The Intensity of Formal Daycare Attendance Decreases the Shared Environment Contribution to
School Readiness: a Twin Study

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Abstract

Few studies have examined the genetic and environmental pathways through which formal daycare attendance and school readiness are associated. The purpose of this study was to explore if daycare attendance could moderate genetic and environmental contributions to school readiness. A sample of 648 (85% White; 50% Female) pairs of twins was used to compute a GxE, CxE and ExE interaction analyses. Each standard deviation of formal daycare intensity (high number of hours per week), but not age of onset decreased the contribution of shared environment (-0.13) but not genes or unique environment to school readiness. The results support the hypothesis that daycare acts as a normalizing environment, possibly buffering the negative effects from low-quality home environments on cognitive abilities.

Keywords: Daycare, School readiness, GxE interaction, Twin study

Word count: 119

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Introduction

Like other developed countries, the majority (53%) of Canadian children under 5 years of age attend daycare (Adema & Ali, 2015; Canada, 2011). As daycare becomes more common, researchers, policy-makers and educators have become increasingly interested in documenting its effects on children's development. Cohort studies and randomized control studies have shown that good quality daycare enhances preschool and school-age cognitive abilities, especially for children from low socioeconomic status (SES) households (Erel, Oberman, & Yirmiya, 2000). In particular, good daycare can compensate, at least partially, for being raised in low SES households (Laurin et al., 2015). Interestingly, a gene-sensitive study on American twins noticed that daycare attendance at 4 years of age tended to decrease shared environmental influence on academic achievement (Tucker-Drob, 2012). This result is in line with the idea that daycare contributes the most to children from low SES family backgrounds by decreasing negative family-level influence. However, it is unclear if this effect can be replicated in a different set of twins and if different patterns will emerge by exploring continuous and longitudinal measures of the age of onset and the intensity of daycare attendance. Therefore, this study aimed to explore if daycare attendance (from 5 to 48 months of age) can moderate genetic and environmental contributions to school readiness at 60 months in the Quebec Newborn Twin Study (QNTS), a prospective, population-based and genetically informative sample of 662 pairs of twins.

Daycare can be defined as services provided by someone other than the parents to care for and educate children in their absence. This includes formal (center-based) and informal (e.g.,

grandparent custody, nanny) care. Early studies focused on developmental differences between children attending and not attending daycare (Belsky & Steinberg, 1978). Later work recognized that daycare experience is not homogenous and that the characteristics of the experience matter (Peisner-Feinberg, 2004). In particular, two dimensions of daycare have emerged as long-term predictors of child development: quality and quantity (Tran & Weinraub, 2006). Quality of daycare refers to its characteristics such as caregivers' training, child-staff ratio and child-staff relationship (Tran & Weinraub, 2006). Quantity refers to the amount of time experienced in daycare by the child, including age of onset and number of hours per week (Belsky, 2002). Both quality and quantity play a significant role in children's daycare experience.

The effect of daycare on school readiness has been extensively studied (Ramey, 2018). Good quality daycare has repeatedly been associated with better child outcomes, including school readiness and language development (Tran & Weinraub, 2006), higher academic grades, and admission to more selective colleges (Vandell, Burchinal, & Pierce, 2016). Also, daycare's quality interacts with its quantity: under low quality, high quantity yields no or even negative outcomes, whereas under high quality, high quantity can yield positive outcomes (Melhuish, 2004). Indeed, daycare attendance, high number of hours of attendance per week, and early age of onset are all positively associated with preschool receptive vocabulary and semantic fluency, especially when daycare quality is high (Gialamas, Mittinty, Sawyer, Zubrick, & Lynch, 2013; Kave, Shalmon, & Knafo, 2013; Lee, 2016; Luijk et al., 2015).

