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The special role of middle childhood in self-control development: Longitudinal and genetic evidence

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Abstract

Despite the importance of self-control for well-being and adjustment, its development from early childhood to early adolescence has been relatively understudied. We addressed the development of mother-reported self-control in what is likely the largest and longest longitudinal twin study of the topic to this day ($N = 1889$ individual children with data from at least one of five waves: ages 3, 5, 6.5, 8–9 and 11 years). We examined rank-order change in self-control from early childhood to early adolescence, genetic and environmental contributions to variance in the trait and differential developmental trajectories. The relative contribution of genetic and environmental factors to change and stability was also examined. Results point at middle childhood as a period of potential transition and change. During this period the rank-order stability of self-control increases, heritability rates substantially rise, and a cross-over occurs in two of the self-control trajectories. Nonadditive genetic effects contribute to both stability and change in self-control while the nonshared environment contributes mostly to change, with no effect for the shared environment. Our findings suggest that new genetic factors, that emerge around age 6.5 and whose effect on self-control is carried on along development, may partially account for changes in self-control around late middle childhood, and explain the growing stability in the trait approaching early adolescence. We discuss the implications of the special role of middle childhood for self-control development.

KEYWORDS
longitudinal twin study, middle childhood, personality development, self-control, stability and change

1 | INTRODUCTION

Self-control is a core temperamental trait which develops throughout childhood to becomes an important aspect of adult personality. It involves processes such as delaying gratification, concentration, planning, following instructions and adapting emotions and behavior to situational requirements and social norms (Berger, 2011; Moffitt et al., 2011). Linked to multiple life outcomes, from academic achievement to financial success, satisfactory long-term relationships and better health, self-control is considered a core element in facing successfully many challenges along the life-course (Duckworth & Seligman, 2017; Mischel et al., 2010; Moffitt et al., 2011).

Given its importance both for the individual and the society (e.g., facilitating following laws and social norms) it is important to understand the developmental course of self-control. First sprouts of the "mature" self-control, involving self-awareness and planning a sequence of actions, usually emerge around age 2–3 and increase in prevalence during the early years as the brain develops more sophisticated mechanisms for planning and impulse control (Berger, 2011). Self-control is expected to continue rising over the years, but less is known regarding this process between early childhood and young adulthood. Specifically, both early childhood and preadolescence have been hypothesized to be "key periods" of development and change in self-control with long-term implications for future outcomes (McClelland & Cameron, 2012; Moffitt et al., 2011; Valcan et al., 2017). However, not much research has followed children across these two periods. In addition, the sources of change and stability in self-control along the years are still unknown.

A developmental outlook on personality change provides several important, nonexhaustive perspectives (Caspi et al., 2005). First, *mean-level change* refers to the average change in a trait along development—whether a trait level of an entire population is increasing or decreasing (e.g., young children as a group have lower self-control than adults). Second, *rank-order stability* refers to the extent to which the ordinal position of an individual within the population on a certain trait tends to remain the same along the years (e.g., a child with low self-control levels compared to others will also be an adult relatively lower on self-control). Finally, *the sources of change* relate to the contribution of factors such as genetics and the family environment to stability and change in self-control.

Here, we focus on rank-order stability and change, and examine the sources of stability and change in self-control along the years with a longitudinal twin sample. Relying on five measurement points with time intervals of 1.5–2.5 years, we were able to closely examine changes in self-control during the potentially turbulent period from early childhood to early adolescence. We address this topic with a study of monozygotic (MZ) and dizygotic (DZ) twins followed from age 3 to age 11.

1.1 | Rank-order stability

Though mean levels of self-control and related traits naturally rise with age within the population (Bleidorn et al., 2009; Bridgett et al., 2015; Caspi et al., 2005; Gülseven, Liu, et al., 2021), research shows that at the individual level self-control shows considerable stability. Longitudinal studies found moderate to high rank-order stability along the life-course in conscientiousness, a personality trait closely related to self-control (Bleidorn et al., 2009; Caspi et al., 2005), and in related traits (e.g., self-regulation, effortful control), with correlations generally ranging between 0.40 and 0.80. Thus, the ordinary position of an individual's self-control level within the population tends to remain quite stable along the years, although change may also occur (Briley & Tucker-Drob, 2014; Eisenberg et al., 2010).

RESEARCH HIGHLIGHTS

- This is likely the largest and longest genetically informative study of self-control to this day, following development from early childhood to early adolescence.
- Results from a longitudinal twin design describe the end of middle childhood as a period of potential transition and change.
- During this time stability and heritability rates of self-control rise substantially and cross-over occurs in two of the self-control subgroups.
- Genetic factors that emerge around age 6.5 may partially account for changes in self-control around the end of middle childhood.

Research on lifespan personality change shows that stability is generally mild during infancy and toddlerhood and tends to increase with age to high rates during adulthood (Caspi et al., 2005). Stability of conscientiousness, specifically, continuously increases across adulthood (B. W. Roberts & DelVecchio, 2000; Specht et al., 2011). In the infancy to preschool period some have found mild rank-order stability (~0.20) which increases to moderate stability (~0.40) in self-control related traits (Friedman et al., 2011), and others have found high or moderate stability which increases to high stability (Kochanska & Knaack, 2003; Putnam et al., 2008; Spinrad et al., 2012). In middle childhood studies found moderate (~0.40) to high (~0.70–0.80) rank-order stability in self-control and effortful control (De Fruyt et al., 2006; Eisenberg et al., 2005; Vazsonyi & Huang, 2010). Similar findings have been shown in adolescence (Beaver et al., 2008; Higgins et al., 2009; Ray et al., 2013). While some found that stability rates increased with age, others did not find an increase in stability but rather a steady moderate to high stability (e.g., De Fruyt et al., 2006; Raffaelli et al., 2005). In addition, most of the aforementioned studies either had only one to three measurement points, or focused on one developmental period only (e.g., adolescence), and none of them followed children from early childhood to early adolescence. Using five measurement points, with fairly narrow time intervals of 1.5–2.5 years, we expected rank-order stability to be moderate to high and to increase with age along the period of early childhood to early adolescence.

