Published in final edited form as:

Child Dev. 2008 ; 79(4): 930–943. doi:10.1111/j.1467-8624.2008.01168.x.

Genetic Influences on Activity Level in Early Childhood: Do Situations Matter?

Kimberly J. Saudino and
Boston University

Jeffrey A. Zapfe
Acentech Inc.

Abstract

Although genetic influences on individual differences in activity level (AL) are well documented, few studies have considered the etiology of AL from a contextual perspective. In the present study, cross-situational and context-specific genetic effects on individual differences in AL at age 2 were examined. The AL of 312 twin pairs (144 monozygotic and 168 dizygotic) was mechanically assessed with actigraphs in the home and in laboratory test and play situations. AL displayed significant genetic variance in all 3 situations. Moreover, actigraph scores significantly correlated across situations. Multivariate genetic model-fitting analyses found that the observed cross-situational continuity in AL was due entirely to genetic factors. Situational differences in AL arise from genetic, shared environmental, and nonshared environmental influences.

Activity level (AL) is a pivotal individual differences variable in infancy and early childhood. A core dimension of nearly every temperament theory, AL is a highly salient feature of child behavior that has been linked to various facets of child health and development. Twin studies of temperament in infancy and early childhood have yielded considerable evidence that AL is genetically influenced (e.g., Braungart, Plomin, DeFries & Fulker, 1992; Cyphers, Phillips, Fulker, & Mrazek, 1990; Saudino & Eaton, 1991, 1995; Saudino, Plomin, & DeFries, 1996; Stevenson & Fielding, 1985); however, this is only a first step in the understanding of the etiology of this important temperament dimension. There are many questions that remain unanswered. For example, although developmentalists frequently acknowledge the importance of contextual factors on temperament (e.g., Mangelsdorf, Schoppe, & Burr, 2000), short-term situational changes in AL have rarely been considered from a behavioral genetic perspective. Because temperament is viewed as being stable, questions of genetic and environmental contributions to situational change have largely been ignored by temperament researchers. However, different situations place different demands on the individual and elicit different behaviors.

Longitudinal studies of developmental changes in AL suggest that genetic factors contribute to stability, whereas change is due to environmental factors (Saudino & Cherny, 2001a;

Saudino et al., 1996), but the factors that influence developmental change and short-term situational change need not be the same (Plomin & Nesselroade, 1990). Behavioral change across situations is generally assumed to be due to environmental differences; however, this is an empirical question. It is possible that genetic factors contribute to short-term change as the individual goes from situation to situation. That is, individual differences in responding to specific situations might be influenced by genetic effects (Phillips & Matheny, 1997).

There is little doubt that AL is influenced by situational factors. The types of toys available, the presence of peers, and the stressfulness, novelty, or restrictiveness of the situation can affect children's mean levels of AL (e.g., Eaton & Keats, 1982; Fagot & O'Brien, 1994; Pinto & Tryon, 1996). More specific to the question of individual differences and cross-situational consistency and change, there is also change in terms of one's ordinal position within the group. For example, observations of AL at home correlate only modestly with observations of AL in playgroup situations or at school (Fagot & O'Brien, 1994; Schaughency & Fagot, 1993). Similarly, correlations between mechanical measures of AL taken in free play and test settings tend to be low in both clinical and control samples (Barkley & Ullman, 1975). Thus, the child who is active in one situation is not necessarily active in another. If this is the case, there must be some difference in the genetic and/or environmental influences on individual differences in AL across situations.

Detecting Genetic Influences on Situational Change

The etiology of cross-situational consistency and change in temperament can be explored by using multivariate genetic analyses that assess the extent to which genetic effects on a measure of temperament in one situation are shared with genetic effects on another measure of the same dimension in a different situation. *Cross-situational* genetic effects are genetic influences that overlap across different situations. Such situation-general genetic factors contribute to the stability of temperament across situations. *Contextual* genetic influences are genetic effects that are unique to a specific situation and, consequently, contribute to situational changes in temperament. For example, in the MacArthur Longitudinal Twin Study, multivariate genetic analyses have been used to examine the extent to which genetic effects on a measure of shyness in the laboratory overlap with shyness in the home environment (Cherny, Fulker, Corley, Plomin & DeFries, 1994; Cherny et al., 2001). Although shyness in the laboratory and home were only modestly correlated, there was substantial overlap between the genetic influences involved in both situations. This finding of cross-situational genetic effects for shyness in the laboratory and the home means that genetic factors contribute to the stability of shyness across the two situations. Indeed, the observed phenotypic correlation between the two measures of shyness was almost entirely due to overlapping genetic effects. In contrast, differences between shyness in the laboratory and in the home were due primarily to environmental factors, although there were some small contextual, or situationally specific, genetic influences on shyness in the home.

What is the role of genetic influences on situational change in AL?

Although not well studied, prior research suggests that genetic factors may contribute to *both* cross-situational stability and situational change in AL. For example, multivariate genetic analyses of teacher and tester-rated temperament in the Colorado Adoption Project

found that although teacher and tester ratings of AL at age 7 were only modestly correlated ($r = .19$), there was substantial genetic overlap between the two measures (Schmitz, Saudino, Plomin, Fulker, & DeFries, 1996). Forty-six percent of the genetic variance in tester ratings was shared with teacher ratings. Moreover, only genetic factors contributed significantly to the covariance between teacher and tester ratings, indicating that what teachers and testers see in common in children's AL is due to genetic influences. Despite this evidence of cross-situational genetic effects, there was also significant genetic influence unique to tester ratings, indicating context-specific genetic effects for activity (i.e., 54% of the genetic variance on tester ratings was independent of genetic variance on teacher ratings). Similar results have emerged from an application of a multitrait-multimethod approach to infant twin data comprising three temperament dimensions (activity, emotional tone, and sociability) assessed three different ways (tester rating, playroom observation, and parent rating) that found substantial context-specific genetic variance in addition to cross-situational genetic variance (Phillips & Matheny, 1997).