In Quebec, daycare is subsidized and organized into centers with specific educational programs. However, access to these programs is not universal, mainly because of the lack of places, but also because some parents choose other means of daycare. A provincial survey conducted in 2003 (three years after the QNTS cohort finished daycare) showed that, in general,

preschool educational services were of acceptable quality, but quality differed by type of daycare services: family type daycare setting and private daycares were rated on average as acceptable, whereas public center-based daycare settings were rated as good or excellent (Drouin, Bigras, Fournier, Desrosiers, & Bernard, 2004). Hence, for studies in this population sample of children, type of daycare has been repeatedly used as a proxy for quality (Geoffroy et al., 2007; Geoffroy et al., 2010; Laurin et al., 2015). These studies reported a larger positive impact of formal versus informal daycare on cognitive school readiness, receptive vocabulary, number knowledge, and reading performance in 6 and 7 years old and on provincial standardized exams at 12 years of age. Although, there is a wealth of research on the association of daycare and school readiness, only one study has examined the etiologic pathway through which daycare attendance may impact school readiness. However, this study has not looked at continuous and longitudinal aspects of daycare attendance while adequately correct for all potential selection factors into daycare.

The Twin Model to Assess the Contribution of Genetic and Environmental Factors

Genetically informative study designs using samples of twins have contributed to this research area by exploring genetic etiology of school readiness. The twin model uses the natural occurrence of MZ twins, who share 100% of their genetic background, and dizygotic (DZ) twins, who share on average 50% of their genetic background to estimate genetic and environmental contributions to individual differences. Correlations between twins from the same family are calculated for a given trait. The extent to which MZ twins are more similar than DZ twins indicates a contribution of genes (A), heritability, to the variance of a given phenotype. The remaining variance can be explained by shared environment (C) that yields similarities between

twins, and non-shared environment (E) that yields differences between twins regardless of zygosity.

The partition of variance into genetic and environmental components assumes additivity of their contributions. However, it is possible that their contributions do not simply add up. Indeed, the contributions of A, C and E could vary as a function of a specific environmental exposure. For example, a significant Gene-Environment (GxE) interaction suggests that the effect of the environment depends on genes, or conversely that the effect of genes depends on the environment (Boardman, Domingue, & Daw, 2015; Rutter, 2006; Shanahan & Hofer, 2005). It applies to patterns in which genetically gifted individuals thrive in their school readiness despite a low-quality environment that negatively affect others, or in which individuals with inherited learning difficulties continue to struggle despite the optimal support that benefits others.

Genetic components of school readiness have been extensively studied in twin designs (Polderman et al., 2015). In the preschool years, individual differences in cognitive abilities have been shown to be explained mostly by shared environmental factors and to a lesser extent by genetic and unique environmental factors $A^2 = .32$, $C^2 = .53$, $E^2 = .15$ for school readiness at 5 years of age (Lemelin et al., 2007); $A^2 = .25$, $C^2 = 0.54$, $E^2 = .21$ for math skills at 4 years of age; $A^2 = .18$, $C^2 = .61$, $E^2 = .21$ for reading skills at 4 years of age (Rhemtulla & Tucker-Drob, 2012)).

Surprisingly, G×E interaction in the context of daycare has been sparsely studied. We found only two studies that tested GxE interaction in the context of daycare. Both examined the same set of 600 twins from the United States attending and not attending daycare at 4, but did not examine continuous, longitudinal moderators (Tucker-Drob, 2012; Tucker-Drob & Harden, 2013). The first study tested the hypothesis of a GxE interaction on the development of

externalizing behavior problems. The authors found that daycare presence at 4 decreases the shared environment contribution and increases the genetic contribution to externalizing behavior at 5. Among children who did not attend daycare, externalizing at age 5 was predominantly due to environmental influences (52% shared environment, 34% non-shared environment) rather than genetic influences (13%), whereas among children who had attended preschool at 4, genetic influence on externalizing was higher (67%), and shared environmental influences were smaller (0%) (Tucker-Drob & Harden, 2013).

The second study particularly relevant for the present work investigated GxE interaction with daycare and reading and math scores at 4 and 5. The author found that daycare presence at 4 decreases shared environmental contribution to math and reading scores but not genetic and unique environmental contributions. Among children who did not attend preschool at age 4, shared environmental influences accounted for 72% of the variance in math scores and 73% of the variance in reading scores at age 5. These contributions were smaller among children who attended preschool at age 4: shared environmental influences accounted for 47% of the variance in math scores and 43% of the variance in reading scores at age 5 (Tucker-Drob, 2012).

