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The developmental relationship between language and motor performance from 3 to 5 years of age: a prospective longitudinal population study

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Abstract

Background: Previous research has found that language and motor skills are closely interrelated developmental areas. This observation has led to questions about the specificity of these domains, and the nature of the associations. In this study, we investigated the longitudinal relationship between language and gross and fine motor performance from 3 to 5 years of age.

Methods: We tested the prediction across and within developmental domains using cross-lagged panel models. In addition, estimates of specificity for each domain were calculated. Analyses were performed using parental reports in a sample of 11 999 children from a prospective population study.

Results: Structural equation modelling revealed unique positive predictions from early language performance to later fine and gross motor skills. Neither gross nor fine early motor skills uniquely predicted later language performance. Both language and motor skills were stable from 3 to 5 years of age. Motor skills were more stable in boys than in girls. Boys had lower scores than girls on fine motor performance, but gender differences in cross-lagged associations between language and motor performance were non-significant. The variance specific to language performance decreased from 68% to 46% in relation to fine motor skills and from 61% to 46% in relation to gross motor skills from 3 to 5 years of age.

Conclusion: From 3 to 5 years of age the stability within each developmental area is high, and unique prediction from one domain to the other is weak. These results implicate stable and correlated developmental pathways at this age.

Keywords: Longitudinal, Language development, Motor development, Co-occurrence, MoBa

Background

Associations between language and motor skills have frequently been recognized. The developmental pathways within each domain have been described in terms of rapid changes, plateaus, as well as wide variability (Iverson 2010) and common traits between domains have been found (Hill 1998). Consequently, it has been difficult to disentangle the associations. Most previous research on this association has focused one-sidedly on motor profiles in children with Specific Language Impairment (SLI) (Iverson and Braddock 2011). A growing literature investigates the interrelatedness of these developmental domains (Iverson 2010; Alcock and Krawczyk 2010). However, previous literature has been dominated by focus on one out of three perspectives, rather than combining them. These three perspectives are; 1) co-occurrence of difficulties, 2) stability of each domain across time, and 3) predictive power from one domain to another across time. Most previous studies are hampered by small sample sizes and are often limited to clinical rather than population based samples, mainly with Specific language impairment (SLI) or Developmental coordination disorder (DCD) (Hill 1998; Iverson

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and Braddock 2011). The purpose of the present study is to gain new knowledge about the developmental relationship between language and motor performance across age by combining the three perspectives described above in one population based longitudinal study.

Several theories suggest links between motor development and specific aspects of language. The development of gestures is the foremost example of this. Motor skills influence the performance of gestures and studies have shown that children with language delays very often have a history of problems with gestures (Iverson and Goldin-Meadow 2005; Zambrana et al. 2012a). Further, theories of motor cognition, i.e. the notion that cognition is embedded in actions, suggest that perception and action share common computational codes and underlying neural architectures. This idea has been further developed in the study of mirror-neurons. It has been suggested that the mirror-neuron system is the basic neural mechanism from which language has developed, and that this system represents a strong link between language and action representation (Rizzolatti and Arbib 1998). Theories of embodied cognition argue that motor resonance enhances language comprehension (Glenberg and Kaschak 2002; Fischer and Zwaan 2008). These theories suggest that a broader developmental focus should be employed both in research and in clinical practice when investigating language and motor development.

Lately, researchers have questioned the specificity of several developmental disorders (Goorhuis-Brouwer and Wijnberg-Williams 1996; Snowling 2012). The frequent overlap in symptoms across domains in developmental disorders as well as co-morbid diagnoses suggests less clear distinction between clinical groups, especially in children, than suggested by the diagnostic systems. When comparing children diagnosed with SLI or DCD to children with no previously suspected disorder but with low standard scores on language or motor skills, researchers found that diagnosed children were more pervasive underachievers on a large set of measures of developmental difficulties additional to those corresponding to their diagnosis compared to those with low standard scores (Dyck and Piek 2010). This observation suggests that a broader developmental focus should be employed both in research and in clinical practice.