These two studies are a first step in exploring genetic and environmental contributions to short-term situational change; however, in both studies, situational variance is confounded with method variance. For example, in the Schmitz et al. (1996) study, the informants differed across situation (i.e., the test and school situations). Similarly, in the Phillips and Matheny (1997) study, both informants *and* measures differed across the three situations. Research has clearly shown that for ratings of temperament and/or behavior problems, different informants typically do not contribute the same information about the child's behavior (Achenbach, McConaughy, & Howell, 1987; Mangelsdorf et al., 2000). Therefore, the confounding of situational and method variance in these studies limits conclusions regarding cross-situational consistency and change because it is difficult to say whether the context-specific genetic variance refers to true situational change or method differences.

Disentangling situational variance from method variance

To understand true situational change, we must disentangle situational variance from method variance. To do this, it is necessary to assess the behavior of interest with the *same* measure across different situations. For some dimensions of temperament (e.g., emotionality), this is difficult because different informants are often needed for different situations (e.g., home and school). This, however, is not a problem with AL because AL can be mechanically assessed across a variety of situations.

Despite the advantages of mechanical measures of AL, only one prior study has used mechanical motion recorders to explore situational effects in the etiology of individual differences in AL. A sample of school-aged twins wore motion recorders in a laboratory cognitive testing situation and during a 25-min break in testing (Wood et al., 2007). AL in the two situations was substantially correlated ($r = .52$), and AL was significantly heritable in both situations (h^2 test = .24, h^2 break = .30). In contrast to prior work suggesting contextual or situationally specific genetic effects (i.e., Phillips & Matheny, 1997; Schmitz et al., 1996), the genetic correlation between the two situations was estimated as 1.0, indicating complete overlap between the genetic influences operating on the two situations. At question, however, is whether the two laboratory situations were sufficiently different to

reasonably expect that they would have different genetic etiologies. That is, more diverse situations may produce different results.

In the present study, cross-situational and context-specific genetic effects on individual differences in AL at age 2 were examined using mechanical motion recorders to assess AL in the home as well as in the laboratory. Twins wore motion recorders for 2 days in their homes, thus providing a naturalistic measure of AL. In addition, two laboratory-based measures of AL were obtained: one taken during a standardized test situation and another based on the child's behavior in a series of play-based activity episodes. Although the testing situation is a limited context in which to observe children's behavior, it is a standard situation that facilitates comparisons among children. Moreover, the somewhat stressful nature of the test situation enriches observations of certain temperament-like behaviors. In contrast, the laboratory play situation allows us to evaluate behaviors that may be more typical of children's day-to-day activity. Play situation episodes are standard across children, but activity within each episode is directed by the child. Thus, the present study explores situationally specific genetic effects in the home and in the laboratory situations and between the laboratory test and the play situations. Although we made no specific predictions about differential heritability across situations, it was predicted that AL would be genetically influenced in each of the three situations. Further, based on prior research and temperament theory, it was hypothesized that cross-situational continuity would be largely due to genetic factors (i.e., genetic influences contribute to the phenotypic correlation between situations). Nonetheless, given that laboratory measures of AL are typically modestly correlated with AL in the home, it was also predicted that there would be some context-specific genetic effects.

Method

Sample

The Boston University Twin Project sample was recruited from birth records supplied by the Massachusetts Registry of Vital Records. Twins were selected preferentially for higher birth weight and gestational age. No twins with birth weights less than 1,750 g or with gestational ages less than 34 weeks were included in the study. Twins were also excluded if one or both twins had a health problem that might affect motor activity (e.g., cerebral palsy, club foot) or had chromosomal abnormalities. The present analyses include 312 same-sex pairs of twins (144 monozygotic [MZ] and 168 dizygotic [DZ]), mean age 2.07 years ($SD = 0.05$). Although the sample was predominately Caucasian (85.4%), ethnicity was generally representative of the Massachusetts population (3.2% Black, 2% Asian, 7.3% mixed, and 2.2% other). Socioeconomic status according to the Hollingshead (1975), four-factor index ranged from low to upper middle class (range = 20.5 – 66; $M = 50.9$, $SD = 14.1$).

Zygosity was determined via DNA analyses using DNA obtained from cheek swab samples. In the cases where DNA was not available ($n = 3$), zygosity was determined using parents' responses on physical similarity questionnaires, which have been shown to be more than 95% accurate when compared to DNA markers (Price, Freeman, Craig, Ebersole, & Plomin, 2000). In our present sample, we were able to assign zygosity with certainty to 99% of the

twin pairs using the parent questionnaire; moreover, agreement between questionnaire and DNA zygosity analyses was very high ($\kappa = .94$).

Procedure Overview

The twins were assessed within approximately 2 weeks of their second birthday. The procedure consisted of two visits, 48 hr apart, to the laboratory. At the initial visit, the motion recorders were attached to each child. After attachment of the motion recorders, one twin was assessed within a standardized test situation while the other twin was assessed within the laboratory play situation (both described subsequently). The second visit was scheduled for 48 hr following the attachment of the motion recorders. At this visit, the situations were reversed for each twin. Motion recorders were then removed, and the record sheets and cheek scrapings collected. Twins were assessed by different testers; however, for each twin, the tester was the same across the two laboratory situations. In the present study, the term *home situation* refers to all time spent outside the laboratory.

Test situation—The administration of the mental scale of *Bayley Scales of Infant Development – Second Edition* (Bayley, 1993) was used to provide a structured test situation for assessing AL. Assessment of AL during administration of the Bayley mental scale has been widely used in behavioral genetic research, but prior research has relied solely on observer ratings within this context (e.g., Braungart et al. 1992; Matheny, 1980, 1983; Saudino et al., 1996).

Play situation—Activity episodes from the *Laboratory Temperament Assessment Battery – Preschool Version* (Lab – TAB; Goldsmith, Reilly, Lemery, Longley, & Prescott, 1995) were used to provide standard play situations for assessing AL. Four Lab – TAB activity episodes were included in the present study: Corral of Balls: the child plays in a corral enclosure filled with many brightly colored balls (3 min); Arc of Toys: the child is presented with a variety of age-appropriate toys and is permitted to play with whatever toys he or she chooses (5 min); Workbench: in this measure of fine motor activity, the child is shown a work bench toy and is permitted to play with it (3 min); and Fidgeting Video: the child is seated in a child chair in front of a television monitor and shown an age-appropriate video (4 min).