Overall, the results from the studies by Tucker-Drob suggest that daycare presence may diminish shared environmental influences on academic achievement at 5, but these results suffer from several limitations that we tried to address. Tucker-Drob compared the genetic and environmental contributions to school abilities of children who did and did not attend daycare at 4 years of age. As a result, it only examined the binary effect of daycare presence without evaluating earlier enrollment and without adequately correct for selection factors. By contrast, the current study goes beyond that of Tucker-Drob. 1- We evaluate multiple aspects of daycare attendance (daycare intensity and age of onset) to yield a better representation of daycare

experience (Peisner-Feinberg, 2004) and to better understand what aspects may matter more in terms of potential developmental effects. 2 – Instead of one single time point, we use longitudinal measures of daycare attendance to get a portrait of attendance between 5 months and 4 years. 3 - We use continuous moderator instead of a binary moderator. Simulations have shown to be a good strategy to adopt continuous moderators whenever available, allowing for nonlinear moderation to model any threshold (binary) effects and increasing the power to detect a continuous moderation (Purcell, 2002). 4 – Tucker-Drob controlled for three relevant selection factors in three separated G-E model. We instead followed the recommendations made by Duncan & Gibson-Davis (2006) and controlled for all theoretically relevant factors available in our dataset that could potentially bias our conclusions in one model (Duncan & Gibson-Davis, 2006). This strategy reduces the risk for social selection bias.

Objectives of the Present Study

There is a wealth of research on the association between daycare and school readiness, but a few have examined the genetic and environmental pathways through which formal daycare attendance may play a role in school readiness. The purpose of this study is to explore if daycare attendance (age of onset, number of hours per week 5 to 60 months of age) can moderate genetic and/or environmental contributions to school readiness at 60 months while accounting for relevant selection factors in a prospective, population-based and genetically informative sample of 662 pairs of twins from the QNTS.

Method

Participants

The present study used the QNTS sample. The QNTS is a population-based longitudinal study of 662 pairs of twins born between April 1995 and December 1998 in the Greater Montreal Area, Canada (Michel Boivin et al., 2019). Cognitive and environmental data including daycare attendance have been collected quasi-yearly from the twins and their parents from 5 to 60 months of age and beyond. The initial QNTS sample was representative of the Quebec population in terms of family educational attainment and ethnicity (M. Boivin et al., 2013). At the first wave, the average household income was approximately CAN \$54,000, which is slightly higher than the average income of families in the same region at that time (M. Boivin et al., 2013). Ethical approval of study protocols was obtained from Laval University's and Sainte-Justine Hospital's research ethics boards. Consent was obtained from the twins' parents prior to each data collection. Analyses were performed on a subsample of 648 twin pairs (245 MZ pairs and 403 DZ pairs) for whom we had data on daycare attendance at one or more time points when twins were 6 months ($M = 6.3$, $SD = .73$), 20 months ($M = 19.6$, $SD = .82$), 32 months ($M = 31.9$, $SD = .99$), and 50 months old ($M = 50.2$, $SD = 1.9$). We used all available data and managed missing data with full information maximum likelihood to maximize power.

Measures

Daycare attendance. At the child's ages 6, 20, 32 and 50 months, mothers reported on daycare attendance and the weekly number of hours their child spent in various daycare settings. We derived the following two formal daycare attendance variables: (1) intensity and (2)

age of onset. Formal daycare intensity was the average number of hours per week of daycare attendance across the four-time points. Age of onset is the age of the child when entering a formal school like setting for the first time. This variable was treated as a continuous variable. Children who never attended daycare, but attended kindergarten were given the age at which they entered kindergarten ($M = 64.49$, $SD = 3.16$) months. Indeed, although kindergarten is not mandatory, 98.1% of eligible children were enrolled in 2002-2003 (Ministère de l'Éducation, 2010), time at which participants enrolled in kindergarten. Scores were derived from participants with daycare attendance at all four-time points ($N=770$). This smaller sample has higher family income, higher number of siblings, higher proportion of intact family, higher health at birth, higher proportion of White family, and lower number of cigarettes smoked during pregnancy. As twin concordance was very high for daycare attendance ($r = .99$), we computed an interfamily score by averaging the daycare attendance means for both twins. Thus, daycare attendance was used as a family-wide environmental moderator in GxE testing.