Arguments have been proposed for grouping neurodevelopmental disorders together, such as language and motor difficulties (Viholainen et al. 2006; Andrews et al. 2009). These disorders have several common features (Rutter et al. 2006). They involve similar neural structures, and the development is characterized by a delay/deviance rather than a remission or relapse (Jancke et al. 2007). Both of these disorders involve some degree of cognitive impairment and have a marked male preponderance (Rutter et al. 2006). The genetic influences on individual differences in both domains are quite strong (Fox et al. 1996; Spinath et al. 2004). Language difficulties have been found to be highly hereditary (Spinath et al. 2004), and children with DCD have been found to have neurological similarities to children with SLI, such as frequent rolandic spikes during sleep, suggesting a genetic component (Scabar et al. 2006). More research is needed on potential common genetic factors influencing development of both skills. Factors such as socio-economic status (Payne et al. 1994), parental history of difficulties (Choudhury & Benasich 2003), or low birth weight (Ribeiro et al. 2011) are known to influence both language and motor skills. Thus, a child with slow development in one of the domains will also be at risk of developmental delay in the other.

Motor skills are often divided into gross and fine motor skills. These are described as overlapping but different (Hill 2001). Some studies have found that language skills were associated only with gross and not fine motor skills (Piek et al. 2008; Alcock and Krawczyk 2010), but an overall finding in literature concerning children with language delays is that they are characterised by deficits in both gross and fine motor skills (Hill 2001; Noterdaeme et al. 2002).

Studying at risk populations, two literature reviews have concluded that contrary to the definition of SLI, people with SLI may exhibit non-linguistic problems, such as impairments of gross and fine motor skills, and other functional problems (Hill 2001; Ullman and Pierpont 2005). These findings are consistent with the results from a meta-analysis of 14 clinical studies indicating an association between gross and fine motor delay and language delay in children (Rechetinikov and Maitrat 2009). Comparing language profiles in children with DCD or SLI to controls, results showed that the language profiles of children with either DCD or SLI are similar in the majority of cases (Archibald and Alloway 2008). Also, research comparing motor profiles in children with SLI or DCD shows that both groups are significantly lower than controls on motor scores (Hill 1998). Few longitudinal studies have investigated developmental stability of language and motor skills in general populations and results from these are inconsistent. However, the prospective longitudinal study Early Language in Victoria Study (ELVS) (Reilly et al. 2009) showed that about half of late talkers catch up with their peers, and a Finnish follow up study (Cantell et al. 2003) suggested that about half of children with motor delay also catch up with their peers.

Symptoms of delayed or deviant language development are related to a variety of different developmental outcomes such as ADHD, emotional and behavioural problems (Toppelberg and Shapiro 2000; Beitchman et al. 1996). Likewise, impaired motor function early in life has been found to be a precursor of problems with language acquisition later on (AmielTison et al. 1996; Cantell et al. 1994). Only a few studies have analysed the relationship between language and motor development longitudinally in community samples [Rechetinikov and Maitrat 2009; Archibald and Alloway 2008]. Piek and colleagues (Piek et al. 2008) studied the relationship of early motor development and school age motor and cognitive development in 33 typically developing children. They demonstrated that parent-reported scores on the Ages and Stages Questionnaire (ASQ), measuring gross motor skills during infancy, predicted later motor and cognitive performance. The same association was not found for fine motor skills (Piek et al. 2008). These results are consistent with the claims that early locomotor experiences are an essential agent for developmental change (Iverson 2010; Campos et al. 2000). However, the association was limited to working memory and speed of processing only and no association was found between early gross motor skills and later verbal comprehension (Campos et al. 2000). Another study of typical language development in 102 children between 9 and 23 months demonstrated large variability in both gross and fine motor skills within each child across age, between the children at each age level and across the developmental domains (Darrah et al. 2003). Further, one study on 21 month old children (Alcock and Krawczyk 2010), investigated various motor skills, including oral movements, in association with language production, comprehension, and complexity. Results showed no residual associations between gross and fine motor performance and measured aspects of language development when controlling for oral motor movements. These studies do not support a clear predictive power from one domain to the other. Some studies support language and motor skills as separate domains while others suggest that motor skills are a prerequisite for language development (Iverson 2010) or that language predicts motor performance (Webster et al. 2005).