1.2 | Differential trajectories in self-control development

One perspective that helps understanding how rank-order and mean-level changes are integrated, is that of developmental trajectories. Although self-control tends to show rank-order stability, not all individuals follow the same developmental patterns. While for some individuals self-control remains stable, for others self-control development

involves substantial change: increase, decrease, or nonlinear patterns (Bowers et al., 2011; Ray et al., 2013; B. W. Roberts et al., 2001).

In young children change predominates (specifically, an *increase* in self-control related behaviors), and trajectories are usually differentiated by the starting point and the growth rate of self-control levels. Studies with 1–3-year-old and 3–7-year-old children have found that half or more of the children had both a higher starting point in self-control related behaviors, and a faster growth rate along the years. The rest of the children started with lower levels of the trait which increased at a slower pace. The early developers also usually maintained their advantage across the years (Friedman et al., 2011; Montroy et al., 2016; Wanless et al., 2016).

Few studies have focused on developmental trajectories in self-control across middle childhood. However, in a study which followed children from age 5 to 10, more complex trajectories emerged, depending on the specific self-control related behavior which was examined. While attentional focusing showed stable trajectories (high, low, and moderate), persistence showed one high and stable trajectory, and two trajectories with opposite patterns of an increase versus a slight decrease (Zhou et al., 2007).

In the current study, we wished to examine whether children's stability or change in self-control differs during early childhood to early adolescence. Given the paucity of research regarding self-control trajectories across middle childhood, we hoped that our study could help to shed light on the possibility of different developmental patterns of self-control.

1.3 | Genetic and environmental contributions

Another key question regarding self-control development concerns its genetic and environmental etiology. By comparing similarity levels between MZ and DZ twins, twin studies decompose the trait's variance into sources of heritability (i.e., variability due to genetic factors), environment shared by the twins (e.g., similar parenting, school), and environment not shared by the twins (e.g., differential parenting, accidents and illnesses; This estimate also includes measurement error) (Saudino & Micalizzi, 2015).

Regarding self-control related traits, studies that focused on middle childhood have found moderate (~30%) to high (~55%–75%) heritability for effortful control according to maternal reports (Lemery-Chalfant et al., 2013; Scott et al., 2016). High heritability rates (~60%) have also been found for observed executive functions at age 5 years (Fujisawa et al., 2019). In adolescents, high heritability rates (~50%–75%) have been found for self-reported low self-control (Beaver et al., 2008) and for observed executive functions (Miyake & Friedman, 2012). Most of these studies reported a negligible effect for the shared environment, both in children and in adolescents (Beaver et al., 2008; Lemery-Chalfant et al., 2013; Miyake & Friedman, 2012; Scott et al., 2016), though Fujisawa et al. (2019) have found a significant effect for the shared environment regarding observed executive functions during early childhood. In a large longitudinal study of a multiage sample of children and adolescents (aged 4–14 during the first

wave), heritability estimates of mother rated low self-control ranged from moderate (~30%) to very high (~90%), while the shared environment accounted for 0%–30% of the variance, with higher shared environment rates at the younger ages (Connolly & Beaver, 2014).

The findings of substantial heritability and of little evidence for shared environment effects seem to be robust across different age groups, different self-control related constructs and different measurement methods (Blonigen et al., 2008; Bridgett et al., 2015; Saudino & Micalizzi, 2015; Scott et al., 2016). However, few studies have examined change in heritability of self-control and related traits along the childhood years. Those which have, mainly with adolescents, usually found either stable heritability rates (e.g., Blonigen et al., 2008, for self-reported constraint) or some increase in heritability along the years (e.g., Anokhin et al., 2011, for observed delayed gratification).

In the current study, we hoped to better understand the dynamics of heritability between early childhood and early adolescence. We expected to find moderate to high heritability and negligible shared environment influences at the different ages. In addition, we tested whether heritability increases with age during this period.

1.4 | Genetic and environmental contributions to stability and change

Studies on adults have often shown that the rank-order stability of conscientiousness can be attributed mainly to genetic factors, with a small contribution of the nonshared environment, while change is attributed to nonshared environmental factors, sometimes accompanied by new genetic factors (Bleidorn et al., 2009; Caspi et al., 2005; Kandler et al., 2010). Similarly, in adolescents, genetic factors were found to contribute to stability in self-control and related traits across studies, while the shared environment had no significant effect on stability or change (Beaver et al., 2013; Briley & Tucker-Drob, 2014).

In contrast to the findings in adults, genetics were found to have moderate to large contributions to change within children and adolescents (Beaver et al., 2013; Larsson et al., 2004; Niv et al., 2012). This may mean that the expression of some genes begins in specific periods due to developmental, structural and/or hormonal changes, or that their expression may vary according to exposure to certain environments, which leads to changes in self-control (Beaver et al., 2013). The nonshared environment has been found to explain the rest of the variance in stability and change, with small to large contributions (Beaver et al., 2013; Briley & Tucker-Drob, 2014; Larsson et al., 2004; Niv et al., 2012).

Most of the existing knowledge regarding the sources of change and stability in self-control comes from studies on adults and adolescents. Previous studies on the topic have rarely examined children and have rarely relied on more than two-time points. In the current study, with the use of five-time points, we intended to closely examine the contribution of genetic and environmental factors to stability and change in self-control between early childhood to early adolescence. We hypothesized that the nonshared environment would contribute mostly to change, and that stability would be accounted for mainly by

genetics. However, the extended developmental period of our study enabled to study the possibility that with development, new genetic factors will contribute to change in self-control.

1.5 | The current study

Despite the rising interest in self-control and its importance, little is known about the development of self-control across childhood and toward adolescence. Specifically, although early childhood and preadolescence have been hypothesized to be periods of special developmental importance in self-control (Moffitt et al., 2011; Valcan et al., 2017) these periods are relatively understudied regarding patterns of stability and change. Therefore, we aimed to examine change patterns in self-control between early childhood and early adolescence and the contributions of genetic and environmental factors to stability and change.

We expected to find (a) Moderate to high rank-order stability which may increase with age; (b) Several differential developmental trajectories, with a large group showing high and stable self-control; (c) Moderate to high heritability rates which may increase with age, with little effect of the shared environment; (d) Substantial contributions of genetics to stability and smaller contributions to change. We address these questions with the largest and longest genetically informed study to date on the development of children's self-control.