School Readiness. Twins were administered the Lollipop test, a widely used measure of school readiness, in a laboratory setting at 60 months, the summer before school entry (Bigrasi, 2003; Chew & Morris, 1984). This measure has been shown to successfully predict early school achievement (Forget-Dubois et al., 2007; Lemelin et al., 2007). Twins were tested by two different testers, in two different rooms, to avoid inflated twin similarity. The test was administered in French (85%) or English (15%), depending on the predominant language of the child. We included school readiness data from 908 (384 monozygotic, 524 dizygotic) twins. The Lollipop test consists of 52 items divided into 4 subtests each assessing a component of cognitive school readiness: (a) Identification of Colors and Shapes; (b) Picture Description and Spatial Recognition; (c) Identification of Numbers and Counting; and (d) Identification of Letters and Writing. An overall score can be obtained by combining the scores of the four subtests. The

scores for subtests 1 to 3 range from 0 to 17, scores for subtest 4 range from 0 to 18, and overall scores range from 0 to 69. The overall score was used in the present study. Cronbach alpha for this total score was $\alpha = .73$.

Control variables. Because the parents' choice to send their children to daycare is not random, we controlled for several selection factors susceptible to affect daycare attendance in our GxE model. Selection factors are variables predicting the parents' choice of daycare intensity. We examined 14 selection factors that have previously been associated with daycare attendance in a demographically and geographically similar sample (Geoffroy et al., 2007). The following selection factors were assessed by the mother when her twins were 5 months old, unless otherwise specified: (a) **siblings**, that is, the average of the number of siblings from 0 to 18 years of age living in the child's household at 5 and 48 months; (b) **family income** assessed on an 11-item scale ranging from no income to above \$80,000 per year at the first four-time points. Income at the four-time points were averaged. (c) **marital status**, that is, whether the family unit consisted of two biological parents or not; (d) **health at birth** (i.e., "Compared to other babies in general, how is your child's health at birth?") assessed on a five-point scale ranging from poor (1) to excellent (5); (e) **ethnicity**, that is, whether or not the child is White (proportion of White = 85%); (f) **pregnancy smoking**, that is, the average number of cigarettes smoked per day throughout the whole pregnancy; (g) **breastfeeding**, that is, whether or not the mother had breastfed the child; (h) birth weight measured in grams from medical birth record; (i) **maternal age** at the twins' birth measured in years; (j) **gestational age** in months at the first wave of assessment from medical birth record; (k) **sex**; (l) **family functioning** assessed with a subset of the family assessment device which comprises 12 items reflecting the quality of family relationships, such as problem solving, communication, roles, affective responsiveness, and behavioral control (Speranza et al., 2012), with scores ranging from 0 to 30, a high value

indicating a dysfunctional family environment; (m) **maternal education**, that is, the number of years of education of the mother reported at 60 months; (n) **paternal education**, that is, the number of years of education of the father reported by the father at 60 months.

Statistical Analyses

All summary statistics and phenotypical analysis were performed in the open-source statistical computing environment *R* (Team, 2018). Structural equation modeling applied to the twin model provides an efficient way to estimate genetic and environmental contributions to variance and covariance in a phenotype (Rijsdijk & Sham, 2002). We used Structural Equation and Twin Modeling in *Mplus* version 8.1 (Muthén & Muthén, 2017) to fit structural equation models to the phenotypic covariance structure between twins.