In a previous study, we investigated the relationship between language and motor skills in typically developing children from 18 months to 3 years of age (Wang et al. 2012). The study explored the association between language and motor skills (a distinction between gross and fine motor skills was not made in this study) both concurrently and over time. The results showed that whereas both skills were quite stable across age, early motor performance was an equally strong predictor of later language performance as early language performance was. Early language performance did not predict later motor performance. At 18 months of age typically developing children are in the beginning of rapid changes in development in both language and motor performance (Darrah et al. 2003). At the age of 3, however, most children are able to use and understand basic language, and are also able to move around and manipulate their physical environment (Campos et al. 2000). It is therefore important to see whether findings based on development from 18 months to 3 years can be replicated at older ages.

In the present study we investigate the co-occurrence, stability, and change in language and gross and fine motor performance from 3 to 5 years of age in a large, prospective longitudinal population study. This study is based on the same sample as in our previous study. Our main aim is to scrutinize the developmental relationship between language and fine and gross motor performance across age. More specifically we hypothesise; there are cross-sectional correlations – language and motor performance are associated at both 3 and 5 years of age; language and motor performance are both stable from 3 to 5 years of age, language performance at 3 years of age predicts change in motor performance from 3 to 5 years of age, and motor performance at 3 years of age predicts change in language performance from 3 to 5 years of age; there are gender differences – boys have poorer skills in both language and motor domains, and we explore whether there are gender differences also in associations within and across domains over time. Finally, we hypothesize that associations are similar for both gross and fine motor performance. We also investigate the specificity of each developmental domain.

Methods

Participants

The Norwegian Mother and Child Cohort Study (MoBa) is a prospective population-based pregnancy cohort study conducted by the Norwegian Institute of Public Health (Magnus et al. 2006). Participants were recruited from all over Norway from 1999–2008. A total of 38.5% of invited women consented to participate. Informed written consent was obtained from all participants. The cohort now includes 109 018 children. Follow-up is conducted by questionnaires at regular intervals and by linkage to national health registries. The study was approved by the Regional Committee for Medical Research Ethics and the Norwegian Data Inspectorate.

By June 2011 (data release version 5), 25 474 children had turned 5 years of age and were thus eligible for the present study. Data from three waves of data collection were used; 17 weeks (Q1), 3 years (Q6), and 5 years (Q5yr). We also used data from the Medical Birth Registry of Norway (MBRN). For inclusion in this study, mothers must have answered both the 3-year questionnaire and the 5-year questionnaire. A total of 12 383 children satisfied this criterion. A total of 384 children were excluded because of serious physical malformations, cerebral palsy, Down's syndrome, cleft palate or because of missing information on MBRN data. This gave a total number of 11

999 participants (6 025 boys and 5 974 girls), corresponding to 47% of the eligible 5 year olds.

Demographic, health-, pregnancy- and birth-related variables have previously been examined to investigate potential self-selection bias in MoBa. Despite risk prevalence differences between the sample and the population, estimates of risk exposure and child developmental outcomes were not significantly different when MoBa participants were compared with the entire population of Norwegian mothers (Nilsen et al. 2009).

Measures

Language skills

Language skills were assessed through maternal ratings on selected items from the Ages and Stages Questionnaire (ASQ) (Squires et al. 1999) included in the MoBa questionnaires. The ASQ has been validated in a Norwegian sample and found to be a successful diagnostic tool for developmental difficulties (Richter and Janson 2007). At 3 years, language was measured by six ASQ items, and at 5 years, by seven ASQ items. All items had three response categories (yes, sometimes, and not yet). Because the ASQ originally was intended as a screening tool, most items had skewed distribution across response categories. One item at 5 years singled out with 99.5% responding "yes", meaning that virtually all children mastered the skill and was excluded (Question 3: Does your child use four- and five- word sentences? For example, does your child say, "I want the car"?). More information on the items is presented in Additional file 1.

Motor skills

Fine and gross motor skills at 3 years were assessed through maternal ratings on four items from the ASQ. All items had three response categories (yes, sometimes, and not yet). At 5 years motor skills were measured by ten items (five items on gross and five on fine motor skills) from Child Development Inventory (CDI) (Ireton et al. 1977). At 5 years one item indicating gross motor skills was excluded because of low factor loadings to the latent variable (< .40) (question 5: Rides a two-wheeled bike, with or without training wheels). The distribution of responses to CDI-items was also skewed (See Additional file 1 for further information).

