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Sally Ozonoff
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute

Gregory S. Young
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute

Stacy Goldring
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute

Laura Greiss Hess
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute, laura.hess@dominican.edu

Andriana M. Herrera
Institute of Child Development, University of Minnesota

See next page for additional authors

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Sally Ozonoff,
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute, 2825 50th Street, Sacramento, CA 95817, USA

Gregory S. Young,
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute, 2825 50th Street, Sacramento, CA 95817, USA

Stacy Goldring,
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute, 2825 50th Street, Sacramento, CA 95817, USA

Laura Greiss-Hess,
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute, 2825 50th Street, Sacramento, CA 95817, USA

Adriana M. Herrera,
Institute of Child Development, University of Minnesota, Minneapolis, MN, USA

Joel Steele,
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute, 2825 50th Street, Sacramento, CA 95817, USA

Suzanne Macari,
Child Study Center, Yale University School of Medicine. New Haven, CT, USA

Susan Hepburn, and
Department of Psychiatry, University of Colorado Health Sciences Center, Denver, CO, USA

Sally J. Rogers
Department of Psychiatry, University of California – Davis Health System, M.I.N.D. Institute, 2825 50th Street, Sacramento, CA 95817, USA

Sally Ozonoff: sjo7.onoff@ucdavis.edu

Abstract

Gross motor development (supine, prone, rolling, sitting, crawling, walking) and movement abnormalities were examined in the home videos of infants later diagnosed with autism (regression and no regression subgroups), developmental delays (DD), or typical development. Group differences in maturity were found for walking, prone, and supine, with the DD and

Correspondence to: Sally Ozonoff, sjo7.onoff@ucdavis.edu.

Autism-No Regression groups both showing later developing motor maturity than typical children. The only statistically significant differences in movement abnormalities were in the DD group; the two autism groups did not differ from the typical group in rates of movement abnormalities or lack of protective responses. These findings do not replicate previous investigations suggesting that early motor abnormalities seen on home video can assist in early identification of autism.

Keywords

Autism; Motor; Early identification

Introduction

One of the earliest views of the behavioral profile of autism stressed the intactness of early motor development. Children with autism were often described as graceful, agile, and well coordinated (e.g., Rimland 1964). Early motor abilities were seen, especially in contrast to other areas of development, as an “area of intact—or almost intact— functioning” (Gillberg et al. 1990, p. 933). Within a decade, however, there was growing recognition that individuals with autism experience motor difficulties. Unusual gait, including slower pace, decreased step length, increased knee flexion, and unusual upper extremity positions during walking, were described in individuals with autism (Damasio and Maurer 1978; Vilensky et al. 1981). Several studies have now found evidence of motor delays and impairments in children with autism when they are compared to children with typical development. Empirical studies using standardized measures of motor function have documented balance and gait difficulties, slower speed in timed movements, reduced postural stability, and oromotor impairments (Jansiewicz et al. 2006; Minshew et al. 2004; Page and Boucher 1998). Motor difficulties are one of the common sources of referral for occupational therapy (Baranek 2002).

Not all studies support the contention that motor impairments are an essential part of the autism phenotype, however. A sophisticated biomechanical assessment of five adults with autism and five healthy controls (Hallett et al. 1993) did not replicate the gait abnormality findings of Vilensky et al. (1981). The only significant difference found between the groups was decreased range of ankle motion. Mean gait velocity and mean length, width, and symmetry of steps were virtually identical across the two groups, suggesting that lack of significant differences was not due to low power. By retrospective parent report, Mayes and Calhoun (2003) reported normal onset of early gross motor milestones in the majority of their sample with autism.

It is also not yet clear whether the motor skills of children with autism differ from those of children with other forms of developmental delay and cognitive impairment. Most studies reported above used typically developing control groups. In other studies, when motor abilities of children with autism were compared to children with developmental delays matched on mental age, no group differences emerged. For example, no differences in running, jumping, throwing, catching, and balance were found between children with autism and those with mental retardation in a study by Morin and Reid (1985). A more recent study

found no differences between children with autism 21–41 months of age and children with general developmental delays in reflexes, balance, locomotion, grasping, object manipulation, or visual-motor integration (Provost et al. 2006). Similarly, Rogers and colleagues did not find differences in fine motor maturity or motor planning in 2-year-olds with autism compared to developmentally matched typical and atypical groups (Rogers et al. 2003). And no differences between school-aged children with autism spectrum disorders and children with specific language disorders (Noterdaeme et al. 2002) or learning disabilities (Miyahara et al. 1997) were found across multiple fine and gross motor functions, coordination, and balance in other recent investigations.

Finally, the timing of when motor abilities diverge from typical development is not known. Most studies have focused on older children with autism. The only studies of preschool-aged children provide mixed results, with one documenting gross and fine motor deficits relative to typical controls but not mental-age matched controls with developmental delays (Provost et al. 2006) and the other finding no differences relative to either group (Rogers et al. 2003).

The timing of onset of motor delays and their specificity to autism are of central importance, given recent assertions that motor differences can aid in the early identification of autism. In an influential and highly publicized study, Teitelbaum and colleagues stated that movement disturbances in autism are “present at birth and can be used to diagnose autism in the first few months of life” (Teitelbaum et al. 1998, p. 13982). The Eshkol-Wachman Movement Notation system was utilized for analysis of home video from 17 infants later diagnosed with autism. A variety of movement abnormalities were found in all subjects with autism. For example, one subject was described as showing persistent asymmetry at 4 months of age in a prone position, with his right arm trapped under his chest. Rolling was often abnormal; in some children, rolls consistently began from a sidelying rather than a supine position, while in others there was a lack of segmental or corkscrew rolling and persistent *en bloc* (or “log”) rolling without rotation. Asymmetrical sitting with unequal weight distribution was reported, as well as a lack of protective extension when balance was lost. In walking, the authors stated, “in every autistic child we have seen so far, some degree of asymmetry has been found” (Teitelbaum et al. 1998, p. 13985). Although the paper mentions that 15 typically developing infants were studied, there is no data presented on this group (nor is it clear whether video was coded by raters unaware of group membership), so the specificity of these movement abnormalities to autism is not clear from this study. Despite this limitation, the paper concludes that, “simple movements such as those described in the present paper might help in the diagnosis of potential autism” (Teitelbaum et al. 1998, p. 13987).

