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The Association between Positive Maternal Parenting and Corpus Callosum Development in Young Children

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Abstract

In this prospective study, we aimed to determine the impact of maternal parenting and attachment on brain development in early childhood. This study examined the longitudinal effect of maternal parenting and attachment to their children on the growth of the children's corpus callosum. The participants were 10 healthy children and their mothers. They were recruited at 1 year of age. Magnetic resonance imaging and diffusion tensor imaging were performed on the children at 2 and 6 years of age. The increase in corpus callosum fractional anisotropy was obtained by calculating the difference between images acquired at 2 and 6 years. The increase in corpus callosum fractional anisotropy from 2 to 6 years of age was affected by attachment and maternal affective parenting. The maternal affective parenting strategies were assessed using the Maternal Behavior Research Instrument (MBRI), which has a self-report scale. The weight attributed to the effect of maternal affective parenting on the increase in corpus callosum fractional anisotropy was greater than that of attachment (p < .001). The results showed that everyday life experience, particularly the affective aspect of maternal caring, is an important factor affecting the development of the brain at an early age.

Key words: child development, attachment, corpus callosum, brain development, maternal parenting

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Introduction

The corpus callosum (CC) is the largest commissure between the two hemispheres of the brain, comprising approximately 200–350 million bundles of nerve fibers (Kalaycıoğlu et al., 2009). It connects and integrates the activities of the left and right cerebral hemispheres. In general, the volume of the CC grows continuously until early adulthood, although subregions show different growth rates during childhood development (Hasan et al., 2009). The CC is associated with cognitive capacity and includes the interconnections in the anterior and the posterior regions and those in the cerebral cortical regions, corresponding to the areas where nerve fibers pass through (Hofer & Frahm, 2006; Fryer et al., 2008; Kalaycıoğlu et al., 2009).

This causes anisotropic diffusion, which is most frequently quantified as fractional anisotropy (FA) (Fabri et al., 2014; Qiu et al., 2015). Anisotropic diffusion increases as myelination progresses in the brain after birth and it decreases as the structure of the white matter in the brain loosens with aging. Accordingly, FA has been found to increase with age in studies with newborn babies, children, and adolescents, while a decrease in FA due to aging can be interpreted as reflecting extracellular space expansion caused by decreased neuronal axons and myelin sheaths in the white matter. A high FA level in the CC is associated with higher cognitive functioning, such as better working memory (Qiu et al., 2015), and suggests either more myelination of nerve fibers or an increase in the structural integrity among neurons. Experience-dependent pruning and elimination of fibers through the CC continues from early childhood to young adulthood (Giedd, et al., 1996). Although the number of callosal fibers is fixed around the time of birth, structural changes in the CC, which is the most prominent white matter structure, continue after birth (Luders et al., 2010).

Few cohort studies have examined the relationship between parenting and child brain development, such as the growth of the CC (Kok et al., 2015). Specifically, insufficient research has been conducted on the effects of positive parenting in normally developing infants and children, as previous studies have primarily focused on negative dimensions and pathological development in infants and young children who have experienced deprivation or who were raised in an institution (Barnett, 2005). According to such studies, the brains of children raised in an institution early in life and who were subjected to experiential deprivation are underdeveloped compared to the brains of normally developing children, as shown by decreased volumes of gray and white matter of the posterior region of the CC and other areas (Bauer et al., 2009; Mehta et al., 2009). Further, the experience of abuse, such as physical abuse and negligence, during infancy and early childhood is associated with decreased CC size (Belsky & de Hann, 2011). The correlation between inhibition problems and a smaller CC tends to be weaker in children of highly sensitive mothers, indicating that even if the CC is insufficiently developed early in life, maternal sensitivity during infancy and early childhood can suppress later behavioral issues (Kok et al., 2014). Thus, recent research articles emphasize the impact of a mother's sensitivity and parenting quality on brain development in young children.

Secure parent-child attachment is a reliable predictor of child development (Fearson, Bakermans-Kranenburg, Van IJzendoorn, Lapsley, & Roisman, 2010). Longitudinal studies support that securely attached children show better performance on cognitive tasks such as those measuring executive function (Bernier et al., 2015; Bernier et al., 2012). The timepoint of 12 months has been studied with infants in the “strange situation” to assess parental attachment (Ainsworth et al., 1978), and based on this, numerous studies have evaluated infant attachment at 12 months (Braungart & Stifter, 1991; Scher, 2001).