Covariates

Information on the child's APGAR scores five minutes after birth, birth weight, and gestational age, was retrieved from MBRN. Information on parents' age, income, education and Norwegian language background was gathered during pregnancy (Q1). Information about maternal psychological distress (anxiety and depression) was assessed using a five-item short version of the Hopkins Symptom Checklist-5 (SCL-5), at both 3 and 5 years. The short version used has been shown to have good construct validity (Strand et al. 2003). Information about the child's age at return of the questionnaires was included as covariate at both 3 and 5 years.

Analyses

The relationships among latent variables were examined with cross-lagged panel models. The models specified associations between language performance and motor performance at 3 years, auto-regression coefficients for each of the factors, cross-lagged regression coefficients, and association between language performance and motor performance at 5 years (see Figures 1 and 2).

The structural equation model (SEM) analyses were done using Mplus 6 (Muthén and Muthén 2007). Because of the non-normal distribution of several variables in the study, estimation procedures robust to deviations from the normal distribution were utilized in all SEM analyses. Weighted least square parameter estimates using a diagonal weight matrix with standard errors and mean- and variance adjusted chi-square tests, using a full weight matrix (WLSMV) (Muthén and Muthén 2007) were applied.

Models including control for communication and motor skills at 18 months of age were also estimated, but did not alter the associations between language and motor skills from 3 to 5 years of age in a noteworthy manner. Results from analyses of this relationship from 18 months to 3 years of age are presented elsewhere (Wang et al. 2012). Finally, analyses were done to calculate the percentage of shared and specific variance for the latent factors at 3 and 5 years.

Missing data

WLSMV estimation works in four steps and uses a procedure for handling of missing with elements from maximum

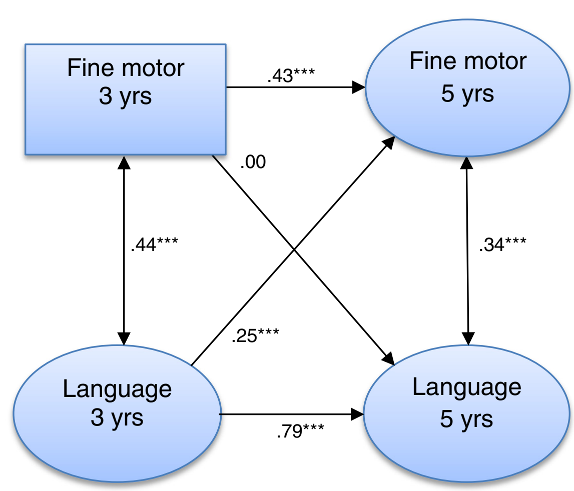

Figure 1 Results from cross-lagged panel analysis. Correlations, auto-regressive-, and cross, lagged correlations between language and fine motor performance at 3 and 5 years of age.

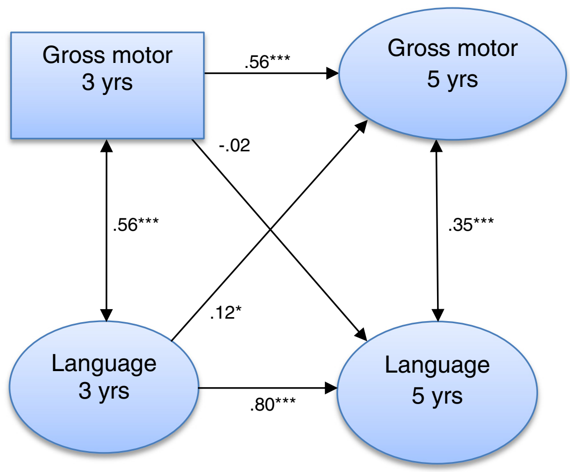

Figure 2 Results from cross-lagged panel analysis. Correlations, auto-regressive-, and cross, lagged correlations between language and gross motor performance at 3 and 5 years of age.

likelihood estimation and pairwise present deletion. This procedure was used for outcome measures. Missing value analysis (MVA) and an expectation-maximization (EM) algorithm were used to impute missing values for covariates using SPSS (Inc. S 2008).