2 | METHOD

2.1 | Participants and procedure

Families participated as part of the Longitudinal Israeli Study of Twins, a study on social development, in which all Hebrew-speaking families of twins born in Israel during 2004–2005, according to data provided by The Ministry of the Interior, were invited to participate (Knafo, 2006; Vertsberger et al., 2019). When twins reached the ages of 3, 5, 6.5, 8–9, and 11, mothers were asked to fill questionnaires regarding each twin's temperamental characteristics including self-control, as well as demographic and additional information. The age 6.5 and 8–9 waves oversampled families who participated in a lab experiment, to which mainly same-sex twins were invited. Therefore, we focused on same-sex twins to increase comparability across waves. An additional wave, at age 7, was smaller and limited to the Jerusalem area and thus not reported here.

Mothers filled questionnaires either at home or at the lab as part of a larger study that is beyond the scope of the current study. At age 11, questionnaires were answered at home, either online (79%) or by pen-and-paper. At each new wave, past participants were contacted and invited to participate. Supplementary Table S1 presents the mean age of children and mothers at each wave and final sample sizes according to zygosity. Two mothers' age 11 answers were disqualified as they had a mix-up with their own, or their twins' identifying information. Mother reports were available for 1,889 children (945 families) for at least one data point. For 240 children (121 families) data were available from all

measurement points (See Supplementary Table S2 for the number of families with one to five measurement points).

2.2 | Measures

2.2.1 | Self-control

Mothers rated four items on a 0–2 scale (0 = *not true/rarely*, 2 = *certainly true/often*). For each item, mothers were requested to rate how frequently the child behaves in the depicted manner, or how well the item describes the child. Items were taken from the Strengths and Difficulties Questionnaire (Goodman, 1997) and from the Infant-Toddler Social and Emotional Assessment (Carter et al., 2003) and addressed self-control related behaviors such as persistence, compliance, and concentration (i.e., "Keeps trying, even when something is hard"; "Generally well-behaved, usually does what adults request"; "Thinks things out before acting"; "Good attention span, sees tasks through to the end"). The scale's psychometric qualities were examined in a previous study and found to be good (Pener-Tessler et al., 2013). To examine the psychometric qualities in the current sample, we used Mplus version 5.21 (Muthén & Muthén, 1998–2010) to conduct a confirmatory factor analysis (CFA) combined with a path model in which self-control at each wave predicted self-control at the following wave (see Supplementary Figure S1). Fit indices for the model were excellent and the standardized loadings for all item indicators were significant, positive and large across ages (0.45–0.78, lower for the compliance item, 0.29–0.40). These results confirmed that at all waves items loaded on a single factor. To support the assumption that the same construct is being measured across ages, we conducted an additional CFA in which the loadings of each item were fixed to be equal across ages. The fit of this model was still excellent, and the standardized loadings for item indicators were similar to those of the unconstrained model (see Supplementary Figure S2). Thus, self-control scores were averaged for each age separately.

2.2.2 | Zygosity

Twins' zygosity was determined according to DNA samples when available (see Avinun & Knafo-Noam, 2017), or according to an algorithm based on parental reports regarding twin similarity (Goldsmith, 1991).

2.3 | Analyses

Descriptive statistics and attrition analysis were conducted using RStudio (RStudio Team, 2020). In order to examine whether attrition systematically affected results, we compared families who participated in two consecutive measurement points to families who participated in only one of the two, on self-control and demographic variables (i.e., twins' zygosity, mothers' religiosity, mothers' education level and mothers' income level). We also examined whether participants with

only one to two measurement points differed from participants with three measurement points or more on these variables. Next, we examined whether excluding participants with only one to two measurement points affected attrition analyses. Sex differences in self-control mean-level at all ages were also examined, and the following analyses were conducted both for the entire sample and for boys and girls separately.

Rank-order stability was examined by simple longitudinal correlations of self-control along the years, using RStudio (RStudio Team, 2020). To examine whether there were different developmental trajectories for self-control we used Mplus version 5.21 (L. K. Muthén & Muthén, 2010) to conduct a latent class growth analysis (LCGA). We used the type = COMPLEX command to enable the use of the MLR estimation method which does not assume independence of observations and allows using both twins in an analysis by considering twins as nested within families.

We started with a single-class growth model, beginning with a linear single-class growth model, and proceeding to a quadratic single-class growth model, given the trend that has been spotted of an increase followed by a decrease in self-control mean along the years (see descriptive statistics below). The model with better fit indices and a lower BIC value was preferred as a starting point for the LCGA (B. O. Muthén, 2015). Slopes were constrained according to the time intervals between waves (i.e., 0 for the first slope indicating the first wave, 2 for the second slope indicating the 2 years interval between ages 3 and 5, 3.5 for the third slope indicating the interval between the first age 3 wave and the age 6.5 wave, and so on) (Jung & Wickrama, 2008).

We then examined alternative models with one more class at a time, until the best solution was achieved. In order to allow the identification of distinct classes prior to conducting the growth mixture modeling we fixed the within-class variances of the growth factors to zero (Jung & Wickrama, 2008). The final number of classes was selected according to the best fitting model as indicated by a lower BIC than those of the alternative models. In addition, according to the criteria for selecting a model, suggested by Jung and Wickrama (2008), we also ensured that the Lo-Mendell-Rubin adjusted LRT test for the selected model was significant, the proportions for all classes in the model were greater than 1%, and the entropy of the solution was acceptable. Lastly, we considered the model's interpretability in selecting the number of classes.

To examine genetic and environmental contributions to self-control we used RStudio (RStudio Team, 2020). We first calculated intraclass correlations between MZ and DZ twins' self-control at each age. Next, to compare models and estimate the contribution of different genetic and environmental effects to the variance in self-control at each age, model fitting analyses were carried out on self-control at each of the ages. First, at each age we compared the classic additive genetic model, that is, ACE, which includes additive genetic (A), shared environmental (C), and nonshared environmental effects (E) to a nonadditive genetic model, that is, ADE, including both additive and nonadditive genetic effects (D), and nonshared environmental effects (see Results section for an explanation regarding the alternative models, and supplemental materials for the comparisons). The best-fitting model was chosen according to Akaike's Information Criterion (AIC).