We first estimated univariate ACE decomposition for school readiness. Then, to estimate if the contributions of A, C and E to school readiness vary as a function of daycare attendance, we conducted a basic continuous GxE interaction analysis (Purcell, 2002). This model allows to test whether daycare attendance has a moderating effect on any or all of its A, C, and E components, while controlling for its main effect on school readiness (as in Figure 1). The variance of the trait is partitioned into latent A, C and E components and each of the components are expressed as a linear function of the moderator. To do so, the GxE analysis simultaneously estimates 8 parameters including β_m the regression phenotypic coefficient (i.e., the regression coefficient for the relationship between daycare and school readiness); the unmoderated coefficient a, c and e for the trait variable (i.e., school readiness); and the effect of the moderator on each ACE parameters β_a , β_c and β_e . β_a , β_c and β_e corresponds to the linear slope of the ACE parameters (of school readiness) varying as a function of the moderator (daycare attendance). For each twin pair conditional on the twins' measured environment moderator (M), the expected trait

(school readiness) mean for twin i is given by $M_i = \mu + \beta_m$ where μ is the mean of the trait (school readiness). The residual trait variance unexplained by the main effect is then partitioned into A, C and E components as so:

$$Var(T_i) = (a + \beta_a M_i)^2 + (c + \beta_c M_i)^2 + (e + \beta_e M_i)^2$$

And the expected heritability of school readiness for a given daycare attendance would be expressed by

$$A^2 = (a + \beta_a M)^2$$

We estimated the moderating effect of daycare intensity on school readiness and then the moderation of formal daycare age of onset on school readiness. The full model with all 8 parameters was estimated, while controlling for selection factors. Statistical significance was determined at 95% confidence intervals.

Results

Table 1 presents the means and standard deviations for formal daycare attendance indicators and school readiness as a function of zygosity and sex. There were no zygosity or sex differences in school readiness or daycare attendance indicators. Therefore, for all subsequent analyses, we considered scores for males and females together.

Table 2 shows the Pearson's correlations between the daycare variables (intensity and age of onset) and the selection factors. For subsequent analyses, we retained control variables that had an association of ($p < .2$) for both daycare attendance variables (Velentgas, Dreyer, Nourjah, Smith, & Torchia, 2013). Selected control variables were family income, ethnicity (White/not White), pregnancy smoking and breastfeeding (yes/no), paternal education and maternal

education. Daycare intensity and daycare age of onset correlate very strongly and negatively ($-.85^{***}$), indeed starting early allows to be exposed to daycare a greater amount of time. Enrolling in daycare early and for a high number of hours per week is positively associated with school readiness.

Our univariate genetic analysis indicated that school readiness includes a large contribution from shared environmental factors ($C^2 = .46$, 95% CI [.30, .62]) and to a lesser extent from genetic factors ($A^2 = .35$, 95% CI [.21, .50]), and unique environmental factors ($E^2 = .19$, 95% CI [.16, .24]).

Table 3 displays the moderation model estimates for both daycare attendance indicators. Daycare attendance intensity, but not age of onset, significantly moderated the shared environment contribution to school readiness. For intensity, each standard deviation of daycare intensity is associated with a $-.13$ 95% CI $[-.22, -.03]$, (see dotted lines in left panel of Figure 2) shared environment variance decrease. For age of onset, each standard deviation increases the C contribution to school readiness by $.02$ 95% CI $[-.03, .19]$, but without reaching statistical significance (see green lines in the right panel of Figure 2) Daycare attendance indicators did not moderate the additive genetic or unique environment contributions to the variance in school readiness.

Figure 2 presents a graphical summary of the saturated moderation analyses. It displays the moderating effect of formal daycare attendance (the x-axis) on the ACE contribution of school readiness (the y-axis), while taking into account selection factors. Daycare intensity significantly decreases the C contribution to school readiness (the green line), but not the A and E contributions (the red and blue lines, respectively). Indeed, the slope of A and E do not significantly differ from zero. The right panel displays the same model, but by holding the total

variance of school readiness equal to one. This representation allows us to visualize that the relative contribution of A and E increases while the relative contribution of C decreases with increased daycare intensity.