Measures

Mechanical assessment of AL—During the 2-day data collection period, AL was assessed with the Mini Mitter actical (actigraph). This device is a miniature omnidirectional accelerometer that has been designed to detect frequency and intensity of motion within the range of normal human movement (Mini Mitter Company, 2005). Actigraphs have been shown to be valid and reliable instruments for recording the activity of children (Freedson et al., 1997; Janz, 1994). Each twin was randomly assigned four actigraphs, one per limb. Actigraphs were attached by means of Tyvek adhesive wristbands. Arm attachment, at the wrist, was on the dorsal aspect of the forearm proximal to the radial carpal joint. Leg attachment, at the ankles, was superior to the lateral malleoli.

Parents were provided with instructions regarding the care of the motion recorders and a sheet for logging the times when the actigraphs were off a limb. To differentiate actigraphs within twin pair, each actigraph was covered with white surgical tape on which the child's name was printed. Actigraphs were also color coded and keyed to a parent record sheet indicating the color of actigraph that went on each limb. Thus, the parent was able to easily identify the set of actigraphs that belongs to each twin and, further, to match the instrument to the correct limb. Parents were encouraged to engage in normal activities and to maintain daily routines with their children during the 2-day data collection period. The average length of time that the motion recorders were worn was 48.22 hr ($SD = 3.22$).

To adjust for variations in the total time that each instrument was worn within the home and lab situations, the number of activity units was converted to a rate per minute real time. Similar adjustments were made to the data from the test and play situations. Arm and leg activity counts were highly correlated ($r = .69, p < .001$); therefore, composite actigraph scores reflecting overall motor activity for each situation were calculated by averaging the four limb actigraph scores. Aggregating across motion recorders has been shown to increase both the reliability and the validity of AL measures (e.g., Eaton, 1983; Melanson & Freedson, 1995). Consistent with prior research, actigraph scores were positively skewed (Saudino & Eaton, 1991, 1995; Wood et al., 2007) and were square root transformed to create a more normal distribution.

Correlational Analyses

Twin intraclass correlations indexing co-twin similarity were calculated using the double-entry method. Because twin correlations can be inflated by variance due to gender, all scores were residualized for gender effects (McGue & Bouchard, 1984). These residualized scores were used in all behavioral genetic analyses. To evaluate genetic and environmental influences to cross-situational continuity, cross-twin cross-situation correlations were calculated. Cross-twin correlations are the essence of a multivariate analysis of covariance. For the present analyses, the cross-twin cross-situation correlation involved correlating the score of Twin 1 for AL in one situation with score of Twin 2 for AL in another and vice versa. Genetic contributions to the covariance between two measures are implied when the MZ cross-twin correlation is greater than the DZ cross-twin correlation.

Model-Fitting Analyses

Although the major results of a multivariate twin analysis can be gleaned from twin cross-correlations, model-fitting procedures analyze all the data simultaneously, provide tests of the fit of models, yield confidence intervals for parameter estimates, and tests the fit of alternative models (Plomin, DeFries, McClearn, & McGuffin, 2001). Models were fit to raw data using a maximum likelihood pedigree approach implemented in Mx structural equation modeling software (Neale, Boker, Xie, & Maes, 2006). This approach does not yield a chi-square statistic for assessing the fit of the model; however, the fit of a model can be assessed by calculating twice the difference between the negative log likelihood ($-2LL$) of the model and that of a saturated model (i.e., a model in which the variance – covariance structure is not estimated and all variances and covariances for MZ and DZ twins are estimated). The difference in $-2LL$ is asymptotically distributed as a chi-square statistic with degrees of

freedom equal to the difference in the number of parameters in the full model and that in the saturated model.

We fit two multivariate models to the data to examine cross-situational and contextual genetic effects on mechanically assessed AL. Both models decompose the phenotypic variance of each situation and the phenotypic covariances *between* situations into additive genetic effects (A), shared environmental effects (C), and nonshared environmental effects (E); however, each model makes different assumptions about the reasons for consistency across situations. In both models, additive genetic influences refer to the sum of the average effect of all genes that influence a trait. Based on the degree of genetic relatedness, the A factors correlate 1.0 and .5 for MZ and DZ twins, respectively. The C factors refer to the influence of shared rearing environments on twin resemblance. Because all twins were reared in the same family, shared environments correlate 1.0 for both MZ and DZ twins. Finally, the E factors reflect nonshared environmental influences that are unique to each member of a twin pair, including measurement error.

Independent pathway model—The independent pathway model (Kendler, Heath, Martin, & Eaves, 1987) assumes that genetic and environmental factors contribute to covariance between situations through separate genetic and environmental pathways. This model decomposes the genetic, shared environmental, and nonshared environmental variance of AL in the home, test situation, and play situations into genetic and environmental effects that are common to all three measures (i.e., cross-situational effects) and genetic and environmental effects that are unique to each situation (i.e., contextual effects). For example, in Figure 1, the latent variables A, C, and E represent additive genetic, shared environmental, and nonshared environmental effects, respectively, that are common to all three situations. The latent variables denoted in subscripted lowercase represent genetic and environmental effects on AL that are unique to a specific situation (e.g., a_h , c_h , and e_h refer to genetic and environmental influences unique to the home situation). Under this model, covariance between situations can arise due to different factors. That is, although measures of AL may be intercorrelated across all situations, the sources of covariance between any two situations may differ (e.g., the correlation between home and test situations could have a different source than the correlation between the test and the play situations). This model is considered to be “agnostic” in that it does not specify that the same phenotype operates across different situations; rather, it just allows that the phenotypes being assessed in each situation are correlated (Hewitt, Silberg, Neale, Eaves, & Erikson, 1992).

Common pathway model—As compared to the independent pathway model, the common pathway model (Kendler et al., 1987; McArdle, & Goldsmith, 1990) is more restrictive positing that genetic and environmental factors influence covariation between situations through a *single* common pathway. This model suggests that correlations between situations arise because a common phenotype (AL in Figure 2) operates across all situations. This common phenotype is then influenced by genetic and environmental influences. As is the case for the independent pathway model, this model also allows genetic and environmental effects specific to each situation. Under this model, genetic and environmental sources of covariance are the same across all situations. Cross-situational

consistency arises because different situations tap the same latent phenotype (i.e., they are assessing the same behaviors). Differences between situations arise because, to some extent, different contexts also evoke different phenotypes.