We continued the analysis with the selected model and its derivatives (e.g., for the ADE model, the full model would be compared to an AE model that includes only an additive heritability component and a nonshared environment component, and to a DE model that includes only a nonadditive heritability component and a nonshared environment component). The model which fit the data best according to AIC was selected. Estimates of the models' components and their confidence intervals were also considered when choosing the preferred model.

To examine the contribution of genetic and environmental factors to change and stability in self-control within-twin and between-twin variance-covariance matrices across the ages were analyzed by using Cholesky decomposition (Beaver et al., 2013), using RStudio (RStudio Team, 2020). The model that was used in this longitudinal analysis was the model that fit the data best at all ages in the cross-sectional analysis.

3 | RESULTS

In the preliminary analyses on continued participation, only a few differences in demographic characteristics were found between families who participated in two consecutive measurement points and families who participated in only one of the two. These differences were found only at some of the measurement points, with negligible to small effect sizes. Importantly, no differences were found in self-control levels (see Supplementary Table S3). 421 families had less than three measurement points. These participants did not significantly differ from participants with three or more measurement points on most demographic variables. A significant difference in self-control between participants with less than three measurement points and the rest of the sample was found only at age 9, and its effect size was small (see Supplementary Table S4). When excluding participants with less than three measurement points from the sample, results of the preliminary analyses on continued participation remained quite similar (see Supplementary Table S3). Thus, we concluded that the continuity of participation did not systematically affect the results and included the full sample in our analyses in order to increase statistical power (Scheffer, 2002).

3.1 | Descriptive statistics

Means, standard deviations and sex differences of self-control are presented in Table 1. Girls scored higher than boys in self-control across all ages. While mean-level sex differences were significant in the younger ages (3, 5, and 6.5), they were small and became smaller and nonsignificant toward ages 8—9 and 11. Since estimates and change patterns in further analyses were very similar for both sexes across analyses, results are henceforth presented for boys and girls combined.

3.2 | Rank-order stability

Longitudinal correlations appear in Table 2. Across the entire study (8 years) there was evidence for rank-order stability, $r = 0.30$, $p < 0.005$.

TABLE 1 Means and standard deviations of children's self-control across ages by children's sex, and *t*-tests for sex differences at each age

	Age 3	Age 5	Age 6.5	Age 8–9	Age 11
Boys	1.30 (0.43)	1.32 (0.45)	1.35 (0.43)	1.27 (0.48)	1.26 (0.48)
N	798	650	428	364	390
Girls	1.37 (0.42)	1.43 (0.42)	1.43 (0.44)	1.33 (0.47)	1.32 (0.46)
N	802	600	433	391	415
Total	1.33 (0.43)	1.37 (0.44)	1.39 (0.44)	1.30 (0.48)	1.29 (0.47)
N	1600	1250	861	755	805
t-Test	3.50 (1597.1)	4.34 (1247.8)	2.59 (858.12)	1.57 (744.84)	−1.78 (792.86)
Significance (*p*)	<0.001	<0.001	0.01	0.12	0.08
Effect size (Cohen's *d*)	0.17	0.25	0.18	0.11	0.13

Note. Parentheses indicate standard deviations for boys, girls and total; degrees of freedom for the *t*-tests. *t*-Test the tests for sex differences at each age. The two last rows indicate the significance and the effect size of the difference.

**TABLE 2** Simple correlations between self-control scores across ages

	Age 3	Age 5	Age 6.5	Age 8–9
Age 5	0.45 (1035)			
Age 6.5	0.36 (751)	0.48 (605)		
Age 8–9	0.34 (632)	0.45 (559)	0.61 (525)	
Age 11	0.30 (690)	0.46 (589)	0.56 (476)	0.68 (466)

Note. All correlations are significant, *p* < 0.005. Number of children in parentheses. Correlations are based on scale scores and do not correct for unreliability, thus are somewhat smaller than the associations in the combined CFA and path model supplementary Figure S1.

The rank-order stability of self-control along the years, as shown in adjacent measurements, was moderate during early to middle childhood (ages 3–6.5) and high from middle childhood to early adolescence (ages 6.5–11).

3.3 | Differential trajectories in self-control development

The linear single-class growth model, which was conducted as a first step of the LCGA, showed significant intercept and slope parameters (unstandardized coefficient estimates = 1.36, *p* < 0.001; −0.01, *p* = 0.006, respectively), and had a good fit to the data (RMSEA = 0.05, CI: 0.04–0.06, CFI = 0.95, SRMR = 0.05, BIC = 5413.22). It was followed by a quadratic single-class growth model, which showed significant intercept, linear slope, and quadratic slope parameters (unstandardized coefficient estimates = 1.34, 0.04, and −0.01 respectively, all *p* < 0.005), and had a better fit than the linear model (RMSEA = 0.04, CI: 0.02–0.06, CFI = 0.98, SRMR = 0.04, BIC = 5254.02). Therefore, the quadratic model was selected as the starting point for the LCGA (B. O. Muthén, 2015). One more class at a time was then added to the quadratic model, and fit indices of the models were compared. Eventually, two- to five-class models were
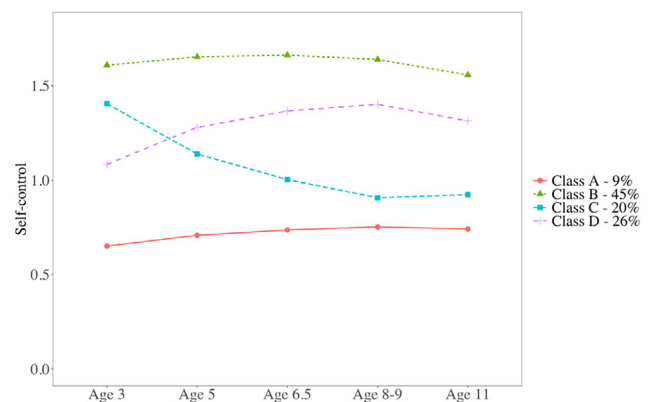
FIGURE 1 Change in self-control levels over time according to the four-class solution of the latent class growth analysis. Percentages adjacent to the class letter indicate the rounded proportion of the sample in each class

compared. Supplementary Table S5 presents selection criteria for the alternative models that were examined.