Considering the constant influence of the environment on brain development early in life, parenting during this period can play a critical role in the composition and structure of the brain. However, further research is needed to investigate how dimensions of positive parenting promote well-balanced brain development, and particularly that of the CC, in normally developing children.

Early attachment typically forms at approximately 7 months after birth and induces specific structural changes in the infant's behavior and brain functioning (Siegel, 2012). Specifically, this mechanism functions as an internal working model of attachment. An 18-month-old infant can be comforted by evoking the memory of the attachment figure, which becomes a mental model and influences the formation of the infant's present and future behaviors (Siegel, 2012).

Thus, given the above, we investigated positive dimensions of parenting, such as maternal attachment and parenting behavior, in relation to the growth of the CC in children between the ages of 2 and 6 years. To this end, we measured brain development using magnetic resonance imaging (MRI) at ages 2 and 6 years. We also assessed attachment in 12-month-old infants. Parenting behavior was investigated using a self-report scale by mothers when their children were 36 months old. The age at approximately 3 years represents the transition period from infancy to early childhood (Belsky et al., 2005) and an age where parenting behavior is commonly measured (Lugo-Gil & Tamis-LeMonda, 2008) and assessed for its ability to predict subsequent brain development. A mother's parenting behavior during this period has critical significance, as it develops based on the child's attachment to the main caregiver. This is also a foundation of the child's interpersonal relationships, which are essential for brain development, as they provide stimulation that affects the maturation of experience-expectant and experience- dependent brain structures and functions (Nelson et al., 2013).

Method

Participants

Study participants were mother-child pairs; first-born children and full-term infants aged 1 year were recruited by public notice. A total of 105 families were enrolled in the study; among the 105 families, 34 families applied to have their children receive an MRI scan at 24 months of age. Ten children received an MRI scan at 6 years of age. They visited G Hospital for the MRI scan. Approval for this study was obtained from the Institutional Review Board of XXX Hospital (IRB no. XXX2305, XXX2016-239). Since the data included information on the development of infants, we obtained the written consent of their legal guardians before participation.

Ten healthy children and their mothers were enrolled in our study. All infants were born at full term (M GA = 39.5 weeks, SD = 1.51 weeks; M weight = 3.30 g, SD = .57 g). Children underwent the first MRI and DTI at 2 years of age, and a second MRI and DTI at the age of 6 years. Sixty percent of the children were first-borns, and the female to male ratio was 4 to 6. Attachment between infants and mothers was assessed at the age of 1 year.

When the children were 3 years old, the parenting behavior of the mothers were assessed using a self-report scale. Only mothers were included in this study because they were unemployed (including parental leave), and thus the children spend most of their time with their mothers. In Korea, during weekdays, mothers devote 6.5 times more time in taking care of their children than do fathers (Lee, 2012). Therefore, in this study, we only assessed maternal parenting behavior because their influence on their children has the greatest impact in everyday life. After the completion of the study protocol, the children and their mothers received a full battery of psychological tests (Korean Wechsler Intelligence Scale for Children-IV, House-Tree-Person, Rorschach ink-blot test, Minnesota Multiphasic Personality Inventory, The Korean Personality Rating Scale for Children, Bender-Gestalt Test, and Sentence Completion Test) as compensation for their participation.

MRI data acquisition

The children were sedated for the MRI scan with a low dose of oral chloral hydrate (30 mg/kg) and they were monitored with an MR-compatible pulse oximeter. The children received individually fitted earplugs (McKeon Products, Warren, MI) and an ear cushion for damping the noise. A physician remained in the scanner room during the examination.