Discussion

The present study explored whether longitudinal daycare attendance indicators, intensity and age of onset, moderate the genetic and environmental contributions to individual differences in school readiness independently of family characteristics associated with daycare use. The main finding is that daycare intensity, that is the average number of hours per week a child spent in daycare between ages 5 and 48 months, decreased the shared environment contribution to school readiness. Each standard deviation of daycare attendance intensity is associated with a -.13 95% CI $[-.22, -.03]$, shared environment variance decrease. The intensity of daycare attendance did not however moderate the unique and genetic contributions to school readiness. By contrast, the age of onset of daycare attendance exerted no moderating effect on the variance components of school readiness.

Formal Daycare as a Normalizing Environment for Vulnerable Children

The results of the present study suggest that daycare possibly exerts its positive effect on school readiness by compensating for a less stimulating environment. Previous research using a singleton design showed that daycare can compensate, at least partially, for a disadvantaged home life. Indeed, daycare was found to be beneficial for children living in a precarious or low-stimulating household but it had little or no impact on children adequately stimulated at home (Belsky & Steinberg, 1978; Network, 2005). For example, children from poorly educated mothers show a consistent pattern of lower scores on receptive vocabulary, academic readiness,

and achievement tests at 6, 7 and 12 years of age in comparison with children of highly educated mothers, unless they receive formal daycare (Geoffroy et al., 2007; Geoffroy et al., 2010; Laurin et al., 2015). This could be explained by the fact that parents who did not obtain their high-school diploma or who live in precarious economic situations may lack the resources to adequately stimulate their children (Forget-Dubois et al., 2009). However, children attending daycare receive input from both parents and daycare providers. As formal daycare centers in this population provide a uniform educational program, daycare attendance intensity could make up for the less optimal learning experiences provided by the family environment.

These phenotypic studies only demonstrated that daycare attenuates the impact of specific family characteristics on children's preschool cognitive development (e.g., SES, maternal stimulation, maternal education) (Belsky & Steinberg, 1978; Geoffroy et al., 2007; Geoffroy et al., 2010; Laurin et al., 2015; Network, 2005). By contrast, building on the twin model, the present study shows that daycare attendance over the full preschool period is not only associated with preschool readiness at 5 years of age but that it decreases more generally the total family-level influence to school readiness (the shared environment contribution). The likely process at play is that daycare attendance acts as a normalizing environment decreasing differences between families (Kovas et al., 2007). Indeed, even though twins in the same family are virtually identical in their daycare exposure (i.e., they attend the same daycare for the same amount of time per week), and different families differ in their daycare exposure (i.e., children attend different daycare centers), individual differences in school readiness decreases with between family differences in daycare intensity. As formal daycare settings provide uniform educational programs in this population, exposure to cognitive stimulation is likely to vary less in daycare settings than it does between families. This is relevant for daycare policy makers because it poses daycare as a way to ensure every child has an equal access to learning opportunities before school

entry. However, restricted access to quality daycare is likely to create a deleterious situation in which children from lower SES families are less likely to enroll in daycare, when they are the ones who appear to benefit the most from it (Busse & Gathmann, 2018; Geoffroy et al., 2010; Peisner-Feinberg, 2004).

Tucker-Drob et al., (2012), in their study of the moderating effect of daycare attendance come to very similar conclusions. The current study replicates their findings, but goes beyond by showing that a longitudinal and continuous measure of formal daycare intensity exerts a similar moderating effect even when controlling for several selection factors into daycare. Our results show that although daycare may act binarily as a moderator, it also possibly acts in a more continuous manner.

Etiological Contributions to Early Cognitive Development

The present study also provides insights into the environmental and genetic contributions to cognitive abilities in early development. It is well established that the shared environmental contribution to cognitive abilities is high during the preschool years (~60%) and gradually decreases from school entry into adolescence, a point at which it becomes negligible (de Zeeuw, de Geus, & Boomsma, 2015; Tucker-Drob, Briley, & Harden, 2013). One hypothesis to explain this trend is the enrollment into the school system (Briley & Tucker-Drob, 2013). In school, children are exposed to a homogeneous learning environment, therefore diminishing environmental variance and differences between families (Downey, von Hippel, & Broh, 2004; Tucker-Drob, 2012). Although appealing, this hypothesis lacks empirical support mainly because school is mandatory, making it nearly impossible to have variability in school exposure to elucidate whether the observed trend is a normal developmental process or a school effect.