In a later study looking at early detection of Asperger syndrome, Teitelbaum and colleagues (2004) described similar movement difficulties, including asymmetries in prone lying and crawling, log rolling, asymmetrical tonic neck reflex (ATNR) that persisted past the age of developmental appropriateness, and lack of protective responses when balance was lost. This study again lacked control data, making replication of these findings important.

Two other home video studies have examined early motor behavior. Adrien et al. (1993) found significantly more hypotonia in the first year of life and unusual posturing in the

second year of life in infants later diagnosed with autism, relative to typically developing infants, rated blind to group status. Baranek (1999) examined social, communication, and repetitive behaviors between 9 and 12 months of age in the home video of children with autism, developmental delays, or typical development. Ratings were done without awareness of diagnosis. Of relevance to early motor development, the group with autism engaged in more mouthing of objects than the other two groups and more unusual posturing than the typical group.

One objective of this study was to evaluate the hypothesis that infants with autism can be distinguished from infants with typical or delayed development in the first 2 years of life on the basis of home videos of early motor behavior and that motor differences can assist in early identification. The study focused on the timing, maturity, and typicality of the same early gross motor behaviors examined by Teitelbaum and colleagues (1998), including lying in prone and supine, rolling, sitting, crawling, and walking. An additional objective of the study was to examine whether there were any early motor indicators of a later regression in a subsample of children with autism whose parents described their onset as involving a significant loss of skills after a period of typical or mostly typical development. Given the relatively small sample sizes and the replication intent of this study, we wanted to be aware of even moderate size group differences in motor maturity or movement abnormalities and thus we examined and interpreted both statistically significant ($p < .05$) and marginally significant ($.05 < p < .10$) effects.

Method

Participants

A total of 103 participants were recruited from two separate sites: 82 from the UC Davis M.I.N.D. Institute in Sacramento, California and 21 from the University of Colorado Health Sciences Center in Denver, Colorado. The Sacramento sample was recruited from the M.I.N.D. Institute Research Participant Recruitment Core and local agencies serving individuals with developmental disabilities. The Denver sample was recruited through ongoing studies and the University of Denver subject pool. Participants were seen twice, at initial enrollment when video was collected and inclusion eligibility determined (Time 1) and 1–2 years later for an assessment battery that was part of a larger study (Time 2).

Participants fell into three groups: Autistic Disorder, non-autistic developmental delays of mixed etiology, and typical development. The group with Autistic Disorder ranged in age from 26 to 61 months at the time of home video collection. They were free from other medical conditions (e.g., seizures, Fragile X syndrome), had no visual or hearing impairments, and were born at a gestational age of 37 weeks or greater. Multiple diagnostic criteria were used to confirm the presence of autism. Each child (1) had been previously diagnosed with Autistic Disorder or Pervasive Developmental Disorder Not Otherwise Specified (PDDNOS; American Psychiatric Association 2000) in the community, prior to referral to the study, (2) received a current clinical diagnosis of DSM-IV Autistic Disorder by study personnel, and (3) met full criteria for Autistic Disorder on both the ADI-R and the ADOS. Children meeting these criteria were then subdivided into two groups based on onset status. The Autism:No Regression (AutNR) group was defined by responses of no loss

(score of 0) to two items on the ADI-R: question 11 (loss of at least five words) and question 25 (loss of social interest and engagement). The Autism:Regression (AutR) group was defined by a score of 1 on question 11 (loss of at least five words) and/or a score greater than 0 on question 25 (probable or definite loss of social interest and engagement). Since the regressive pattern of onset occurs relatively less frequently, children with regression were over-recruited to have relatively equal numbers in the onset subgroups.

The group of children with developmental delays (DD) was recruited to provide both a chronological and developmental age match for the groups with Autistic Disorder. Children with DD ranged in age from 24 to 56 months at the time of recruitment. All had normal vision and hearing, unimpaired hand use, and full mobility. None had a current or previous clinical or DSM-IV diagnosis of Autistic Disorder or PDDNOS and none met criteria for autism or autism spectrum disorder on the ADI-R or ADOS. None were born before 37 weeks gestation. The group was etiologically heterogeneous, including 13 children with global developmental delays of unknown etiology, 1 with Down syndrome, and 11 with speech-language delays.

The typically developing (TD) group was recruited to provide a developmental age comparison for the groups with Autistic Disorder. The TD group ranged in age from 16 to 42 months at initial enrollment. All had normal hearing and vision, did not present with any significant medical or developmental concerns, and were born at 37 weeks gestational age or greater. None met criteria for an autism spectrum disorder on any diagnostic instrument.

Materials

Autism Diagnostic Interview-Revised (ADI-R; Lord et al. 1994)—The ADI-R is a structured, standardized parent interview developed to assess the presence and severity of symptoms of autism. It provides an algorithm that reliably distinguishes children with Autistic Disorder from those with other developmental delays or typical development.

Autism Diagnostic Observation Schedule (ADOS; Lord et al. 2002)—The ADOS is a semi-structured standardized interaction that measures symptoms of autism. All participants received Module 1, for preverbal or minimally verbal children.