MRI was performed on a conventional 3.0-T MRI (Verio, Siemens, Munich, Germany) using a Siemens matrix coil. The DTI scanning protocol was the same as that used in our previous studies (Jeong et al., 2016; Shim et al., 2012; Shim et al., 2014). At 2 years of age, natural sleep was induced in infants, and several DTI sequence parameters were substituted as follows: b = 0 and 800 s/mm^2 and TR/TE = 10,100/76 ms. The scanning time for the DTI sequences was 10 min 18 s. At 6 years of age, the DTI sequence parameters used were as follows: b = 0 and 800 s/mm^2, TR/TE= 13,000/76 ms, number of diffusion gradient directions = 30, number of excitations = 2, FOV = 230 mm, matrix = 128 × 128, slice thickness = 1.8 mm, voxel = 1.8 × 1.8 × 1.8 mm, and flip angle = 90°. The scanning time for the DTI sequence was 14 min 33 s. At 6 years of age, the DTI sequence parameters used were as follows: b = 0 and 800 s/mm^2, TR/TE = 13000/76 ms, number of diffusion gradient directions = 30, number of excitations =2, FOV = 230 mm, matrix = 128 x 128, slice thickness = 1.8 mm, voxel = 1.8 x 1.8 mm, flip angle = 90◦. The scanning time for the DTI sequence was 14 min 33 s.

Image analysis (or CC measurements)

FA maps were generated from each individual using the FMRIB Software Library (FSL, Oxford, United Kingdom) (Smith et al., 2004). The DTI data were first corrected for eddy current-induced spatial distortion using the non-diffusion-weighted (b = 0) image. Images were brain-extracted using the Brain Extraction Tool (Smith, 2002), and individual FA maps as well as the eigenvalue maps (λ_1, λ_2, and λ_3) were generated by using DTIFit implemented in FSL (Behrens et al., 2003). The CC was manually traced on the mid-sagittal slice created from the FA image using FSLView (Figure 1).

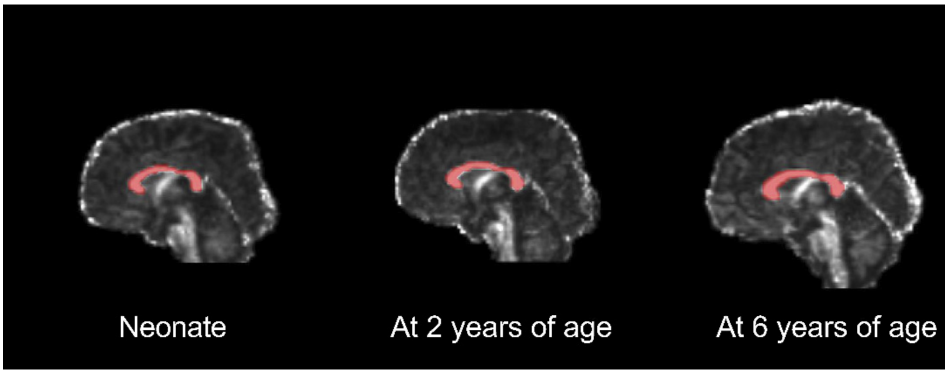

Figure 1. Image analysis for measurement of the corpus callosum. Fractional Anisotropy (FA) maps were generated from each individual using the FMRIB software Library (Smith et al., 2004). The corpus callosum is shown on a mid-sagittal FA map. The corpus callosum region of interest is outlined in red. Reprinted from *FslView* by Analysis Group FMRIB, 2016, https://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FslView

Attachment Q-Sort

Mothers completed the Korean version (Lee et al., 1997) of the Attachment Q-Sort Version 3 (Waters, 1987) when their children were 1 year old. The Attachment Q-Sort is a well-established home-based assessment tool for identifying maternal attachment (Newland et al., 2016). The Attachment Q Sort consists of a description of the child's secure based behavior observed during interaction with the mother. The observer and the infant's mother observe the child's behavior in natural situations. Based on this, the observer and the child's mother classify 90 cards with contents related to attachment behavior as nine sets of 10 cards in one group according to the degree of similarity to the child's behavior. A score of 9 points is assigned to the cards that are most similar to the child's behavior, and 1 point is assigned to the cards that are least similar to the child's behavior. Scoring consists of a correlation score between the standard score and each individual's score. The attachment score was calculated based on the five domains categorized by Pederson and Moran (1995): Secure-Base Behavior (14 items), Affective Sharing (3 items), Compliance (6 items), Enjoyment of Physical Contact (5 items), and Fussy/Difficult (14 items).