Results

Descriptive Statistics

Table 1 lists the means and standard deviations by sex and zygosity. We evaluated the mean differences using generalized estimating equations (GEE) implemented in the SAS GENMOD procedure to account for dependence in the data due to the fact that our sample comprised pairs of twins. GEE are an extension of the standard generalized linear models that allow modeling of correlated data (Liang & Zeger, 1986; Zeger & Liang, 1986). Consistent with previous research on mechanically assessed AL (Saudino & Eaton, 1991, 1995), males were significantly more active than females (home: $z = -2.32, p < .05$; test: $z = -5.27, p < .001$; and play: $z = -4.08, p < .001$). The effect sizes as estimated by Cohen's d (Cohen, 1988) ranged from .24 to .48, indicating that the means for males and females differed by approximately one quarter to one half of a standard deviation. These effect sizes are comparable to those reported in metaanalyses of sex differences in temperament (Eaton & Enns, 1986; Else-Quest, Shibley Hyde, Goldsmith, & Van Hulle, 2006). More important to our twin analyses, MZ and DZ twins did not significantly differ in AL (home: $z = -.74, p = .46$; test: $z = -.68, p = .50$; and play: $z = .46, p = .65$).

AL Agreement Across Situations

Phenotypic correlations revealed substantial consistency in AL across the test and play situations ($r = .53, p < .001$). However, AL in the two laboratory situations were more modestly associated with AL at home (test: $r = .34, p < .001$ and play: $r = .33, p < .001$).

Twin Correlations

Twin intraclass correlations and cross-twin cross-situation correlations are presented in Table 2. For all three situations, the intraclass correlations for MZ twins exceeded those for DZ twins, suggesting genetic influences on AL. The very high intraclass correlations for both MZ and DZ twins in the home situation are particularly noteworthy and suggest that shared environmental influences also contribute to cotwin resemblance in this situation. Cross-twin cross-situation correlations for MZ twins were consistently higher than those for DZ twins, indicating that genetic factors contribute to the phenotypic correlation between AL across all three situations.

Model-Fitting Analyses

Univariate genetic analyses of AL in each situation (available from the first author) indicated that AL was significantly heritable in all three situations, suggesting that it is reasonable to inquire as to the extent to which there are cross-situational genetic effects (i.e., multivariate genetic analyses are warranted). Table 3 presents the fit statistics for the multivariate model-fitting analyses. As indicated by the nonsignificant chi-square statistics for the overall fit of the model, both multivariate models adequately describe the data. Because the common pathway model is nested within the independent pathway model, it is

possible to determine the relative fit of the two models by comparing the difference in chi-square statistics between the two models. As can be seen, imposing the more restrictive common pathway model to the data did not result in a significant decrement in the fit of the model ($\chi^2 = 1.589$, $df = 4$, $p = .811$). Moreover, its considerably lower Akaike's information criterion (difference = 6.411) provides substantial evidence for the common pathway model as the best-fitting overall model. We were able to further simplify the common pathway model by dropping all paths that were nonsignificant in the full model. The reduced model included additive genetic variance (A) on the latent AL phenotype; unique genetic, shared, and non-shared environmental effects on the home; and unique nonshared environmental effects on the test and play situations.

Figure 3 presents the path estimates from the full and reduced common pathway models. Post hoc power analyses indicated that we had more than 98% power to detect significant genetic covariance, but power to detect common shared environmental and nonshared environmental influences was lower, 23% and 39%, respectively. Therefore, although we present the results for both full and reduced models, to avoid artificial inflation of parameter estimates, we focus on the parameter estimates from the full model (i.e., in reduced models, nonsignificant shared environmental variance is absorbed into genetic variance). The path estimates are standardized partial regressions indicating the relative influence of the latent variables on the phenotypes. The square of these path coefficient estimates represent the proportion of variance for each measure accounted for by the latent variable. For example, the heritability of the latent AL phenotype is $.84^2$. The total genetic variance for AL in the home situation is the heritability of the latent AL factor times the variance in the AL measure that is due to the common factor (i.e., square of the factor loading) plus unique genetic variance (i.e., $[\.84^2 \times .44^2] + .40^2 = .30$). Variance components from both models are presented in Table 4.

Total variance components—AL was significantly heritable in all three situations, with genetic effects accounting for approximately one third of the total variance. As suggested by the twin intraclass correlations, AL in the home displayed significant and substantial shared environmental variance (i.e., more than 50% of the total variance). This pattern did not, however, emerge for AL in the laboratory. The environments that influenced AL in the test and play situations were of the nonshared variety.

Our multivariate model allowed us to test whether estimates of genetic and environmental variances significantly differed across situation. We fit models constraining either the genetic, shared environmental, or nonshared environmental variances to be equal across situations. These models were then compared to the full model. A significant change in chi-square statistic between models indicates that the constrained model provides a poorer fit to the data. It was possible to equate genetic variances ($\chi^2 = 0.636$, $df = 4$, $p = .96$), but neither the shared environmental variances ($\chi^2 = 20.418$, $df = 4$, $p < .001$) nor the nonshared environmental variances ($\chi^2 = 78.172$, $df = 4$, $p < .001$) could be equated across situations. Similar results emerged when genetic variances ($\chi^2 = 6.048$, $df = 4$, $p = .20$) or nonshared environmental variances ($\chi^2 = 88.672$, $df = 4$, $p < .001$) were equated in the reduced models. As indicated by the nonoverlapping confidence intervals, shared

environmental variance was significantly higher and nonshared environmental variance significantly lower in the home situation as compared to AL in the lab.