Mullen Scales of Early Learning (MSEL; Mullen 1995)—The MSEL is a standardized developmental test for children ages birth to 68 months. Four subscales were administered: Fine Motor, Visual Reception, Expressive Language, and Receptive Language. The Gross Motor subscale was not administered because norms are provided only up to 33 months of age and many of the participants were older than this at the time of study entry.

Vineland Scales of Adaptive Behavior (Sparrow et al. 1984)—This parent interview assesses social, communication, motor, and daily living skills. The motor score does not examine gross and fine motor abilities separately, so Gross and Fine Motor age equivalents were used as the primary dependent variables.

Procedure

This study was conducted under the approval of the Institutional Review Board at the University of California, Davis. The study was explained to parents orally and in writing, all questions answered, and consent obtained before conducting assessments to confirm diagnosis, determine onset subtype, and measure developmental level. Families were then asked to provide all available videotape footage of their child from birth to 2 years of age, which was transferred from existing formats to DVD, and the original media returned to families.

Home video footage was catalogued by date, segment start and end time, and number of people in the frame. A new segment was defined when the events, location, or date of the activity on the video changed. Any segments that did not contain the subject, were undated, or were of poor quality were omitted from further study. Baranek's (1999) content coding system was used to further describe each segment. A "social" content code indicated whether the subject was interacting with other people or not during the segment. A "structure" score (1 = low, 2 = medium, 3 = high) indicated the degree to which other people were verbally and/or physically directing the activities of the child during the segment. Segments were also coded for the level of physical restriction (1 = low, 2 = medium, 3 = high) apparent during the segment; those with high restriction (defined as being secured in a seat or held so that motor behavior was not possible) were not included in the study. Finally, segments were coded for their context and categorized into one of the following: routines (e.g., eating, bathing), play, special events (e.g., holidays, birthdays, family gatherings), and passive activity. Inter-rater reliability for the content and context codes was calculated by double-coding approximately 15% of the videotapes, using tapes with 60 or more codable segments to ensure that all categories were represented at a high frequency. All coders were trained to reliability; weighted kappa scores ranged from .60 (for structure) to .80 (for restriction).

Infant Motor Maturity and Atypicality Coding Scales (IMMACS)—A team comprised of clinical and developmental psychologists, an occupational therapist, and a child development specialist collaborated to create a coding system for scoring motor maturity, protective responses, and movement abnormalities. Six gross motor behaviors were rated: prone, supine, roll,[1] sit, crawl, and walk. Protective responses were coded to assess the ability to right oneself following a loss of balance when sitting, crawling, and walking. Motor maturity and protective responses were scored using a rating scale ranging from 0 to 3, with a score of 0 indicating mastery and fully mature development of a behavior and a score of 3 indicating the least mature form typically evident during initial learning of a new motor skill. Each segment was also coded for the presence of the following specific movement abnormalities: hypotonia, hypertonia, or mixed tone abnormalities; hyperflexion or unusual flexion or positioning of limbs; asymmetrical tonic neck reflex (ATNR) after 6 months of age or any other persistent asymmetries in any posture; log roll after 6 months; and static sits in a "W" position for more than 10 s. See Table 1 for more complete

[1]Two forms of roll behavior were originally coded: roll supine-to-prone and roll prone-to-supine. The frequencies of both types of roll behavior, however, were too low to warrant separate analyses and therefore were collapsed into a single "roll" behavior.

descriptions of the coded variables. Motor stereotypies, such as hand flapping, rocking, or repetitive actions on objects, were not included, as the focus in this study was on movement abnormalities that occurred in the developmental course of achievement of typical motor milestones, rather than the presence of specific symptoms of autism defined by motor behavior.

Coders were trained in two phases. The first phase taught identification (presence or absence) of the different motor behaviors, protective responses, and movement abnormalities, using segments from children not participating in the study. Coders were required to establish 80% agreement or higher with standardized training tapes prior to advancement to phase 2. Coders then became reliable on distinguishing levels of maturity and durations (specific onset and offset times) for all motor behaviors and protective responses. Average percent agreement for phase 2 training across all categories was .81. Due to low frequency of movement abnormalities, it was not possible to become reliable on specific atypical motor behaviors (e.g., ATNR, low muscle tone, asymmetry) and therefore these were collapsed into one category called “movement abnormalities.” Mean percent agreement was .81 for movement abnormalities and .86 for protective responses. Disagreements were resolved through discussion.

After training, assistants coded all data in real time using Noldus Observer 5.0 behavioral observation software, with a time resolution of half a second. Files with dated motor segments were imported into Noldus to be coded. To maintain ongoing reliability, 25% of the data files were double-coded. Mean intraclass correlation coefficients (ICC) for specific motor behaviors were .87 for supine, .92 for prone, .92 for roll prone to supine, .96 for roll supine to prone, .86 for sit, .87 for crawl, and .87 for walk. Once all segments had been coded, we examined data for outliers potentially indicative of errors by plotting chronological age by maturity level of each motor behavior. Any data that was inconsistent with developmental principles or that was more than 2 standard deviations above or below the regression line was re-examined and obvious errors were corrected.

Results

Sample Characteristics

Demographic and clinical characteristics of the groups at enrollment are presented in Table 2. There was a significant group difference in gender ($\chi^2 = 15.36$, df=3, $p < .01$), which was due to the heavily male-balanced gender ratio in the autism and DD groups, but not the TD group. There were no significant group differences in SES, ethnicity, or race. There were also no differences on any variable as a function of site (California versus Colorado). Analysis of Mullen age equivalent scores from the initial recruitment assessment revealed no group differences on the Visual Reception ($p = .54$), Fine Motor ($p = .43$), or Expressive Language subscales ($p = .27$). There was a significant group difference on the Receptive Language age equivalent score (F (2, 76) = 3.31, $p < .05$). Post-hoc tests revealed that the AutNR group had marginally lower scores than the DD group ($t = 2.67$, $p = .06$) but did not differ from the other groups. These results suggest the four groups were relatively well matched on intellectual function at initial enrollment.