A four-class solution showed the best fit as indicated by a lower BIC than those of the alternative models examined (BIC [four classes] = 5319.46; BIC [three classes] = 5350.22; BIC [five classes] = 5338.50). In addition, in accordance with the criteria suggested by Jung and Wickrama (2008), the Lo-Mendell-Rubin adjusted LRT test for the four-class model was significant (Adjusted LRT = 58.98, *p* = 0.01), and the proportions for all classes in the model were greater than 1% (smallest class proportion = 9.45%). Though the entropy of this solution was only acceptable (entropy = 0.55), it was not much lower than that of the previous alternative model (entropy [three classes] = 0.59) and it was higher than that of the next alternative model (entropy [five classes] = 0.51). Since the four-class solution both had good fit indices and was more interpretable than the alternative solutions, it was selected.

A graphic representation of the four-class model solution is shown in Figure 1. Supplementary Table S6 presents the growth factors,

TABLE 3 Intraclass correlations between MZ and DZ twins' self-control and estimates for the best fitting model (DE) along the years

	MZ	DZ	(D²)	(E²)
Age 3	0.42[**]	0.05	0.44 (0.36–0.53)	0.56 (0.47–0.67)
Age 5	0.42[**]	−0.01	0.40 (0.37–0.51)	0.60 (0.49–0.73)
Age 6.5	0.39[**]	0.12[*]	0.40 (0.26–0.51)	0.60 (0.49–0.74)
Age 8–9	0.52[**]	0.02	0.51 (0.37–0.62)	0.49 (0.38–0.63)
Age 11	0.59[**]	0.06	0.59 (0.47–0.69)	0.41 (0.31–0.53)

[*]$p < 0.05$.
[**]$p < 0.005$.

proportion, and number of subjects in each class. The smallest class ("A") consistently showed the lowest levels of self-control across the years and its growth measures did not show any significant change over time, either linear or quadratic. The largest class ("B") had the highest levels of self-control across the years and showed a small linear and nonlinear change of some increase in self-control followed by some decrease over the years. The most interesting pattern, however, was demonstrated by the two in-between classes which together make for almost half of the subjects. These two classes showed opposite patterns in self-control development, indicated by both the figure and the opposite signs of their (significant) linear slope and quadratic slope growth factors. Class C started with medium-high levels of self-control at age 3, which gradually decreased until age 8–9, then started rising again between age 8–9 and 11. In contrast, Class D started with medium levels of self-control at age 3, which gradually increased until age 8–9, then dropped between age 8–9 and 11, creating a cross-over between the trajectories of these two classes.

3.4 | Genetic and environmental contributions

Table 3 presents the intraclass correlations between MZ and DZ twins' self-control at each age. While MZ twin correlations were moderate across early to middle childhood (ages 3–6.5) and high from preadolescence to early adolescence (ages 8-9-11), DZ twin correlations were mostly nonsignificant and negligible, indicating no shared environment effects. The correlations also do not conform to the expectations of a classic additive genetic influence model, which predicts that DZ twin correlations would be approximately half the size of MZ twins' correlations, or larger (Saudino et al., 2000). This pattern indicates a potential nonadditive genetic effect, a sibling contrast effect, or both (Mullineaux et al., 2009; Scott et al., 2016). In a nonadditive condition (e.g., genetic dominance, epistasis) only when both siblings receive the same set of genes from their two parents will they be similar to one another. The probability that this would occur is 100% in MZ twins, as opposed to 25% (or less in case of epistasis) in DZ twins. Therefore, in the case of nonadditive heritability, we should expect that MZ twin similarity would be higher than twice that of DZ twins (Saudino et al., 2000).

Another possible explanation for the low DZ correlation is a sibling contrast effect, in which within-pair comparisons lead parents to

rate the twins as more different from one another than they actually are. Contrast effects are more common for DZ than MZ twins, as MZ twins are usually more similar in both looks and behavior (Mullineaux et al., 2009; Saudino, 2003). However, in the presence of sibling contrast effects the phenotypic variance of DZ twins should be significantly greater than that of MZ twins (Saudino et al., 2000), while in our sample the variances of MZ and DZ twins were very similar and did not significantly differ from one another (except in one measurement point, see Supplementary Table S7). Therefore, we excluded the sibling contrast effect model and compared the classic additive genetic model, that is, ACE, which includes additive genetic (A) and shared environmental (C) effects, to a nonadditive genetic model, that is, ADE, which includes both additive and nonadditive (D) genetic effects, but no shared environmental effects.

The ADE model had a better fit to the data at all ages (see Supplementary Table S8), and so we continued the analysis with the ADE model and its derivatives (i.e., AE and DE models). Supplementary Table S9 presents the fit of the ADE, AE, and DE models to the raw data at each age, the specific parameter estimates and their 95% confidence intervals. We found that additive heritability estimates in the ADE model were either zero or very small, and their confidence intervals included zero (at all ages). The DE model showed the best fit to the data at all ages, therefore, we found the DE model to be relevant for describing the current data (see the discussion section for theoretical criticism of the DE model and justification for its selection, see estimates in Table 3). The nonadditive heritability of self-control was moderate across ages 3–6.5 (40%–44%) and increased to large rates across ages 8-9-11 (51%–59%). Accordingly, estimates of the nonshared environmental effects were large across ages 3–6.5 (56%–60%) and decreased across ages 8-9-11 (41%–49%).

3.5 | Genetic and environmental contributions to stability and change in self-control