The maternal behavior research instrument (MBRI)

Mothers also completed the MBRI (Schaefer, 1959) when their children were 3 years old. The MBRI is a self-report instrument for assessing maternal parenting behavior and consists of four domains and 48 items: affective (12 items), rejecting (12 items), autonomic (12 items), and controlling (12 items). In the present study, we only used the affective domain (Cronbach's alpha = .75) because it may represent positive parenting, as well as the emotional experience of parenting. This measure was administered when the children were 3 years old because maternal parenting sensitivity, including affectionate and safety-based characteristics, was measured at age 3 years in previous research (Kok et al., 2014). In this study, we tested the specific influence of parenting characteristics by measuring attachment, emotional/affectionate characteristics, and safety-based characteristics.

Statistical analysis

The analysis focused on the relation between CC FA values (2 years of age, 6 years of age, and the difference between 2 and 6 years), affective parenting (3 years old), and attachment (1 year old). The data were analyzed using IBM SPSS AMOS Statistics version 23 for Windows (IBM, Armonk, NY). First, correlation analysis was performed for CC FA values and sex, and for CC FA values and affective parenting and attachment. Second, to assess significant associations, structural equation modeling was used to predict the pathways between affective parenting and the difference of CC FA values and between attachment and the difference of CC FA values. Statistical significance was set at $p < .05$.

Results

The CC FA value at 6 years of age was significantly correlated with CC FA at 2 years of age ($p < .001$) (Table 1).

Table 1. *Correlation among sex and CC FA values at ages 24 and 72 months (n = 10)*

Variables	Sex		CC FA (2 years)		CC FA (6 years)	
	r	*p*	*r*	*p*	*r*	*p*
Sex	1	-	.			
CC FA 24 months	.308	.458	1			
CC FA 72 months	-.293	.412	.808*	.015	1	-

CC, corpus callosum; FA, fractional anisotropy; *r*, correlation; *p*, significance level; *indicates significance at $p < .05$.

The correlations of the differential between CC FA values at 2 and 6 years of age with attachment to the mother (Q-sort) at 1 year of age (Table 2, Figure 2) and parenting behavior at 3 years of age were computed (Table 2, Figure 3), the predictability was tested, and the results are presented below.

The increase in CC FA from ages 2 to 6 years was significantly correlated with the Secure-Base subdomain of attachment to the mother at 1 year of age. These findings suggest that early attachment was associated with the development of the CC later in life. The effect was tested using a predictive model, and the path was significant (path coefficient = .906, $p < .001$) (Figure 4).

Table 2. *Correlation of the differential between CC FA values at ages 2 and 6 years with attachment to the mother and mother's parenting behavior*

	Difference in CC FA value between 2 and 6 years	
	r	*P*
MBRI		
Affective	.887*	.048
Attachment		
Affective Sharing	.226	.532
Secure-Base Behavior	.886*	.049
Enjoyment of Physical Contact	-.017	.962
Compliance	.460	.230
Fussy/Difficult	.289	.430

CC, corpus callosum; FA, fractional anisotropy; MBRI, maternal behavior research instrument.
* indicates significance at $p < .05$.

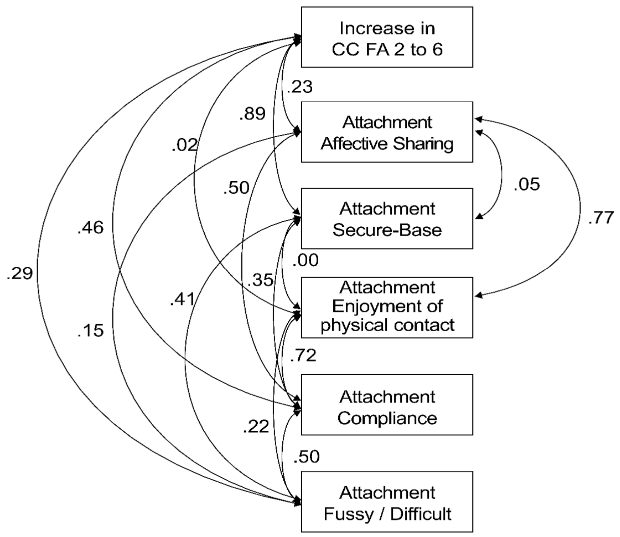

Figure 2. Correlation between attachment subdomains at 1 year of age and increase in corpus callosum fractional anisotropy (CC FA) values. The correlation was significant only between secure-base attachment and increase in corpus callosum FA from 2 to 6 years of age and the correlation value, r was .89 and significant at $p < .05$.