Videotape Characteristics

To ensure that characteristics of the video did not vary as a function of group, we analyzed a number of variables generated by the first phase of video cataloguing and scoring. Specifically, we examined the mean age and age range represented by all codable video for a child, as well as the total number and total duration of all codable video segments. Table 3 presents the means and standard errors as well as significance tests of these measures. Inspection of post-hoc tests using Tukey's least significant difference revealed that the TD group's mean age across all video segments was significantly lower than the mean age for both the AutNR group ($t = 3.03$, $p < .01$) and the DD group ($t = 2.59$, $p < .05$). For the overall age range of video segments, the AutR group had a significantly greater age range than both the DD group ($t = 2.15$, $p < .05$) and the TD group ($t = 2.78$, $p < .01$). In contrast, no group differences were observed for either the total number or total time of codable segments. Given that group differences in mean video age could influence analyses of motor maturity, we used mean age in video as a covariate in subsequent analyses.

We next examined whether there were differences in the contexts of video segments across groups. As can be seen in Table 3, there were no group differences in the context of video segments. As a final analysis of video characteristics, we examined the overall restriction and structure imposed on the child during each of the video segments. Since chronological age was significantly negatively correlated with level of restriction ($r = -.39$, $p < .001$), we used mean age of video as a covariate in this analysis. Mean age of video was not used as a covariate in the analysis of mean level of structure, given that the correlation between level of structure and chronological age was not significant ($r = .16$, $p = .12$). Means and standard errors for the restriction and structure data are presented in Table 3. There was no significant group effect for mean level of restriction. A marginally significant effect was observed for mean level of structure. Post-hoc comparisons revealed that the AutNR group had significantly higher structure scores than both the AutR group ($t = 2.13$, $p < .05$) and the TD group ($t = 2.02$, $p < .05$). Similarly, the DD group had marginally higher structure scores than both the AutR ($t = 1.88$, $p = .06$) and TD groups ($t = 1.78$, $p = .08$). Since structure was not conceptually relevant to the performance of motor behavior in the way that restriction was, we did not use mean structure scores as a covariate in any further analyses despite the marginally significant group effect. Indeed, there were no significant relationships between maturity scores and structure.

Current Motor Functioning

We analyzed age equivalents from the MSEL Fine Motor subtest and Vineland Gross and Fine Motor subscales collected at Time 2 to examine whether there were group differences in current motor functioning (Table 4). Analyses of variance, using age at time of testing as a covariate, revealed significant group effects for each of the motor variables. Post-hoc comparisons revealed that, after controlling for chronological age, the TD group had significantly higher motor scores on the MSEL and Vineland than each of the clinical groups (AutNR, AutR, DD). In contrast, there were no significant differences among the clinical groups on any measure of current motor function.

To further explore group differences in motor functioning, we also examined retrospective parental reports of the age at which four motor milestones (roll, sit unsupported, crawl, walk independently) were achieved (see Table 5). There were significant group differences in parent-reported ages of acquisition of all four milestones. Post-hoc analyses revealed an overall pattern of children with DD achieving motor milestones later than the AutR and TD groups, with the AutNR group in between. Specifically, for parent-reported age of first roll, the DD group was significantly older than the other three groups (versus TD, $t = 4.16$, $p < .001$; versus AutR, $t = 3.87$, $p < .001$; versus AutNR, $t = 2.16$, $p < .05$). For parent-reported age at first unsupported sit, the DD group was significantly older than both the TD ($t = 3.12$, $p < .01$) and AutR groups ($t = 2.28$, $p < .05$), whereas the AutNR group was marginally older than the TD group ($t = 1.86$, $p = .07$). For parent-reported age at first crawl, the DD group was again significantly older than both the TD ($t = 3.74$, $p < .001$) and AutR groups ($t = 3.27$, $p < .01$), and the AutNR group was again marginally older than the TD group ($t = 1.94$, $p = .06$). Finally, for parent-reported age at first independent walking, the DD group was again significantly older than both the TD ($t = 5.17$, $p < .001$) and AutR groups ($t = 3.73$, $p < .001$) and marginally older than the AutNR group ($t = 1.94$, $p = .06$). The TD group, in turn, was significantly younger than the AutNR group ($t = -3.02$, $p < .01$) and marginally younger than the AutR group ($t = -1.66$, $p = .10$).

Developmental Trajectories

We used growth curve modeling to compare groups on the age at which they achieved mature motor functioning on videotape and the early developmental trajectories of the motor behaviors coded from videotape. Using the SPSS Mixed procedure with full maximum likelihood estimation, unconditional mean models and unconditional growth curve models were fit to the average ages at which subjects achieved each of the four developmental maturity levels used in coding each skill. Thus, maturity level was used as the growth or "time" factor, whereas the child's average age at each respective maturity level was used as the dependent variable.[2] In order to model group differences at the most mature level of motor behavior, we recoded maturity levels such that the least mature was equal to −3 and the most mature level was equal to 0. As such, the test for group differences in intercepts became a test for the age at which highest motor maturity was achieved for each behavior.

For each skill, we then examined a series of nested models in which additional parameters were included and tested. Specifically, after fitting an unconditional means model and growth model to serve as a baseline, we examined additional parameters in the following order, retaining only those terms that added significantly to the previous model: (a) mean video age, (b) gender, (c) diagnostic group, and (d) group by time and/or covariate interactions. Contributions of variables added to the models were tested using chi-square tests of the differences between models' −2 Log Likelihood values, using the difference between the number of model parameters as the degrees of freedom for the test. Fixed effects that were found to add significantly to the model were retained.