Our results, which build on the natural occurrence of children attending formal daycare settings bypass this limit. Indeed, formal daycare resembles school in its setting and educative purpose. However, it is non-mandatory, so children may attend it or not, at various ages, and with various intensities. This natural heterogeneity in daycare exposure allowed us to observe that formal daycare attendance intensity decreases the contribution of shared environment to cognitive abilities, even when children are enrolled at a very early age. It is therefore probable that daycare creates the same pattern we observe after school entry and that it is these environmental settings and not merely development that causes a decrease in the contribution of shared environment to cognitive abilities.

More importantly, the observed moderation of the intensity of formal daycare attendance suggests that etiological patterns vary within subgroups of a given population. This means that additive etiological models may in fact be misleading. Indeed, results show that under conditions of high intensity, shared environmental contributions to school readiness may actually be negligible at this age.

Limits of the Present Study

The novelty of our results should be considered within the limits of the study design. First, twins possibly differ from a singleton sample in daycare attendance as with studies of families with numerous children. Indeed, twins from our sample attended daycare with a weekly average of 6.78 hours ($SD = 9.36$; range = 0 to 38.75) which is lower than a same age singleton sample at the same time 14.33 hours ($SD = 15.06$; range = 0 to 46)(Geoffroy et al., 2010). Parents with more than one infant may choose to delay daycare entry because of the increased cost (Cleveland & Krashinsky, 1998). However, results may be generalizable because differences in means are less likely to affect the test for moderation within a sample.

Second, because $G \times E$ models use definition variables (variables with a value for each subject in the data set), every participant with a missing moderator (i.e., formal daycare intensity and age of onset) was excluded from the analysis. This results in a smaller sample size 770 versus 1296 than originally enrolled. Although this subsample comprises a lower proportion of less fortunate family, we consider the results generalizable to the general population. Indeed, phenotypic analyses have already shown that the association between daycare attendance and school readiness is greater in less fortunate families. Therefore, it is likely that the moderating effect we observed would not decrease by including a larger number of less fortunate families.

Third, the present study remains observational in nature and daycare conditions were not randomly assigned, but rather selected by the parents making it impossible to infer any causality. For example, it is possible that parents choosing to send their children to daycare are more similar than parents who do not, in which case the observed moderating effect could partially stem from the parents' choice to use formal daycare. To partial out this confounding effect, we followed the recommendations made by Duncan and Gibson-Davis (2006) (Duncan & Gibson-Davis, 2006) and controlled for several theoretically and empirically relevant factors to reduce the effect of social selection bias (Geoffroy et al., 2007). However, other unmeasured confounding factors could be at play. Therefore, further studies should assess the outcome before and after daycare enrollment to assert plausible causality inferences.

Lastly, we restricted our analysis to a subtype of daycare, formal daycare, because of its documented higher and more uniform quality (Drouin et al., 2004) and its stronger association with school readiness and school abilities (Geoffroy et al., 2010). Nonetheless variability in quality remains among formal daycare centers, upholding the possibility that the interaction we found is driven by the variance in daycare quality. Typically, quality is measured directly with

specific characteristics such as the caregivers' training, child-staff ratio, and child-staff relationship. As daycare quality was not directly assessed in this study, we cannot exclude its possible implication in the moderation process whereby parents may be more likely to send their children in higher quality centers.

Conclusion

In sum, the results reported here support the idea that formal daycare acts as a normalizing environment, possibly buffering the liability stemming from less stimulating home environments during the preschool years. Also, daycare attendance could precipitate the documented decrease of the contribution of shared environment to cognitive abilities after school entry. Further genetically sensitive designs investigating daycare moderating effects should include outcome measures previous to daycare entry to assert plausible causality inference as well as later outcomes measures to assess if the potential effects remain throughout development. In any case, direct measures of daycare quality are needed to determine if the interaction is driven by a subset of high-quality daycare centers.