Sources of covariance between situations—The significant factor loadings on the common latent AL factor indicate that the home, test, and play situations tap a common AL phenotype. This common AL factor explained 40% (i.e., $[\.44^2 + .72^2 + .70^2]/3 = .40$) of the variance in our AL measures. Variation in the common AL phenotype is due to genetic influences (70%), neither shared nor non-shared environmental influences significantly influenced this common factor. In other words, covariance between situations (i.e., cross-situational consistency) arises because of common genetic influences. Genetic correlations indicating the extent to which genetic effects on AL in one situation correlate with genetic effects on AL in another situation, *independent of the heritability of each measure*, were substantial. The genetic effects on AL in the home correlated .68 (95% CI = 0.43 – 0.92) with AL in both laboratory situations. Similarly, the genetic correlation between AL in the test and in the play situations was 1.0 (95% CI = 0.78 – 1.0).

Cross-situational and situation-specific variance components—The genetic, shared, and nonshared environmental variances for each AL measure were decomposed into effects common across situations and those that are unique to a situation (Table 4). Approximately 50% of the genetic variance on AL in the home is situation specific (i.e., $16/30 = 53\%$). Neither AL in the test nor in the play situations displayed any unique genetic variance. Only AL in the home situation displayed significant shared environmental variance, accounting for more than 50% of the total variance on this measure; not surprising then was the finding of significant situation-specific shared environmental effects for the AL home measure. The only effects that were unique to the test and play situations were nonshared environmental influences, which include child-specific effects and measurement error.

Discussion

Do situations matter? There are two ways in which behavioral genetics research can approach this question. First, does the magnitude of genetic and environmental influence on AL differ across context or setting? A second, and perhaps less obvious, question involves the extent to which there is overlap between the genetic and the environmental effects on AL in the home and two laboratory situations. This latter approach addresses the issue of genetic and environmental influences to cross-situational consistency and context-specific effects. In the paragraphs below we will discuss situational effects from both perspectives.

As would be predicted from temperament theory, AL in all three situations was genetically influenced. There was little evidence of differential heritability across situation. Situational differences were, however, apparent in the nature and magnitude of environmental influences. AL in the home environment was substantially influenced by shared environmental factors (explaining 56% of the variance). This was not the case for AL in the laboratory test or play situations that displayed no significant shared environmental variance.

The finding of significant and substantial shared environmental variance on AL in the home is particularly interesting given that this finding does not emerge when parent ratings are used to assess AL (e.g., Goldsmith, Buss & Lemery, 1997; Neale & Stevenson, 1989; Saudino & Cherny, 2001b). Nonetheless, prior studies that have used mechanical measures to assess AL in the home environment have hinted at shared environmental influences. For example, Plomin and Foch (1980) used a weeklong pedometer measure to assess the AL of twins in middle childhood. Genetic influences on individual differences in AL were significant; however, the very high correlations between MZ and DZ twins suggested that shared environmental influences were substantial (MZ: $r = .99$, DZ: $r = .94$). Similarly, actometer-based studies of infants, toddlers, and adolescents have suggested possible shared environmental influences on AL, but these early studies were limited by very small sample sizes (Saudino & Eaton, 1991, 1995; Saudino, Thompson, & Gagne, 2000). The present findings provide the strongest evidence to date for shared environmental influences on mechanically assessed AL. The failure for parent ratings to display shared environmental influences likely arises from rater contrast biases, which magnify existing behavioral differences between cotwins. Indeed, when contrast biases have been included in behavioral genetic models of parent-rated AL, significant shared environmental effects have emerged (Saudino, Cherny, & Plomin, 2000; Saudino, McGuire, Reiss, Hetherington, & Plomin, 1995).

What shared environments might be contributing to variability in AL in the home? There are several possibilities. Family practices and schedules (e.g., meal times, bed times, family outings, and caretakers' tolerances for AL) are a likely source of common variance between cotwins. It is also possible that the increased shared environmental variance in the home situation reflects twin-specific environments. For example, the twins playing together and sharing toys may contribute to resemblance in AL. However, there are three lines of evidence that suggest that our finding of shared environmental influences on AL in the home is not simply a twin effect. First, MZ and DZ twins did not significantly differ in variances for home AL, suggesting that that shared environmental variance is not a result of cooperative sibling interaction effects. Second, for a subsample of families ($n = 144$), we asked parents to complete an activity diary listing the approximate amount of times that the twins engaged in common activities (e.g., storytime, preschool). In this subsample, the pattern of very high MZ and DZ twin resemblances (e.g., MZ: $r = .83$, DZ: $r = .65$) and significant shared environmental effects remained after residualizing home AL scores for time spent in common twin activities. Finally, a previous study of nontwin siblings also showed substantial resemblance for a 48-hr measure of actigraph AL (Saudino, Wertz, Gagne, & Chawla, 2004). The reported correlation for nontwin siblings in this earlier study (.58) does not significantly differ from our correlation for DZ twins and when compared to the MZ twin correlation also suggests shared environmental influences. This is particularly noteworthy because the nontwin siblings differed in age by approximately 3 years and because there were subtle methodological differences across the two studies. For example, children in the sibling study wore only two actigraphs (which reduces the reliability of the AL measure and would attenuate the sibling correlation) and the AL measure included time spent in the lab (which could also attenuate the nontwin sibling correlation). Thus, although

we cannot definitively rule out twin-specific environments, it would appear that our finding of shared environmental influences in the home is not merely a twin-specific effect.

Whatever the source of these shared environmental effects, they do not have an enduring influence across situation. That is, although there are family-wide factors that influence AL in the home, they do not influence AL outside the home. As indicated previously, shared environmental influences did not significantly contribute to AL in either the laboratory test or the play situations. Moreover, our multivariate modeling clearly indicated that the shared environmental variance on AL in the home was situation specific.

The home and laboratory situations also differed in the magnitude of nonshared environmental influences operating on AL. In the home, nonshared environmental influences were modest, explaining less than 15% of the variance in AL. In contrast, approximately 50% of the variance in the two laboratory situations was due to nonshared environmental influences. In all cases, nonshared environmental influences were situation specific. Nonshared environmental variance comprises those environmental factors that are unique to each member of a twin pair and that make twins different from each other. This includes measurement error; however, given that the same devices were worn continuously across the 48-hr data collection period, differences in the magnitude of nonshared environmental variance across situation cannot be simply attributed to measurement error. One possible source of nonshared environmental variance in the two laboratory situations was the tester. Although testers followed standardized protocols in the test and play situations, tester personality, behavioral standards, and even mood may have influenced their interactions with the children tested. Additionally, twins were tested in the same situations on different days, which may also have contributed to nonshared environmental variance specific to each situation.