[2]We used child's average age at each maturity level as the best representation of reliable performance of the respective motor behavior at any given maturity level. Although we also examined earliest age of maturity level appearance, the results were not substantially different than those presented for mean age. For subjects who did not have multiple instances of a behavior at a given maturity level, the data for that maturity level was not used in the analysis.

To verify assumptions of linearity, inspection of scatterplots and OLS equations for each individual suggested reasonably linear associations between maturity level and chronological age for each of the motor skills. For maturity levels of roll behavior, however, there were few subjects with enough data or enough variability to model development adequately and so we did not include rolls in growth curve analyses. To assess possible violations of normality and homoscedasticity, level-1 and level-2 residuals from the best-fit models were examined further using graphic inspection. For several variables, violations of normality and homoscedasticity were found using normal Q-Q plots, scatterplots of residuals, and formal tests (i.e., Shapiro-Wilk). These distributional anomalies were addressed by transforming variables using either natural logarithms and/or square-root transformations and then re-examining the residuals generated from growth curve models. Although these transformations successfully addressed problems with the distributions, they did not substantially affect any of the results obtained when fitting models to the original untransformed variables. Therefore, to facilitate presentation and interpretation, we report growth curve models fitted to untransformed data.

For each of the five motor behaviors—walk, crawl, sit, prone, supine—the best fitting models all involved the inclusion of mean age of video segments as a significant predictor of the age at which highest motor maturity was achieved. Mean age of video segments was not found to moderate any other variables in any of the models and thus was retained only as a covariate of age at highest maturity. Gender was not a significant predictor of either age at highest maturity or rate of change and did not interact with (moderate) any other variables in the models. The effect of group and the group by maturity interactions were consistently included and evaluated in each of the models given that the associated parameters and tests were of primary interest to this study. Table 6 presents the parameter estimates for the final growth curve models for each of the behaviors. Prototypical growth curves are displayed in Fig. 1.

For maturity of walk, group differences were found for age at most mature walk (F (3, 74.75) = 5.70, $p < .001$). Planned comparisons revealed that both the DD group ($t = 3.50$, $p < .001$) and the AutR group ($t = 3.40$, $p < .001$) achieved most mature walking at significantly later ages than the TD group. The overall interaction between maturity and group approached significance (F (3, 80.12) = 2.23, $p = .09$) and appeared to be due primarily to the AutR group achieving motor maturity at a significantly slower rate than the TD group ($t = 2.47$, $p < .05$).

For maturity of crawl, there was no overall group effect for age at most mature crawl or for developmental rate, although the contrast for the difference between the DD group and the TD group for the age at most mature crawling was significant ($t = 2.03$, $p < .05$).

For maturity of sit, there was similarly no overall group effect for age at most mature sit or for developmental rate, although contrasts for trajectories suggested that both the AutNR group ($t = 1.84$, $p = .07$) and the DD group ($t = 1.69$, $p = .09$) achieved motor maturity in sitting at marginally slower rates than the TD group.

For prone, a significant group difference in age at highest maturity was found (F (3, 42.49) = 3.88, $p < .05$). Planned comparisons revealed that the DD group was significantly older at most mature prone behavior than the TD group ($t = 3.06$, $p < .01$) and that the AutNR group was marginally older at most mature prone behavior than the TD group ($t = 1.78$, $p = .08$). There were no group differences in developmental rates.

For maturity of supine, a significant group difference in age was found (F (3, 39.76) = 2.87, $p < .05$). Planned comparisons revealed that the AutNR group was significantly older at most mature supine behavior than the TD group ($t = 2.01$, $p = .05$). Although there was no overall group difference for developmental rate, the AutNR group achieved maturity at a marginally slower rate than the TD group ($t = 1.87$, $p = .06$).

Movement Abnormalities and Protective Responses

Preliminary examination found low frequencies of movement abnormalities and protective responses, with the majority of subjects exhibiting no instances of either category of behavior on home video. The distributions were highly positively skewed and therefore non-parametric tests of mean rank differences were used to examine group differences. To control for the total number of behaviors coded, we calculated movement abnormalities and protective responses as proportion scores prior to analysis. The mean rank data and chi-square tests of significance using Kruskal-Wallis analyses are shown in Table 7. We found significant group differences in movement abnormalities demonstrated during sitting and prone lying. Follow-up comparisons using Mann–Whitney U tests revealed that the DD group evidenced significantly more abnormalities during sitting than both the AutR group ($U = 194.00$, $p < .01$) and the TD group ($U = 130.00$, $p < .01$). Similarly, the DD group evidenced more abnormalities in prone than both the AutR group ($U = 162.00$, $p < .05$) and the TD group ($U = 126.00$, $p < .05$).

Protective responses were coded during only three motor behaviors: walk, crawl, and sit. The mean rank data and associated Kruskal–Wallis chi-square tests of significance are also shown in Table 7. There was no group effect for either walk or sit. The group effect for crawl, however, was marginally significant ($\chi^2 = 7.49$, df = 3, $p = .06$). Follow-up tests revealed that the DD group exhibited significantly fewer protective responses when crawling than the AutR group ($U = 183.00$, $p < .01$).

Discussion

One objective of the present study was to examine the hypothesis that movement abnormalities in the first months of life can assist in early identification of autism. Teitelbaum and colleagues' (1998) study is intriguing and worthy of replication because motor impairments are often found in slightly older children and adults with autism and any method of reducing the age of diagnosis and referral for services is important to examine further. The results of the current study do not replicate those of Teitelbaum et al. however. We did not find elevated rates of movement abnormalities or fewer protective responses in infants later diagnosed with autism when home video was coded by reliable raters unaware of diagnostic status. In all cases, when group differences were apparent, they were driven by the DD group, which displayed higher rates of movement abnormalities in sitting and prone

and fewer protective responses in crawling than the other groups. Rates of movement abnormalities in children with both regressive and non-regressive autism were very similar to those of children with typical development, with no group differences that were even marginally significant.