Declaration of Conflicting Interests

The authors declared they had no conflicts of interest with respect to his authorship or the publication of this article.

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Table 1

Means, standard deviations and analysis of variance by sex and zygosity for school readiness and formal daycare attendance

Variables	All		MZ		DZ		Female		Male		ANOVA p-value		
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>zyg</i>	<i>sex</i>	<i>zyg * sex</i>
School readiness	42.8	13.0	42.5	12.6	43.0	13.3	43.5	13.1	42.1	12.9	.50	.20	.76
Intensity	6.8	9.4	7.0	9.5	6.6	9.3	6.7	9.5	6.9	9.2	.80	.71	.42
Age of onset	48.1	18.4	48.6	18.9	47.8	18.1	48.0	19.1	48.3	17.7	.24	.33	.28

Note. MZ = monozygotic; DZ = dizygotic; ANOVA = analysis of variance; zyg/sex/zygsex = p-value associated variance attributable to zygosity/sex/the *zygosity * sex* interaction.

Table 2*Correlations between control variables, school readiness and daycare intensity and age of onset*

	Daycare intensity	Daycare age of onset	School readiness	N
Family income	.27***	-.15**	.30***	1288
Siblings	-.20***	.22***	-.11**	1282
Marital status (intact)	.01	.03	.10*	1277
Health at birth	.02	.04	.10*	1242
Ethnicity (Whites)	-.20***	.16***	.03	1252
Pregnancy smoking	-.12**	.11**	-.18***	1290
Breast feeding (yes)	.15**	-.13**	.16***	1279
Birth weight	.04	-.06 ^{..}	.07 ^{..}	1204
Maternal age at birth	.09*	.02	.21***	1294
Age at first cycle	-.02	.00	-.02	1292
Sex (male)	.02	.01	-.02	1296
Family functioning	-.07 ^{..}	.03	-.07 ^{..}	1210
Paternal education	.27***	-.25***	.29***	1168
Maternal education	.20***	-.17***	.30***	1258
Daycare intensity	-	-.85***	.21***	770
Daycare age of onset	-.85***	-	-.14**	843
School readiness	.21***	-.14**	-	908

Note. *** $p < .001$. ** $p < .01$. * $p < .05$. ^{..} $p < .2$.

Table 3

Standardized parameter estimates with 95% confidence intervals for the full GxE model for daycare intensity and age of onset.

	Intensity			Age of Onset		
	Est	95%CI	<i>p</i>	Est	95%CI	<i>p</i>
Additive genetic (A)	.63	[.47, .75]	.00	.63	[.47, .75]	.00
Shared environment (C)	.62	[.46, .74]	.00	.63	[.47, .75]	.00
Unique environment (E)	.41	[.35, .46]	.00	.42	[.36, .47]	.00
A x daycare moderation (β_a)	.05	[-.03, .11]	.26	-.05	[-.14, .05]	.39
C x daycare moderation (β_c)	-.13	[-.22, -.03]	.02	.07	[-.03, .19]	.26
E x daycare moderation (β_e)	-.02	[-.06, .03]	.53	-.02	[-.06, .03]	.53

Note. Est = Estimates; 95%CI = 95% confidence intervals.

Figure 1

Path Diagram of the GxE Model for One Twin

Note. Only one twin is shown for simplicity. M = moderator; a , c , e = unmoderated genetic, shared environment, and unique environment components, respectively; β_a , β_c , β_e = moderator effect on the a , c , and e , respectively; β_0 = mean effect intercept; β_m = mean linear effect of the moderator on the trait.

Figure 2

Gene $\times$ Environment Moderation of Daycare Attendance on School Readiness while Controlling for Selection Factors

Note. This figure demonstrates the genetic and environmental variance components for school readiness as a function of daycare intensity and age of onset. At the bottom, the total variance is kept at 1, allowing to see how the relative contributions of A, C, and E vary as a function of daycare attendance.