The fact that the magnitude of heritability of AL is similar across all three situations does not mean that the same genes operate in each situation. That is, it is possible that AL in each situation could represent a genetically influenced, but etiologically distinct, phenotype. This does not appear to be the case. Multivariate genetic analyses indicate that the covariation between AL in the home, test, and play situations was best described by a common latent factor, suggesting that to some extent, the same AL phenotype was assessed in all situations. Individual differences in this underlying AL phenotype were due only to genetic influences, indicating that what is common across all situations is genetic. Neither shared nor nonshared environmental influences contributed significantly to cross-situational consistency in AL.

Genetic correlations across situation indicate that approximately 68% of the genetic factors that influence AL in the home also influence AL in the laboratory test and play situations and that the genetic influences in the two laboratory situations are completely overlapping. This finding of substantial genetic overlap between AL across situations is accordant with prior research that finds that cross-situational consistency arises because of common genetic influences (i.e., Phillips & Matheny, 1997; Schmitz et al., 1996; Wood et al., 2007); however, our actigraph methodology and inclusion of the home situation adds more resolution. As with Wood et al., (2007) we found a genetic correlation of 1.0 between actigraph-assessed AL in two distinct laboratory situations (test and play in our study and

test and break in the Wood et al., 2007, study). Phillips and Matheny (1997) report a genetic correlation of .59 between AL in the laboratory play and in the test situations, but as indicated earlier, they used different methods to assess AL across the two situations, which likely contributed to the lower genetic correlation. We suggest that when methodology is consistent across situations, AL within standard laboratory situations is not genetically distinct. This is not necessarily the case for AL beyond the laboratory. Although there was considerable overlap between AL in the home and in the laboratory, there were genetic influences unique to the home situation. Approximately 50% of the genetic variance on AL in the home was situation specific (i.e., independent of genetic variance on the common AL phenotype) indicating context-specific genetic effects for AL. Unlike prior research (Phillips & Matheny, 1997; Schmitz et al., 1996), our finding of contextual or situational-specific genetic effects is not confounded by method effects. Thus, genetic factors contribute to both cross-situational consistency *and* situational change. Environmental influences, however, contribute only to situational change.

The present results are consistent with temperament theory that predicts that individual differences in AL are genetically influenced and show some consistency across situations (Goldsmith et al., 1987). Our genetically sensitive design paired with actigraph methodology allowed us to examine the source of this consistency across situations and to evaluate sources of short-term situational change. The findings support both a cross-situational and a contextual view of the genetic underpinnings of temperament. Consistency in AL across situations is due to common genetic influences. However, even though genetic factors are solely responsible for cross-situational continuity, there is also evidence of situationally specific genetic effects on AL in the home. Our interpretation of these situation-specific effects is that different contexts provide different views of AL and thus engage different genetic influences on processes relevant to each context.

The limitations of this study should be acknowledged. Our sample of just more than 300 twin pairs is relatively small. Although we had ample power to detect significant genetic variance and covariance, our power to detect shared environmental effects on AL was more variable (ranging from approximately 20% in the lab to more than 90% in the home). For this reason, we highlight the results from the full model as reduced models that set nonsignificant nonzero parameters to zero can bias estimates. Similarly, very large samples are required to detect significant differences in heritabilities across measures; therefore, our sample does not provide a powerful test of differential heritability across situations. We would note, however, that the magnitudes of heritabilities across situations were very similar, ranging from .30 to .37 in the full model, and even in the reduced model where the range was greater, the 95% confidence intervals were overlapping. Despite the limitations imposed by our sample size, the present study makes a unique contribution to the developmental literature. Most studies of genetic influences on AL have relied on parent-rating measures or brief behavioral observations, few have considered situational effects. Our 48-hr actigraph measure of AL across three situations provides a novel and rigorous test of situational effects on AL from a behavioral genetic perspective.

In conclusion, although what is common among AL assessed in the three situations is largely genetic, situations do matter—provided that the situations are sufficiently different.

Although the two standard lab conditions displayed no shared variance beyond the common genetic variance, the more diverse home environment revealed additional shared variance (both genetic and environmental) in AL. These results have important implications for molecular genetics research seeking to find specific genes associated with AL. The fact that to some extent, different genetic influences operate on AL across different situations means that researchers will need to consider the situation in which AL is assessed. Failures to replicate molecular genetic findings may be due to situational differences between studies. This would be especially true when comparing results across lab and nonlab situations. Molecular genetic studies of AL may benefit from a multisituation approach, which would allow identification of genes that are associated with the common AL phenotype (i.e., cross-situational genes). That is, given that the AL common factor was highly heritable, the search for cross-situational genes may increase the power of molecular genetic studies of AL.

Acknowledgments

The Boston University Twin Project (BUTP) is supported by grant MH062375 from the National Institute of Mental Health. The authors gratefully acknowledge the parents and twins in the BUTP. We also thank Dr. Michael Neale for his generous assistance with Mx.