A second objective of the present study, beyond the Teitelbaum et al. replication, was to examine early trajectories of motor development to see when they diverged from the DD and typical comparison groups. Growth curve models found overall group differences in the age at which the highest level of maturity was achieved for three behaviors: walk, prone, and supine. The group difference in walking was due to both the AutR and DD groups showing significantly later ages of highest maturity than the typical group. For prone, the group difference was driven by the DD group and, to a slightly lesser extent, the AutNR group, both showing later ages of highest maturity than the typical group. For supine, the group difference was due solely to the AutNR group showing a significantly later age of maturity than the typical group. Additionally, the DD group showed a significantly later age of highest crawl maturity when compared to the TD group. In terms of rates of change in motor maturity, the AutR group showed a significantly slower rate of development of walking, the AutNR group showed a marginally slower rate of development of supine lying and sitting, and the DD group showed a marginally slower rate of sitting development, relative to the TD group.

These findings demonstrate a relatively consistent pattern of slowed motor development in all three clinical groups when compared to the typically developing group. Children with general developmental delays show the most substantial abnormalities in rate and quality of motor development, but children with autism also demonstrate delays that are consistent with the more pronounced motor difficulties documented at later ages in many studies using standardized measures. Thus, as in previous studies (Miyahara et al. 1997; Noterdaeme et al. 2002), motor delays associated with autism were difficult to differentiate from motor delays associated with DD. This suggests that early signs of motor delay may simply be a consequence of developmental disorder in general and not specific to autism.

It is interesting to note that the motor differences in the AutNR group were specific to early behaviors such as prone, supine, and sit, whereas the only difference in the AutR group was in walking, the latest maturing motor behavior we studied and the only one whose acquisition overlaps the age at which regression typically occurs. Thus, the results for walking may reflect the onset and progression of the regression process, whereas the results for prone, supine, and sit behaviors may reflect an earlier disruption of development in the AutNR group. This presents new questions about when and how motor skills in children with autism become deficient. These findings suggest that motor deficits in autism are not secondary to more basic deficits in social, communication, and cognitive skills. The rate of motor development appears to slow in the second and third years of life. It is possible that an active pathological process occurs in both social-communicative and motor domains with the onset of autism symptoms, presumably due to underlying neurological changes.

The present findings do not suggest that movement abnormalities can be used to identify autism any earlier than social-communication deficits. Recent studies of the very early

phenotype of autism suggest that symptoms emerge between 9 and 18 months of life in most children, with even early social-communicative behaviors looking largely intact before the first birthday in most infants later diagnosed with autism (Bryson et al. 2007; Yirmiya et al. 2006; Yirmiya and Ozonoff 2007; Zwaigenbaum et al. 2005). Studies using prospective samples have not found differences in motor behavior, assessed with standardized instruments, at 4 months (Yirmiya et al. 2006), 6 months (Landa and Garrett-Mayer 2006), 12 months (Zwaigenbaum et al. 2005), or 14 months (Yirmiya et al. 2006) of age. These studies raise questions about the inclusion of motor assessment in tools for early detection of autism. Subtle abnormalities in muscle tone, motor control, and praxis are difficult to measure even with expert clinical examination or biomechanical methods. The present study measured motor behaviors and abnormalities that could be coded reliably from home video, but was not a comprehensive analysis of motor functions, so it is possible that more sensitive examinations could be useful in the early identification of autism. However, the present results suggest that home video, parent report, or live evaluation using existing instruments will likely not be helpful to earlier detection.

An additional objective of the present study was to examine whether there are any differences in early motor behavior in children with autism who experience a developmental regression. Several independent research teams have reported delays in social-communicative development prior to the onset of regression (Goldberg et al. 2003; Ozonoff et al. 2005; Werner et al. 2005). The present investigation examined whether early motor differences might provide warning signs of impending regression. If this was the case, it might improve early detection of regression risk, as pediatricians routinely screen motor development at well-baby visits, in contrast to social-communication development. We found only one statistically significant difference in motor development in the AutR sample, the age at which most mature walking behavior was observed on home video. There were no differences in acquisition of other early motor behaviors or movement abnormalities that distinguished the AutR group from the other groups prior to the regression, suggesting that warning signs of impending regression are not apparent in the motor system.

In conclusion, this study does not support previous assertions that specific movement abnormalities, as seen on home video, can detect autism, nor does it demonstrate that delays in acquisition of motor milestones are specific to autism. While motor screening may not identify autism in particular, it is important for early detection of developmental delays in general pediatric settings. And it remains critical to identify valid and reliable markers that detect specific autism risk, so that intensive intervention efforts that may lessen the disability of the disorder can be provided as early as possible.