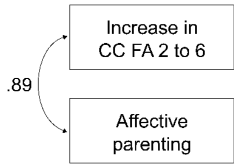

Figure 3. Correlation between affective parenting at 3 years of age and increase in the corpus callosum fractional anisotropy (CC FA) values. The value of the correlation coefficient, r, was .89 and significant at $p < .05$.

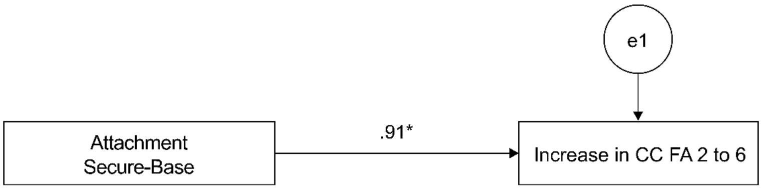

Figure 4. Attachment at 1 year of age predicts corpus callosum fractional anisotropy (CC FA) values at 6 years of age

Furthermore, a significant correlation was found between the increase in CC FA from ages 2 to 6 years and the affective parenting dimension of the mothers' parenting behavior when the children were 3 years old. The effect was tested using a predictive model, and the path was significant (path coefficient = .913, $p < .001$) (Figure 5).

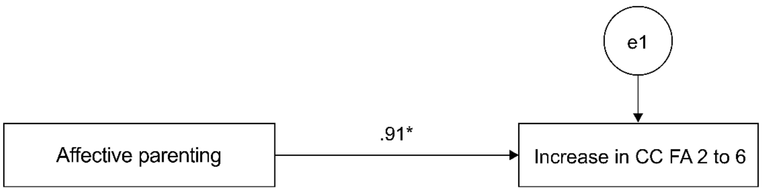

Figure 5. Affective parenting at 3 years of age predicts corpus callosum fractional anisotropy (CC FA) values at 6 years of age.

We then simultaneously tested the effects of the Secure-Base subdomain of attachment at 1 year and the affective parenting behavior at 3 years old (Figure 6). The significant effect of Secure-Base disappeared in the presence of affective parenting in the model, but the latter remained significant (path coefficient = .38, $p < .001$).

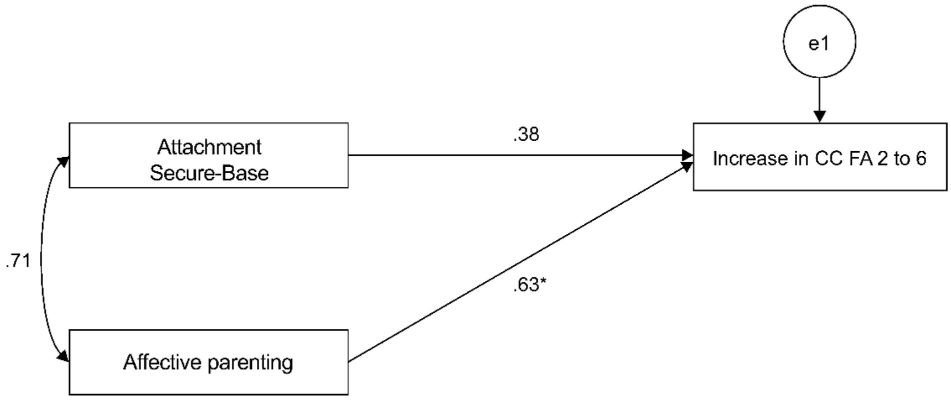

Figure 6. The effect of affective parenting at 3 years of age on the increase in corpus callosum fractional anisotropy (CC FA) values at 6 years of age.