We used the nonadditive genetic, nonshared environment model (DE) for the longitudinal Cholesky decomposition analysis as this was the model that fit the data best at all ages in the cross-sectional analysis (see Supplementary Table S9 and Table S10 for the ADE longitudinal analysis). Thus, henceforth, when mentioning genetics, we
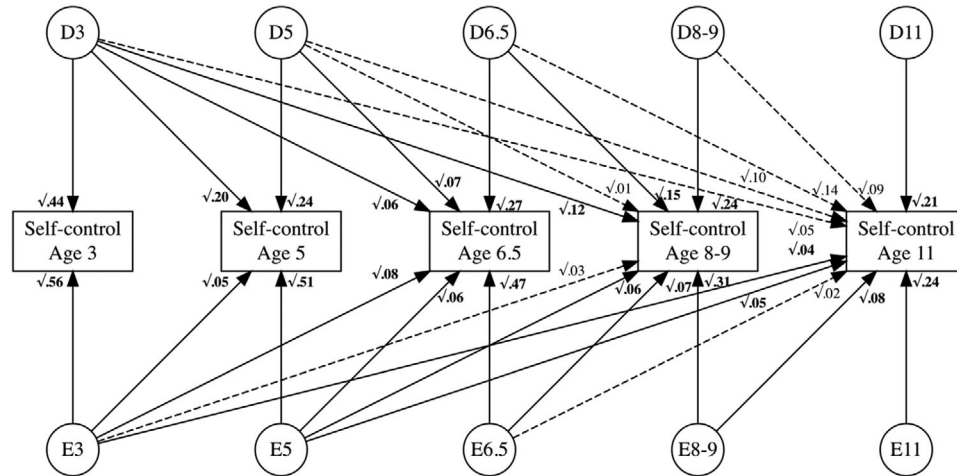
FIGURE 2 Cholesky decomposition of variance components of self-control at the different ages according to the DE model. *Note.* Circles indicate variance components of estimates, and rectangles indicate observed scores on self-control from maternal reports. D = Nonadditive heritability, E = Nonshared environment and error. The number in each circle represents the age to which the variance component is attributed. Estimates for which confidence intervals did not include zero are bolded. Dashed arrows represent estimates for which confidence intervals included zero. See Supplementary Table S11 in the supplemental material for confidence intervals of all estimates

refer to nonadditive genetic effects and environmental effects refer to nonshared environmental effects.

Figure 2 presents the results from the DE Cholesky decomposition model. The squared path estimates summed across the D and E components at each age account for 100% of the variance in self-control in the specific age. Nonadditive genetics accounted for both stability and change in children's self-control along the years. The genetic effects present at age 3 were partially carried on to all following ages, contributing to stability in self-control. The new genetic effects emerging at ages 5, 6.5, 8–9, and 11 demonstrate the contribution of genetics to change. The nonshared environment contributed mostly to change in self-control along the years. However, it also contributed to stability, as there was some carry-over of small environmental effects from previous ages.

Interestingly, age 6.5 was the time point that showed the largest proportion of genetic variance stemming from new genetic effects and not from the effects of previous ages (27% out of 40% or 68%). Moreover, the new genetic effects which emerged at age 6.5 had a substantial influence on the following age, accounting for approximately a third of the genetic variance at age 8–9. There was also a trend for an influence of the new genetic effects from age 6.5 to age 11, accounting for approximately a fourth of the genetic variance at this age (though this path was not significant). In comparison, new genetic effects which emerged at most other ages had only a negligible to small longitudinal influence on the following ages, with carried-on effects of 1%–10%.

4 | DISCUSSION

To the best of our knowledge, this is the longest and largest study to track stability and change patterns in self-control development between early childhood to early adolescence, and their possible

sources. Our results bridge the current existing knowledge about development until early childhood and during adolescence and adulthood. They point at the end of middle childhood as a period of potential transition and change in self-control, where heritability rates rise, new genetic effects on the trait emerge and the trait starts to stabilize.

4.1 | Rank-order stability

Our findings of moderate rank-order stability during early to middle childhood, increasing to high stability approaching early adolescence, are congruent with previous findings (Friedman et al., 2011; Ray et al., 2013; Vazsonyi & Huang, 2010), and support the notion that individuals tend to maintain their ordinal position in the population with regard to self-control from a relatively young age, and that as children mature, they are less likely to change this position. However, changes in rank order may also occur, especially at younger ages.

While the current findings of moderate to high rank-order stability in self-control are similar to previous finding, interestingly, they also show a "leap" in stability rates between ages 6.5 and 8–9. This leap may be a manifestation of developmental processes in the brain which are thought to be accelerated approaching preadolescence. For example, there is evidence that the density of prefrontal gray matter reaches a peak during preadolescence, followed by an increase in synaptic pruning and myelination and changes in axonal diameter (Blakemore & Choudhury, 2006; Zelazo & Carlson, 2012).

Another possible explanation for the "leap" in stability may be associated with the role of schooling in self-control development. Around the age of 6–7 children in Israel usually enter school, which imposes new educational and behavioral demands. Previous research has emphasized the contribution of self-control related behaviors to a child's school-readiness (e.g., Blair & Raver, 2015). However, a

relationship in the opposite direction may also exist, as the need to adapt to the new demands may induce the development of higher abilities of concentration, persistence and restraint. The school setting also creates opportunities for practicing self-regulatory skills (Ramdass & Zimmerman, 2011). Indeed, there is evidence that school attendance may improve children's behavioral regulation (Morrison et al., 2010). Hence, the increased stability in self-control may be in part due to the set system that children commit to as they enter school and to which they continue to adhere along the following years. This may account for the finding that self-control at age 6.5 (when many children already attend school) is more similar to self-control at age 8–9 than it is to self-control prior to attending school (e.g., at age 5).

4.2 | Differential trajectories in self-control development

Our results show that while many children show stable self-control levels from early childhood to preadolescence, a substantial proportion of the children demonstrate considerable change. Our finding of a large stable high-self-control group agrees with previous studies of adolescence and middle childhood (Coyne et al., 2015; Ray et al., 2013; Zhou et al., 2007). Notably, a study which followed participants from age 5 to 26 has also found four developmental trajectories, three of which are similar to the current results (i.e., a high-stable group and two intersecting groups) (Diamond et al., 2017). This suggests that the patterns found in the current study between early childhood to early adolescence may reflect a more general phenomenon which expands across wide developmental periods.

The intersecting patterns of two of the trajectories suggest changes in rank order for a nontrivial portion of the sample. This finding is congruent with previous studies with mostly older children (e.g., Hay & Forrest, 2006; Ray et al., 2013). Such intersecting patterns may have implications regarding interventions aimed at improving children's and adolescents' self-control. Moffitt et al. (2011) have shown that low-self-control adolescents are more likely to make mistakes that trap them in harmful lifestyles (e.g., smoking, school drop-out, teenage pregnancy). Accordingly, it seems that individuals who show a large decline in self-control when approaching preadolescence may be at risk for making detrimental decisions as teenagers, but may also be more responsive to intervention than the stable low self-control group. Specifically, while the stable high self-control group may not need any intervention and the stable lower group may show minimal response to intervention, the two intersecting subgroups may have a greater potential for change, as they may be more susceptible to environmental influences and therefore perhaps are better candidates for intervention. If that is the case, then identifying the children who would belong to these subgroups may be especially beneficial for directing interventions most efficiently.