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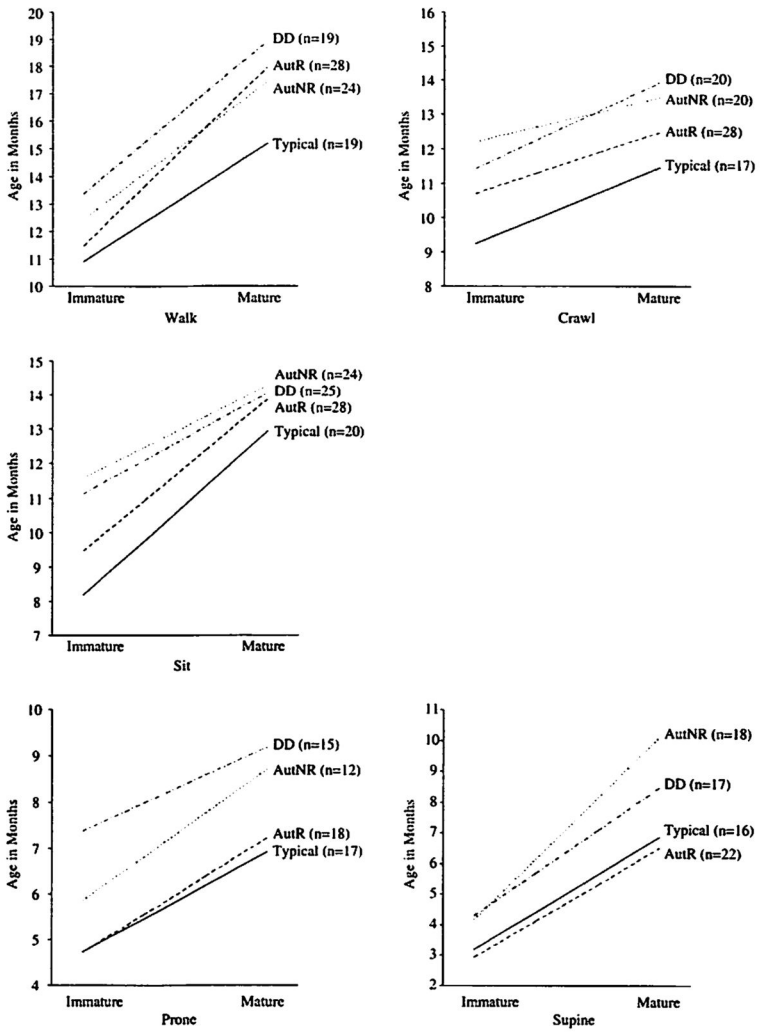

Fig. 1.

Group growth trajectories for maturity of five motor behaviors

Table 1

Motor behaviors coded

Posture	3 = Least mature	2 = Early learning of skill	1 = Emerging mastery	0 = Most mature	Atypicalities
Supine	Newborn flexed posture	Increasing midline control	Emerging arm and leg movements against gravity	Antigravity control of arms and legs	ATNR after 6 months Hypotonia
Prone	Head and chest on surface	Limited neck/chest extension and control	Emerging antigravity control. Prone on elbows, head control	Antigravity control. Upper extremity extension with weight bearing. Head/chest extension	ATNR after 6 months Hypotonia Extreme neck hyperextension
Roll	Attempt to roll, does not get to sidelying	Partial roll. Gets to sidelying only	Immature full roll. Log roll before 6 months	Rolling with rotation. Segmental “corkscrew” rolling	Log roll after 6 months Upper extremity trapped under body Asymmetries
Sit	Sits only with full support.	Unstable, sits with rounded back or light support.	Immature independent sit. Stable yet static	Independent with dynamic trunk movements	Static “W” sit for more than 10 seconds Significantly rounded back Neck hyperextension
Crawl	Combat crawl, rocking in quadruped. Any backwards crawl	Immature crawl, one limb moves at a time	Mature crawl, slower pace, less stable	Swift crawl with reciprocal movements	Rhythmicity interrupted by one or more limbs One limb less active, carried by others “Bunny hopping” Elbow hyperextension Upper extremity internal rotation Crawling on closed fists
Walk	Supported walk, includes cruising on furniture, using a push toy or holding adult hand	Unstable walk. Few tentative steps	Stable walk, no heel strike, arms in high guard, no reciprocal arm swing	Mature walk with heel strike and narrow base of support	Upper extremities in exaggerated high guard position Lower extremity scissoring Toe walking Head/neck hyperextension Knee hyperextension
Protective responses in sit, crawl and walk	No adjustment, no protective responses. Head may hit floor or would if child not caught by adult	Loss of balance causes change in head position (head may pitch forward). Protective mechanisms observed, yet slower	Extremity extension to regain balance. Head and face protected immediately and successfully. Head remains in vertical plane	Postural reactions to loss of balance, including head righting. Baby does not rely on protective extension to keep from falling	

Note: The full coding system can be obtained from the first author

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Table 2

Group demographics and characteristics at initial enrollment

	AutNR	AutR	DD	TD
SES				
Hollingshead (Mean, SEM)	44.35 (3.78)	50.06 (2.10)	43.28 (3.32)	50.21 (2.60)
Gender (n)				
Male	25	23	18	12
Female	1	5	7	12
Ethnicity/race (n)				
African-American	0	2	2	2
Asian	1	5	1	1
Caucasian	19	18	17	19
Hispanic	4	3	3	2
Not reported	2	0	2	0
Mullen age equivalents (Mean, SEM)				
Expressive Language	19.35 (2.72)	20.30 (2.10)	23.40 (2.09)	25.10 (2.31)
Receptive Language	18.71 (2.81)	20.61 (2.15)	27.95 (2.26)	25.90 (2.28)
Visual Reception	25.35 (2.87)	27.52 (1.86)	30.00 (2.44)	26.15 (2.29)
Fine Motor	27.12 (2.80)	29.30 (2.07)	29.35 (2.02)	25.00 (1.91)
Mullen early learning composite	61.0 (4.2)	55.6 (2.6)	64.7 (3.4)	110.1 (3.3)
Mean ADOS communication + social algorithm score(SD)	15.39 (.84)	16.91 (.63)	2.85 (.45)	2.86 (.45)