References

- Achenbach TM, McConaughy SH, Howell CT. Child/adolescent behavioral and emotional problems: Implications of cross-informant correlations for situational specificity. *Psychological Bulletin*. 1987; 101:213–232. [PubMed: 3562706]
- Barkley RA, Ullman DG. A comparison of objective measures of activity and distractibility in hyperactive and nonhyperactive children. *Journal of Abnormal Child Psychology*. 1975; 3:231–244. [PubMed: 1214033]
- Bayley, N. Bayley Scales of Infant Development. 2nd. San Antonio, TX: Psychological Corporation; 1993.
- Braungart JM, Plomin R, DeFries JC, Fulker DW. Genetic influence on tester-rated infant temperament as assessed by Bayley's Infant Behavior Record: Nonadoptive and adoptive siblings and twins. *Developmental Psychology*. 1992; 28:40–47.
- Cherny SS, Fulker DW, Corley R, Plomin R, DeFries JC. Continuity and change in infant shyness from 14 to 20 months. *Behavior Genetics*. 1994; 24:365–380. [PubMed: 7993315]
- Cherny, SS.; Saudino, KJ.; Fulker, DW.; Plomin, RP.; Corley, R.; DeFries, JC. The development of shyness from 14 to 20 months: Shyness in context. In: Emde, RN.; Hewitt, JK., editors. *The transition from infancy to early childhood: Genetic and environmental influences in the MacArthur Longitudinal Twin Study*. New York: Oxford University Press; 2001. p. 269–282.
- Cohen, J. *Statistical power analysis for the behavioral sciences*. 2nd. Hillsdale, NJ: Erlbaum; 1988.
- Cyphers LH, Phillips K, Fulker DW, Mrazek DA. Twin temperament during the transition from infancy to early childhood. *American Academy of Child and Adolescent Psychiatry*. 1990; 29:392–397.
- Eaton WO. Measuring activity level with actometers: Reliability, validity, and arm length. *Child Development*. 1983; 54:720–726.
- Eaton WO, Enns LR. Sex differences in human motor activity level. *Psychological Bulletin*. 1986; 100:19–28. [PubMed: 3526375]
- Eaton WO, Keats JG. Peer presence, stress, and sex differences in the motor activity levels of preschoolers. *Developmental Psychology*. 1982; 18:534–540.
- Else-Quest N, Shibley Hyde J, Goldsmith H, Van Hulle C. Gender differences in temperament: A meta-analysis. *Psychological Bulletin*. 2006; 132:33–72. [PubMed: 16435957]

- Fagot BI, O'Brien M. Activity level in young children: Cross-age stability, situational influences, correlates with temperament, and the perception of problem behaviors. *Merrill-Palmer Quarterly*. 1994; 40:378–398.
- Freedson, PS.; Sirard, J.; Debold, N.; Pate, R.; Dowda, M.; Sallis, J. Validity of two physical activity monitors in children and adolescents; 1997, September; 19th Symposium of European Group of Pediatric Work Physiology; Moretonhamptonstead, UK.
- Goldsmith HH, Buss KA, Lemery KS. Toddler and childhood temperament: Expanded content, stronger genetic evidence, new evidence for the importance of environment. *Developmental Psychology*. 1997; 33:891–905. [PubMed: 9383612]
- Goldsmith HH, Buss AH, Plomin R, Rothbart MK, Thomas A, Chess S, et al. Roundtable: What is temperament? Four approaches. *Child Development*. 1987; 58:505–529. [PubMed: 3829791]
- Goldsmith HH, Reilly J, Lemery KS, Longley S, Prescott A. The laboratory temperament assessment battery-preschool version: Description of procedures. 1995 Unpublished manuscript.
- Hewitt JK, Silberg JL, Neale MC, Eaves LJ, Erikson M. The analysis of parental ratings of children's behavior using LISREL. *Behavior Genetics*. 1992; 22:292–317.
- Hollingshead, AB. The four-factor index of social status. Yale University; New Haven, CT: 1975. Unpublished manuscript
- Janz KF. Validation of the CSA accelerometer for assessing children's physical activity. *Medicine and Science in Sports and Exercise*. 1994; 26:369–375. [PubMed: 8183103]
- Kendler KS, Heath AC, Martin NG, Eaves LJ. Symptoms of anxiety and symptoms of depression: Same genes, different environments? *Archives General Psychiatry*. 1987; 44:451–457.
- Liang KY, Zeger SL. Longitudinal data analysis using generalized linear models. *Biometrika*. 1986; 73:13–22.
- Mangelsdorf, SC.; Schoppe, SJ.; Burr, H. The meaning of parental reports: A contextual approach to the study of temperament and behavior problems in childhood. In: Molfese, VJ.; Molfese, DL., editors. *Temperament and personality development across the lifespan*. Mahwah, NJ: Earlbaum; 2000. p. 1-32.
- Matheny AP Jr. Bayley's Infant Behavior Record: Behavioral components and twin analysis. *Child Development*. 1980; 51:1157–1167. [PubMed: 7193557]
- Matheny AP Jr. A longitudinal twin study of stability of components from Bayley's Infant Behavior Record. *Child Development*. 1983; 54:356–360. [PubMed: 6683619]
- McArdle JJ, Goldsmith HH. Alternative common-factor models for multivariate biometric analyses. *Behavior Genetics*. 1990; 20:569–608. [PubMed: 2288547]
- McGue M, Bouchard TJ. Adjustment of twin data for the effects of age and sex. *Behavior Genetics*. 1984; 14:325–343. [PubMed: 6542356]
- Melanson E, Freedson PS. Validity of the Computer Science and Applications, Inc. activity monitor. *Medicine & Science in Sports & Exercise*. 1995; 27:934–940. [PubMed: 7658958]
- Mini Mitter Company. Actical physical monitoring system instruction manual. Bend, OR: Author; 2005.
- Neale, M.; Boker, SM.; Xie, G.; Maes, HH. *Mx: Statistical modeling*. 7th. Richmond, VA: Virginia Commonwealth University, Department of Psychiatry; 2006.
- Neale MC, Stevenson J. Rater bias in the EASI temperament scales: A twin study. *Journal of Personality and Social Psychology*. 1989; 56:446–455. [PubMed: 2926639]
- Phillips K, Matheny AP. Evidence for genetic influence on both cross-situation and situation-specific components of behavior. *Journal of Personality and Social Psychology*. 1997; 73:129–138. [PubMed: 9216081]
- Pinto LP, Tryon WW. Activity measurements support dimensional assessment. *Behavior Modification*. 1996; 20:243–258. [PubMed: 8768507]
- Plomin, R.; DeFries, JC.; McClearn, GE.; McGuffin, P. *Behavioral genetics*. 4th. New York: Worth; 2001.
- Plomin R, Foch TT. A twin study of objectively assessed personality in childhood. *Journal of Personality and Social Psychology*. 1980; 39:680–688.