Results

Measurement models

Exploratory factor analyses showed that language and motor measures represented two distinct domains at each point in time. The items clustered as expected on all latent variables, except for fine motor skills at 5 years, where one item loaded on both fine and gross motor skills (question 1: Puts together a puzzle with nine or more pieces). Responses on this item were also severely skewed across response categories, and the item was excluded from the subsequent analyses. Next, we conducted confirmatory factor analyses (CFA) on the two waves of data to validate the factor structure of the latent variables language at 3 and 5 years and gross and fine motor skills at 5 years. CFA conducted for language at 3 years of age showed that the standard estimates ranged from .71 to .88 for the six items (Comparative fit index (CFI) = .994, Tucker Lewis Index (TLI) = .989, root mean square error of approximation (RMSEA) = .024). At 5 years the standard estimates for the six items indicating language at 5 years ranged from .64 to .87, (CFA = .988, TLI = .981, RMSEA = .029). The standard estimates for the four items indicating gross motor skills at 5 years ranged from .52 to .92, (CFA = .992, TLI = .977, RMSEA = .032) whereas the standard estimates for the four items indicating fine motor skills ranged from .74 to .83 (CFA = .997, TLI = .991, RMSEA = .034). Two items were available for indicating fine, and two for gross motor skills at 3 years. The standard estimates for these items were fixed to be equal.

Before including the latent variables in structural models, correlation estimates between all latent variables, and the observed variables for gross and fine motor skills at 3 years (see Table 1), were computed independently of each other. All correlations were highly significant.

Cross-lagged panel models

The latent variables from the measurement models were included in two two-wave cross-lagged panel models. The models allowed all structural parameters to be freely estimated, providing good model fit both when including measures of fine (CFI = .983, TLI = .981, RMSEA = .011), and measures of gross motor skills (CFI = .965, TLI = .960, RMSEA = .015). The first model produced $\chi^2(N = 11483) = 885.894$, $p < .001$ with 354 degrees of freedom, whereas the second produced $\chi^2(N = 11483) = 1225.438$, $p < .001$ with 354 degrees of freedom. The structural models are presented in Figures 1 and 2.

Language and fine motor skills

At 3 years, children's language was positively associated with fine motor performance, with the correlation between language and fine motor skills being .44. The regression coefficient for language from 3 to 5 years was .79, and the regression coefficient for fine motor performance from 3 to 5 years was .43. A Wald chi-square test showed that these regression coefficients were significantly different ($p < .001$). The cross-lagged coefficient for language on fine motor performance was .24 ($p < .001$), indicating that language performance at 3 years predicted fine motor performance at 5 years. The cross-lagged coefficient for fine motor on language performance was .00 (ns). A Wald test showed that the cross-lagged coefficients were significantly different ($p < .001$), indicating a weaker prediction from early fine motor performance to later language performance than from early language to later fine motor performance. A Wald test comparing the regression coefficients of early language and fine motor performance on later language performance showed a significant difference ($p < .001$), indicating that early language is better than

Table 1 Unadjusted correlations between language and motor performance at 3 and 5 years of age

	Lang 3	Gross 3	Fine 3	Lang 5	Gross 5	Fine 5
Language 3	1	.57***	.42***	.78***	.42***	.41***
Gross motor 3		1	.67***	.48***	.67***	.39***
Fine motor 3			1	.34***	.53***	.53***
Language 5				1	.72***	.55***
Gross motor 5					1	.55***
Fine motor 5						1

***Significant at p < .001.

early fine motor performance at predicting later language performance. A Wald test comparing the regression coefficients of early language and fine motor performance on later fine motor performance was significant ($p < .001$), indicating that early fine motor performance were a better predictor of later fine motor performance than was early language performance.