Thus, an interesting and potentially important question that arises from the current findings is which children would develop according to each trajectory? Previous studies on adolescents have suggested a number of possible predicting variables of self-control trajectories, such as parental warmth and monitoring, school involvement and association with delinquent peers (Bowers et al., 2011; Na & Paternoster, 2012; Ray et al., 2013). However, some of these variables may be related to earlier factors, perhaps starting from early childhood, or even tied to a child's genetic makeup through processes of passive and evocative gene-environment correlations (Pener-Tessler et al., 2013).

Specifically, genetic variation is one plausible distinguishing factor, which, to the best of our knowledge, has not yet been examined in previous studies (e.g., children in the nonstable groups may be those who are more genetically susceptible to environmental influences). Given our findings of increasing genetic influence on self-control during early childhood to preadolescence (which will be further discussed below), the investigation of genetic variation as a potential distinguishing factor during this period may be of special interest. Future work should aim to address this challenge within a genetically informed study across a broad age range, from early childhood to late adolescence.

4.3 | Genetic and environmental contributions to self-control

Congruent with previous studies, our findings point at self-control from early childhood to early adolescence as determined by genetic makeup and nonshared environment, but not by the shared environment (Lemery-Chalfant et al., 2013; Spengler et al., 2012). However, this does not negate a potential effect of parenting. For example, a recent adoption study found that both the birth mother's self-regulation and the adoptive parents' parenting at age two predicted the adoptive child's self-regulation at preschool years (Bridgett et al., 2018). Such effects may be represented in the nonshared environment contributions, as siblings may receive differential parenting (Knafo & Plomin, 2006).

The genetic effects we found were nonadditive, resulting in MZ twins being much more similar to one another than DZ twins (Mullineaux et al., 2009). Such findings were found in some self-control studies (e.g., Keller et al., 2005; Spengler et al., 2012), but not in others (e.g., Anokhin et al., 2011; Mullineaux et al., 2009). Whereas past evidence supports a substantial genetic contribution to self-control, the finding of a nonadditive (as opposed to additive) genetic contribution calls for further examination.

Complex traits such as temperamental tendencies are usually influenced by a large number of genetic factors, and it is likely that at least some of those factors would have an additive mechanism (Penke et al., 2007). However, in the current study, such additive genetic effects on self-control have not been detected. One possible explanation is gene-gene and gene-environment interactions. It can be argued that additive effects represent the main effect of genes, whereas nonadditive effects could represent interactions between genes (Penke et al., 2007; Purcell & Sham, 2004). Even though dropping the "main" additive effect from our model was statistically justified, it may cause artificial inflation of the "interaction" component, which may result in larger nonadditive estimations on the expanse of additive effects

(Bates, 2020). In addition, interactions between genes and the shared environment increase correlations between MZ twins much more than between DZ twins. This may result in inflated nonadditive genetic effects estimates at the expense of additive and shared environment effects, which can be hard to detect under such circumstances (Purcell, 2002). Therefore, the heritability estimates in our study may in fact reflect both additive and nonadditive genetic influences.

In the future, different study designs (e.g., adoptive twin studies) may help to disentangle confounding reasons for higher MZ twins' intercorrelations (e.g., gene-environment interactions, contrast effects in parental reports) from real nonadditive genetic effects.

Results also showed an increase in heritability approaching early adolescence. One possible explanation is the effect of increased dopaminergic activity in certain brain areas related to reward circuitry, which may affect risk-taking behavior and might vary across individuals depending on their genetic makeup (Braams et al., 2015; Steinberg, 2010). Changes in brain function and structure are usually associated with preadolescence, congruent with the major increase in heritability that was detected in our study around age 8–9. Another explanation for the increase in heritability could be the rise in educational demands as children approach the end of elementary school. Perhaps as the load on children's cognitive resources increases, along with a demand for greater restraint (Anderson et al., 2000; Rudolph et al., 2001), the effect of a child's maximum potential for executive functions capacity and self-restraint becomes more pronounced. Future studies could address these possibilities by incorporating physiological measures and more nuanced schooling data.

4.4 | Genetic and environmental contributions to stability and change

Our results support previous findings regarding stability in self-control being attributed mostly to genetic factors, whereas nonshared environmental factors contribute mostly to change (e.g., Beaver et al., 2008; Spengler et al., 2012). Our findings also point to a substantial contribution of genetics to change in self-control, as has been found in some previous studies regarding middle childhood and adolescence (e.g., Beaver et al., 2013; Larsson et al., 2004).

Specifically, our findings show that new genetic factors that affect self-control emerge between middle childhood and early adolescence. These new genetic effects emerge at age 6.5 and, as mentioned earlier, likely contain a dominant nonadditive component along with an underlying additive component (Bates, 2020; Purcell, 2002). Thus, it seems that much of the growing stability in self-control at ages 6.5–11 can be attributed to the new genetic effects that emerged at age 6.5 and were carried on to age 8–9 with a trend also to age 11. While genetic factors contribute to change in self-control from age 5 to the following ages, they also contribute to stability between age 6.5 and onward.

The new genetic factors may reflect the changes in dopaminergic activity discussed above. Such changes may contribute to instability of self-control between early childhood and early adolescence. However,

as the new brain activity patterns persist, they may contribute to stability in self-control between middle childhood and early adolescence as well as during adolescence.

The new factors might also be related to hormonal changes associated with reward-seeking and risk-taking behavior (Braams et al., 2015; Steinberg, 2010). For some children, hormonal changes could start already when approaching preadolescence, as the onset age of puberty has been shown to decline during the last decades (e.g., Biro et al., 2012). However, in most children, hormonal changes do not occur before the age of 10 (Braams et al., 2015), which is later than when the new genetic factors started to emerge. Future genetically informed studies should include neurobiological and hormonal measures to address this.

These genetic factors may also contribute to the growing plasticity of the brain during preadolescence (Steinberg, 2010; Zelazo & Carlson, 2012). Brain plasticity may make the brain more susceptible to environmental influences, such as the increasing educational demands which characterize this period (Rudolph et al., 2001). Individual differences in plasticity and the timing of subtle brain changes may be influenced by genetic factors, such as the new factors emerging around age 6.5.

