working memory are related to early measures of school achievement [44,45]. Our results suggest that the prevention of academic underachievement in children exposed to MSDP may focus on two modifiable factors: MADP and postnatal care.

## Appendix A. List of life events included in the study

| Since the beginning of your pregnancy, |                                                                                                                                    |
|----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|
| 1                                      | Have you or a close family member or friend been arrested by the police, had problems with the law or immigration or been in jail? |
| 2*                                     | Have you or a close family member or friend been diagnosed with a serious disease, were injured seriously or been hospitalized?    |
| 3*                                     | Have you ever lacked the money to pay for housing for you or your family?                                                          |
| 4                                      | Have you ever lacked the money to pay for electricity, hot water or heating for you or your family?                                |
| 5                                      | Have you ever lacked the money to buy food for you or your family?                                                                 |
| 6                                      | Have you ever lacked the money to buy prescribed medication for you or your family?                                                |
| 7*                                     | Have you ever lacked the money to buy or pay for anything else that you or your family needs?                                      |
| 8                                      | Have you been hit, slapped or kicked?                                                                                              |
| 9                                      | Have you received threats of abuse?                                                                                                |
| 10                                     | Have you been threatened with a weapon?                                                                                            |
| 11                                     | Has anyone forced you to have sex?                                                                                                 |
| 12                                     | Do you have a partner? If no, did you have a partner earlier during your pregnancy?                                                |

(continued on next page)

## Appendix A (continued)

| Since the beginning of your pregnancy, |                                                                                                                  |
|----------------------------------------|------------------------------------------------------------------------------------------------------------------|
| 13*                                    | Have you moved or looked for a new home?                                                                         |
| 14                                     | Has someone moved in with you?                                                                                   |
| 15                                     | Have you lived apart from your husband or partner because of job, travel or other practical reasons?             |
| 16                                     | Did you get married or start living with your partner?                                                           |
| 17                                     | Have you had extra home or family responsibilities such as caring for an older relative or someone else's child? |
| 18                                     | Have you been burglarized or robbed?                                                                             |
| 19                                     | Have you experienced the loss of your house, car, or something else important to you?                            |
| 20                                     | Has anyone close to you died?                                                                                    |
| 21                                     | Have you been in a flood, fire or other major disaster?                                                          |
| 22                                     | Have you experienced discrimination because of your ethnic origin, race or religion?                             |
| 23                                     | Have you been involved in a serious motor vehicle accident?                                                      |
| 24                                     | Have you experienced problems with Welfare services or Social Assistance?                                        |
| 25                                     | Did you separate from your husband or partner because you were not getting along with each other?                |
| 26                                     | Have you gotten divorced?                                                                                        |
| 27*                                    | Has any other important event occurred to you?                                                                   |

Note. The five most frequent life events in the sample are indicated with an asterisk (\*). These life events were endorsed by 14% to 34% of the participants.

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