Language and gross motor skills

The correlation coefficient for language and gross motor skills at 3 years were .30, and .11 at 5 years. The regression coefficient for language from 3 to 5 years was .80, and for gross motor the regression coefficient was .56. These coefficients were not significantly different. The cross-lagged coefficient for early language on later gross motor skills was .13, and was significantly different from the cross-lagged coefficient for early gross motor on later language skills -.03 ($p < .001$). Language at 3 years of age was a significantly better predictor of later language performance than gross motor skills ($p < .001$) and gross motor skills at 3 years of age was a significantly better predictor of later gross motor skills than language performance at 3 years of age ($p < .001$).

Longitudinal domain specificity

In addition a significant increase over time of shared variance with both fine and gross motor development was found for language development (Table 2). In relation to fine motor skills, the variance specific to language decreased from 68% to 46%, whereas in relation to gross motor the decrease was from 61% to 46% from 3 to 5 years of age. For fine motor skills the variance specific to this domain increased from 43% at 3 years to 53% at 5 years, and for gross motor skills the variance specific to this domain increased from 33 to 59% from 3 to 5 years of age.

Gender differences

Girls performed better than boys on all indicators both for language and motor skills at both ages. The largest differences were found in fine motor skills at 5 years (see Additional file 1). These differences were not significance tested. However, to investigate whether there were significant gender differences in the relationships between the latent variables in the final model a multi-group analysis was performed to compare boys and girls on all relevant parameters. Confidence intervals on parameters for boys and girls were compared. Non-overlap between confidence intervals was only found on the covariance between language and gross motor skills at 3 years, with girls having a higher covariance than boys (Table 3). In contrast to the model including both genders, the regression coefficient for early language skills on later gross motor skills was not significant for boys. The difference between boys and girls on this parameter was, however, not significant.

A decomposition of variance similar to the one shown in Table 2 was also done for girls and boys separately (table not shown). No gender differences proved significant, except for a decrease in shared variance with language for gross motor skills in boys.

Table 2 Variance that each developmental domain share with the other at each time point

	3 years of age Var (95% CI)	5 years of age Var (95% CI)
Language:	0.323 (.288-.359)	0.540 (.500-.581)
Fine motor:	0.576 (.501-.650)	0.470 (.426-.451)
Language:	0.398 (.349-.446)	0.544 (.488-.601)
Gross motor:	0.674 (.541-.807)	0.413 (.340-.486)

Discussion

The aim of this study was to examine the development of language and motor performance in children from 3 to 5 years of age and associations between the two domains cross-sectionally as well as longitudinally. Our results were consistent with the hypothesis that motor and language development are associated developmental pathways. We found that the auto-correlations for both language and motor performance are high and stable over time. However, the predictive power from one domain to the across age other found by earlier research (Webster et al. 2005) was weak in our study when controlling for stability within each domain.

Earlier studies, mainly with clinical samples have shown that a large proportion of children with impairments in one area also have impairments in the other (Archibald and Alloway 2008). Our results support this assumption in finding strong cross-sectional associations between language and both gross and fine motor skills. However, our results indicate that between 3 and 5 years of age in the general population the stability within domains is much higher than the effect one domain has on the other. Similar to what has been found by others (AmielTison et al. 1996; Cantell et al. 2003) we find significant developmental associations across domains. However, this was only true for zero order correlations, and the associations disappeared when controlling for stability, except for the association between early language and later fine and gross motor skills. Language also had a significant increase in shared variance with both gross and fine motor performance from 3 to 5 years of age. This means that language at 3 years of age was associated with later fine and gross motor performance over and above what was explained by the correlation between domains at 3 years and the stability of each domain from 3 to 5 years of age. This finding is supported

Table 3 Gender differences on model parameter

	Boys b (CI)	Girls b (CI)	Gender difference
Language and fine motor skills			
b L3-L5	.734 (.653-.816)***	.806 (.713-.899)***	ns
b L3-FM5	.235 (.165-.305)***	.307 (.212-.402)***	ns
b FM3-FM5	.392 (.288-.497)***	.624 (.439-.808)***	ns
b FM3-L5	.023 (−.071-.118) ns	.048 (−.097-.192) ns	ns
cov L3-FM3	.185 (.153-.217)***	.221 (.171-.271)***	ns
res cov L5-FM5	.155 (.120-.189)***	.173 (.120-.226)***	ns
Language and gross motor skills			
b L3-L5	.090 (.043-.137)***	.821 (.723-.920) ***	ns
b L3-GM5	.006 (−.166-.177) ns	.230 (.-088-.372)*	ns
b GM3-GM5	1.053 (.643-1.436)***	.673 (.461-.885)***	ns
b GM3-L5	-.027 (−.190-.137) ns	-.062 (−.192-.067) ns	ns
cov L3-GM3	.264 (.219-.308)***	.391 (.340-.443)***	***
cov L3-GM3	.102 (.044-.160)**	.090 (.043-.137)***	ns