- Plomin R, Nesselroade JR. Behavioral genetics and personality change. *Journal of Personality*. 1990; 58:191–220. [PubMed: 2198339]
- Price TS, Freeman B, Craig I, Ebersole L, Plomin R. Infant zygosity can be assigned by parent questionnaire data. *Twin Research*. 2000; 3:129–133. [PubMed: 11035484]
- Saudino, KJ.; Cherny, SS. Sources of continuity and change in observed temperament. In: Emde, RN.; Hewitt, JK., editors. *The transition from infancy to early childhood: Genetic and environmental influences in the MacArthur Longitudinal Twin Study*. New York: Oxford University Press; 2001a. p. 89–110.
- Saudino, KJ.; Cherny, SS. Parent ratings of temperament in twins. In: Emde, RN.; Hewitt, JK., editors. *The transition from infancy to early childhood: Genetic and environmental influences in the MacArthur Longitudinal Twin Study*. New York: Oxford University Press; 2001b. p. 73–88.
- Saudino KJ, Cherny SS, Plomin R. Parent ratings of temperament in twins: Explaining the “too low” DZ correlations. *Twin Research*. 2000; 3:224–233. [PubMed: 11463143]
- Saudino KJ, Eaton WO. Infant temperament and genetics: An objective twin study of motor activity level. *Child Development*. 1991; 62:1167–1174. [PubMed: 1756660]
- Saudino KJ, Eaton WO. Continuity and change in objectively assessed temperament: A longitudinal twin study of activity level. *British Journal of Developmental Psychology*. 1995; 13:81–95.
- Saudino KJ, McGuire S, Reiss D, Hetherington EM, Plomin R. Parent ratings of EAS temperaments in twins, full siblings, half siblings and step siblings. *Journal of Personality and Social Psychology*. 1995; 68:723–733. [PubMed: 7738774]
- Saudino KJ, Plomin R, DeFries JC. Tester-rated temperament at 14, 20, and 24 months: Environmental change and genetic continuity. *British Journal of Developmental Psychology*. 1996; 14:129–144.
- Saudino KJ, Thompson LA, Gagne JR. Genetic influences on activity level in adolescence: Do the same genetic effects operate on parent ratings, self ratings and mechanical measures? [Abstract]. *Behavior Genetics*. 2000; 30:417–418.
- Saudino KJ, Wertz A, Gagne JR, Chawla S. Night and day: Are siblings as different in temperament as parents say they are? *Journal of Personality and Social Psychology*. 2004; 87:698–706. [PubMed: 15535780]
- Schaughency EC, Fagot BI. The prediction of adjustment at age 7 from activity level at age 5. *Journal of Abnormal Child Psychology*. 1993; 21:29–50. [PubMed: 8463503]
- Schmitz S, Saudino KJ, Plomin R, Fulker DW, DeFries JC. Genetic and environmental influences on temperament in middle childhood: Analyses of teacher and tester ratings. *Child Development*. 1996; 67:409–422. [PubMed: 8625721]
- Stevenson J, Fielding J. Ratings of temperament in families of young twins. *British Journal of Developmental Psychology*. 1985; 3:143–152.
- Wood A, Saudino KJ, Rogers H, Campbell D, Asherson P, Kuntsi J. Genetic influences on mechanically-assessed activity level in children. *Journal of Child Psychology and Psychiatry*. 2007; 48:695–702. [PubMed: 17593150]
- Zeger SL, Liang KY. Longitudinal data analysis for discrete and continuous outcomes. *Biometrics*. 1986; 42:121–130. [PubMed: 3719049]

Figure 1.
Independent pathway model.

Figure 2.
Common pathway model.

Figure 3.
Path estimates from common pathway model.

Note. Estimates for the full model are given in italics. Asterisks indicate that the path was significant ($p < .05$) in the full model. Estimates for best-fitting reduced model are given in parentheses. Dashes indicate that the parameter was not included in the best-fitting reduced model. All paths in the reduced model are significant at $p < .05$.

Table 1
Means (SD) for Activity Level by Sex and Zygosity in Home and Lab Situations

Situation	Males		Females		Effect size	
	MZ	DZ	MZ	DZ	Sex	Zygosity
Home	21.63 (2.49)	21.21 (2.45)	20.79 (2.45)	20.85 (2.10)	.24	.07
Test	24.71 (5.17)	24.37 (4.78)	22.35 (4.48)	22.08 (4.10)	.48	.05
Play	28.75 (7.24)	29.48 (6.53)	26.63 (6.81)	26.45 (6.86)	.38	-.05
<i>n</i>	146	182	142	154		

Note. Effect size estimated as Cohen's *d* expresses group differences in *SD* units. *DZ* = dizygotic twins; *MZ* = monozygotic twins.

Table 2
Twin Intraclass Correlations and Cross-Twin Cross-Situation Correlations (95% CI)

Situation	Home		Test		Play	
	MZ	DZ	MZ	DZ	MZ	DZ
Home	.87 (.83 – .91)	.70 (.61 – .77)				
Test	.30 (.14 – .44)	.18 (.03 – .32)	.53 (.40 – .64)	.32 (.17 – .45)		
Play	.31 (.16 – .45)	.19 (.04 – .33)	.49 (.36 – .61)	.27 (.13 – .41)	.48 (.34 – .60)	.26 (.11 – .39)

Note. Intraclass correlations are given in bold on the diagonal. Cross-twin correlations are given below the diagonal. DZ = dizygotic twins; MZ = monozygotic twins.

Table 3
Fit Statistics for Multivariate Models of Activity Level in the Home, Test, and Play Situations

	Overall fit of model ^a					Relative fit of model		
	-2LL	df	χ^2	df	p	AIC	χ^2	df p
Overall model (saturated -2LL = 9,967.52, 1,813)								
Independent pathway model	9,991.49	1,837	23.97	24	.46	-24.03		
Common pathway model	9,993.08	1,841	25.56	28	.60	-30.44	1.59 ^b	4 .81
Simplification of best-fitting model								
No common C or E and no unique a or c on test or play	9,997.04	1,847	29.52	34	.69	-38.49	3.96^c	6 .68

Note. Best-fitting models are indicated in bold. AIC = Akaike's information criterion; χ^2 = chi-square fit statistic; -2LL = log-likelihood statistic.

^a Overall fit of the model is determined by the difference in -2LL of the model and that of a saturated model.

^b χ^2 difference between the independent pathway model and the common pathway model.

^c χ^2 difference between the full common pathway model and the reduced model.

NIH-PA Author Manuscript

NIH-PA Author Manuscript