4.5 | Strengths and limitations

The current study has several important strengths. It focused on a relatively understudied developmental period which may be of great importance to self-control development, and helped link between the early years, which received more attention in past research, and the highly studied period of adolescence. While previous studies on the topic usually included only two to three measurement points, focused on relatively short or very specific developmental periods (e.g., late adolescence), or had large time intervals of several years between measurement points, the current study included as many as five measurement points along a period of 8 years, with time intervals of 1.5–2.5 years. Multiple measurement points along several years with relatively short time intervals have been argued to be more suitable for the examination of change during the childhood and adolescence years, as development may be expedited during these years (Van den Akker et al., 2014).

In addition, the examination of possible differential trajectories, rather than focusing on a unitary whole-sample perspective allowed us to obtain a more nuanced picture of self-control development (McClelland et al., 2015). Lastly, while the current study replicates some of the previous findings regarding different aspects of self-control development (i.e., rank-order stability, developmental trajectories, genetic and environmental contributions to variance), by integrating these aspects, focusing on a relatively understudied developmental period and adding the longitudinal examination of genetic and environmental sources of stability and change the current study creates a more comprehensive picture of self-control during this developmental period than previously attained. This integrated view allows us to suggest a genetic turning point around age 6.5 which may partially explain some of the patterns in self-control development found in this

study and in others. Though longer and larger studies exist in the field of self-control research, no previous study examined the sources of stability and change in self-control between early childhood and early adolescence with a sample as large and a developmental period as long as the current study presents.

However, the current study also has limitations. First is the small number of items in the self-control measure. Though this measure has been shown to be fairly reliable, congruent with observational measures and predictive of other relevant variables (Pener-Tessler et al., 2013), a more comprehensive self-control measure might have enabled a fuller depiction of the complex self-control trait. Second, in selecting items for this measure we focused on descriptions of self-control that would be applicable across the broad age range of the study (e.g., keeps trying, even when something is hard). This enabled comparable measures across ages. The downside of this approach, however, is that items represent mothers' perception of children's self-control at a specific age, rather than directly comparable behaviors, that would more clearly be reflected in age differences (e.g., is toilet-trained). Thus, the interpretation of means and trajectories should be done in relation to children's relative position in self-control at each age. Third is the use of parent reports. While parent reports of children's temperament may give a better indication of children's day-to-day behavior in their natural environment, they may be biased by parents' views and personalities. We addressed this issue to some extent by comparing MZ and DZ twins' variances (Saudino et al., 2000), and found no support for the existence of a sibling contrast effect in parental reports. However, future studies should aim to replicate our findings using observational measures. Fourth is the substantial attrition along the years. However, the attrition analysis showed that self-control was unrelated to attrition, as well as other demographic elements which were found to be either nonsignificant to attrition or showed small effect sizes. Therefore, despite the attrition, results seem to be fairly representative of the sample.

In addition, while our study provides a good picture of self-control development throughout middle childhood, especially around the time of school entry where frequent measurement points have been obtained (i.e., ages 5–6.5), it may be less equipped for measuring nuanced changes that may occur between ages 8 and 11, where measurement points were less frequent. Between preadolescence and early adolescence, dopaminergic activity in the brain in pathways linking limbic, striatal, and prefrontal areas increases, affecting sensation-seeking and appetitive motivated behavior (Casey et al., 2008; Steinberg, 2010; Van den Akker et al., 2014). During this time there is also an increase in the activation of the HPA axis affecting stress sensitivity (A. G. Roberts & Lopez-Duran, 2019), as well as a rapid increase in the external social and academic demands placed on children as they approach middle school (Van den Akker et al., 2014). These processes may be related to rapid changes in self-control which may be difficult to capture without very frequent measurements along this period. A few previous studies in the field have shown more frequent measurements of self-control along preadolescence to early adolescence (e.g., NICHD SECCYD: Gülseven, Liu, et al., 2021;

Gülseven, Yu, et al., 2021), but lacked the genetical perspective which the current study provides. Future twin studies with more measurement points (e.g., each year, or every 6 months) along preadolescence to early adolescence may shed more light on this matter.

5 | CONCLUSIONS: THE IMPORTANCE OF MIDDLE CHILDHOOD

Our findings stress middle childhood as a period of potential transition and change in self-control. During this period the stability of self-control increases substantially, cross-over of self-control levels occurs in two of the developmental trajectories (which together compounded almost half of our sample), and heritability rates substantially rise. Our findings also suggest that new genetic factors that emerge around age 6.5 may partially account for these changes and explain the growing stability in the trait approaching early adolescence.

In addition to the importance of early childhood and preadolescence for the development of self-control and related traits (e.g., Moffitt et al., 2011; Zelazo & Carlson, 2012), our findings highlight the importance of middle childhood, which may presage the transitions in self-control usually attributed to pre- or early adolescence. The new genetic factors emerging toward preadolescence may facilitate those changes, by effecting neurobiological processes associated with brain plasticity during this time (Bridgett et al., 2015; Steinberg, 2010), or by increasing susceptibility to environmental influences like the growing educational demands by the school system (Morrison et al., 2010; Rudolph et al., 2001). Future studies should examine specific genetic and biological mechanisms underlying the new genetic effects found in the current study and examine their association with external influences such as schooling.

The current findings may have important implications for future studies and interventions. Given the suggested importance of middle childhood, interventions directed at this developmental period may be more beneficial than interventions with younger or older children, though this possibility should be examined empirically. In addition, our finding of different developmental trajectories in self-control suggests that the same intervention may not suit all children. Identifying children who may belong to a specific trajectory at an early stage in development may help both to detect children who are most likely to respond to intervention, and to create more "tailor-made" interventions for the specific needs of different children, hopefully helping them not to make long-lasting mistakes which might jeopardize their future.

To conclude, this study substantially contributes to the understanding of self-control development. Its findings call for further investigation of middle childhood, pointing at this period as especially important to self-control development.

CONFLICT OF INTEREST

The authors have no conflict of interest.

ETHICS STATEMENT

The study was approved by the Herzog Hospital ethics committee (ages 6.5 and 8–9) and by the Hebrew University of Jerusalem ethics committee (other waves). Written informed consent was obtained from all participants.

DATA AVAILABILITY STATEMENT

Data available on request due to ethical restrictions.

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