Discussion

In this study, it was found that the increase in the FA value of the CC was associated with maternal affective parenting and mother-child attachment. These results suggest that the affective characteristics of maternal parenting at 3 years of age, which is the period of transition from toddlerhood to early childhood, may affect the development of neural connections in the CC in children. Furthermore, it was found that attachment, which is a relational characteristic experienced at the beginning of life, may affect cognitive aspects of brain development. Nevertheless, in this study, childhood experiences of mothers' affective parenting at 3 years of age showed greater explanatory power than attachment influence, suggesting the importance of the emotional experiences of children through everyday maternal care. Immordino-Yang and Damasio (2007) previously reported that the core of human potential is the connection between emotion, social functioning, and decision making, and education. The brain begins functioning at an early age; children learn from their experience with adults, which subsequently influences their decision making process. Our results support the claim that CC development is affected by experience before the age of 7 years (Schlaug et al., 1995). As Damasio et al. (1994) mentioned, previous emotional knowledge can guide the reasoning process; therefore, the maternal affective parenting expended and influenced the choices of their children based on emotional repertoire and social considerations in the process of higher cognitive thinking.

A higher FA value signifies increased myelination and density of nerve fiber bundles with development (Snook et al., 2005). Previous findings have shown different trends, depending on the age range of the subjects. FA values tend to decrease after the age of 20 years (Bhagat & Beaulieu, 2004; Pfefferbaum et al., 2000), whereas in infants and young children, the mean diffusivity decreases, and anisotropy and CC FA values increase according to age (McKinstry et al., 2002). Hence, in the present study, we investigated the level of increase in FA from ages 2 to 6 years and found that FA greatly increased, consistent with the aforementioned increasing trend of FA values during infancy and early childhood. A significant correlation in the CC FA value between the ages of 2 and 6 years is consistent with that reported by a previous study conducted with children aged 5 to 18 years (Luders et al., 2010). In previous studies, in measurements conducted at 3 to 6 years of age, the anterior region of the CC was reported to show the most noticeable change (Thompson et al., 2000).

The finding that attachment at 1 year of age and the mother's affective parenting at 3 years of age affect the development of the CC suggests that the internal working model formed through attachment and interpersonal experience, particularly the experience of affectionate interaction with the main caregiver, contributes to changes in brain structure and functioning, as shown by several previous studies (Kok et al., 2014). This finding suggests that although early attachment is an important factor associated with the growth of the CC, affective parenting is a much stronger predictor of CC growth during development in early childhood. Additionally, we have to consider that in a previous study (Kok et al., 2014), the correlation between parenting behaviors and CC length was not significant. There are two possibilities; one involves an investigation of differences in maternal parenting behavior (affective parenting vs. sensitivity and discipline behavior), and the other involves ethnicity (Asian vs. American or European). According to Rolls (2000), the emotional feedback from the mother triggers a reward system because of which infants who get more positive feedback have more experience and motivation. Additionally, changes in the behavioral patterns of Korean mothers can significantly increase CC. However, there is a need to further elucidate this portion of our study.

The value of CC FA is used to assess the integrity of nerve fibers, and a low level of integrity has been associated with impulsivity. A higher value of CC FA is related to high integrity of bundles of nerve fibers, suggesting that it is also associated with higher mental functioning and self-regulation, i.e., low impulsivity. The present findings show that the foundations of such abilities involve maternal attachment, formed when the child is at an early age, and an interpersonal relationship established through affectionate interaction between the child and the mother. As supported by several existing studies, our findings show that both attachment and interpersonal relationship skills are associated with changes in brain structures and functions, specifically the integrity and characteristics of the CC. Yet, several limitations of this study should be acknowledged. First, the sample was not representative of the population considering its small size. Second, maternal affective parenting was not measured by observation of mother-child interaction. Third, the growth of the CC was tested as a whole and not in segments (e.g., posterior, central, anterior). Despite these limitations, this study offers a valuable opportunity to elucidate the power of the long-term correlation of parenting on healthy child brain maturation, especially the growth of the CC, which is related to cognitive capacity.

Conclusion

The Attachment and affectionate features of early parenting influence not the FA value itself, but the increase in FA, serving as predictors of increased cognitive capacity. The finding that mothers' parenting when their children are 3 years old is a stronger predictor of FA increase than the children's attachment when they are 1 year old confirms that everyday experience affects qualitative aspects of brain development and provides a foundation for the development of the CC to empower higher mental functioning. Therefore, future research should investigate the long-term impact of attachment and parenting with consideration of the various socioeconomic classes or cultural areas. Despite the significance of this study, the results are based on the outcomes presented by a particularly small sample size, requiring careful interpretation. In future studies, the results should be re-examined with a sufficient sample size.

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