Table 3

Video characteristics

	AutNR	AutR	DD	TD	*F*
Mean age in video (months)	12.68 (.79)	11.28 (.38)	12.28 (.67)	9.95 (.59)	3.63**
Mean age range in video (months)	14.69 (1.36)	17.57 (1.00)	13.70 (1.56)	12.39 (1.30)	2.91*
Mean number of segments	47.60 (10.85)	54.82 (7.99)	45.20 (11.82)	37.73 (5.27)	.56
Mean duration of segments (minutes)	138.57 (30.46)	152.35 (28.70)	122.28 (32.96)	118.86 (23.39)	.29
Mean segments in “Routine” context (minutes)	4.91 (1.71)	5.44 (.29)	4.81 (1.66)	5.30 (.98)	.04
Mean segments in “Play” context (minutes)	33.67 (7.82)	27.88 (3.54)	31.70 (6.77)	22.15 (3.78)	.86
Mean segments in “Special Events” context (minutes)	9.69 (3.31)	13.83 (6.69)	8.27 (5.79)	12.01 (3.21)	.27
Mean segments in “Passive Activity” context (minutes)	40.43 (8.74)	21.86 (1.96)	38.68 (10.66)	47.67 (4.94)	1.72
Mean restriction score[a]	2.03 (.07)	1.87 (.07)	2.06 (.07)	1.86 (.08)	.69
Mean structure score	2.08 (.08)	1.87 (.29)	2.06 (.44)	1.87 (.37)	2.57†

[a]Estimated marginal means are displayed (controlling for mean age in video)

*$p < .05$;

**$p < .01$;

†$p = .06$; standard errors are in parentheses

Table 4

Group motor functioning at time 2

	AutNR	AutR	DD	TD	*F*
Chronological age at testing	37.75 (2.29)	46.69 (1.92)	41.56 (2.18)	36.27 (1.95)	5.14**
Mullen Fine Motor Age Equivalent[b]	29.86 (2.04)	26.12 (1.78)	29.04 (1.83)	45.44 (2.31)	15.63***
Vineland Motor Standard Score[a]	78.89 (4.81)	76.29 (5.06)	85.59 (3.84)	106.14 (5.13)	7.58***
Vineland Fine Motor Age Equivalent[b]	26.02 (3.47)	25.82 (2.99)	30.84 (3.02)	38.26 (3.63)	2.83*
Vineland Gross Motor Age Equivalent[b]	28.51 (2.73)	26.98 (2.35)	28.89 (2.38)	40.49 (2.86)	5.03**

[a] Mean = 100, SD = 15

[b] Estimated marginal means are displayed (controlling for chronological age)

* $p < .05$;

** $p < .01$;

*** $p < .001$; Standard errors are in parentheses

Table 5

Parental report of age of motor milestones (in months)

	AutNR	AutR	DD	TD	*F*
Roll	5.10[a] (.62)	4.15[a] (.28)	7.00[b] (.92)	3.82[a] (.32)	6.98***
Sit	6.80[cd] (.77)	5.91[d] (.27)	7.69[c] (1.06)	5.17[d] (.32)	3.60*
Crawl	8.31[ef] (.52)	7.32[f] (.42)	9.62[e] (.85)	6.89[f] (.20)	5.46**
Walk	13.44[h] (.57)	12.17[hi] (.46)	15.11[g] (.86)	10.90[i] (.36)	9.75***

Means with different superscripts are significantly different ($p < .05$)

* $p < .05$;

** $p < .01$;

*** $p < .001$; standard errors are in parentheses

Table 6

Growth curve model parameter estimates

	Walk	Crawl	Sit	Prone	Supine
Fixed effects					
Age at highest maturity					
Age at most mature (intercept)	15.54* (.59)	11.91* (.59)	13.66* (.46)	7.15* (.42)	7.26* (.80)
All video age (covariate)	1.33* (.22)	1.72* (.29)	2.65* (.14)	.90* (.31)	1.49* (.35)
AutNR versus TD	1.27 (.80)	.76 (.81)	−.65 (.62)	1.12† (.63)	2.15* (1.07)
AutR versus TD	2.61* (.77)	.81 (.74)	.57 (.59)	.18 (.56)	−.54 (1.00)
DD versus TD	3.10* (.89)	1.66* (.82)	−.17 (.62)	1.83* (.60)	.90 (1.06)
Rate of change					
Motor maturity	1.43* (.23)	.74* (.21)	1.59* (.27)	.73* (.25)	1.23* (.30)
AutNR versus TD	.24 (.31)	−.31 (.28)	−.70† (.38)	.22 (.38)	.76† (.41)
AutR versus TD	.74* (.30)	−.14 (.26)	−.12 (.35)	.10 (.34)	−.03 (.39)
DD versus TD	.43 (.34)	.10 (.28)	−.62† (.37)	.13 (.39)	.16 (.40)
Random effects					
Level 1					
Within-person	2.10* (.30)	1.39* (.20)	3.02* (.34)	.91* (.19)	1.43* (.28)
Level 2					
Age at highest maturity	4.09* (.99)	3.64* (.94)	1.59* (.62)	1.45* (.60)	5.65* (1.75)
Rate of change	.43* (.16)	.20† (.10)	.76* (.24)	.39* (.18)	.44† (.26)
Covariance	1.04* (.35)	.26 (.25)	.91* (.34)	.05 (.24)	.58 (.56)

*$p < .05$,

†$p < .10$. Standard errors are in parentheses

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Table 7

Mean ranks for movement abnormalities and protective responses

	AutNR	AutR	DD	TD	χ^2
Total movement abnormalities[a]	52.52	48.68	58.12	41.86	3.93
Walk	46.36	47.14	49.32	49.80	.29
Crawl	39.43	50.50	46.73	43.42	2.72
Sit	47.58	52.00	60.24	35.57	9.64*
Roll	33.41	25.50	34.39	26.71	3.82
Prone	38.81	35.59	43.89	34.00	7.97*
Supine	46.40	40.36	45.79	36.76	2.85
Total protective responses[b]	56.88	50.41	45.34	49.23	3.93
Walk	55.18	46.29	41.45	48.63	3.06
Crawl	42.17	55.09	37.20	44.66	7.49†
Sit	47.42	50.54	55.84	42.95	2.61

[a] Lower rank scores are better (indicate fewer abnormalities)

[b] Higher rank scores are better (indicate better protection when balance lost)

* $p < .05$;

† $p = .06$