*** = p < .000, ** = p < .005,* = p < .050, ns = not significant, b = regression coefficients, cov = covariance coefficients, res cov = residual covariance coefficients, L3 = language skills at 3 years, L5 = language skills at 5 years, FM3 = fine motor skills at 3 years, FM5 = fine motor skills at 5 years, GM3 = gross motor skills at 3 years, GM5 = gross motor skills at 5 years.
All parameters are unstandardized estimates.

by the overall most common finding in previous literature, that as many as half of the children with language delays in pre-school years later develop motor difficulties (Webster et al. 2005). Early language development thus seems to have a unique contribution to later fine and gross motor development.

The previous study on this population (from 18 months to 3 years of age) also adjusted for stability when investigating the developmental relationship across these domains (Wang et al. 2012). The main results from the current study were consistent with the earlier results with some exceptions. Language did not predict motor development from 18 months to 3 years of age, whereas from 3 to 5 years of age, this association was significant. In the previous study there was a significant association from 18 months to 3 years between motor skills and later language performance, but neither gross nor fine motor performance at 3 years of age predicted language at 5. Wide individual variability in typical language development at 18 months makes defining late development more problematic. In contrast, defining a late developer at 3 is easier. In motor development, however, more observable milestones such as independent walking occur early. At 3 years of age the easiest assessable milestones are reached (Luinge et al. 2006), and the variation in performance no longer predicts performance in language skills at 5. Thus, it seems that development before the age of 3 is different from development after 3 years of age in both domains.

As expected (Zambrana et al. 2012b), we found that boys had lower scores on the measures of language and motor performance than girls. The correlation between language and gross motor skills at 3 years of age was also higher for boys. This implies that in addition to differences in performance level, the developmental relationship of language and fine and gross motor skills is mainly similar across gender.

Conclusions from these results should be considered in light of the strengths and limitations of the study. A major strength of the current study is the prospective-longitudinal design and the community-based sample (Sonuga-Barke 2012). Another strength is the examination of the relationship in a cross-lagged panel model where relations between domains are controlled for development within each domain (Selig and Little 2012). Most previous findings on the association between language and motor performance come from studies using clinical samples and have, therefore, been subject to help seeking biases (Cohen and Cohen 1984). Disorders in both domains have their onsets in early to late childhood. When doing research on clinical groups, some cases might be left out or, as shown by Dyck and Piek, (Dyck and Piek 2010) children seen by specialists have more severe symptoms than undiscovered cases. Furthermore, if there is in fact an association between these domains, children seen by specialists are already at risk of cognitive problems because of their motor problems or vice versa (Wassenberg et al. 2005). Thus, population based samples are needed in order to identify developmental relationships between these domains not limited to the extreme ends of poor performance.

Some limitations should also be considered. First, since a large scale study makes it difficult to assess each child on clinical measures, questionnaires must serve as the source of information. When observation is not possible, measures of children's skills and performances must be based on mother's reports. Mothers have been found to be reliable raters of their child's language skills (Rydz et al. 2006). However, we must also concider the possibility that some of the shared variance found in this study could be due to reliance on verbal instructions on the motor tasks in the both the ASQ and the CDI. Second, different measures are used across different studies, and this can make it difficult to compare results from one study to the other. In the current study different measurements are used across time. Since children's language and motor performance usually develop between 3 and 5 years of age, what we measure are slightly different phenomena at the different ages. This might lead to underestimation of stability across age (for more information on included items, see Additional file 1). It is also important to be aware of the possible consequences of including only two items for measures of fine and gross motor skills respectively at 3 years of age. However, the large sample in this study compensate to some degree for possible measurement errors in the assessment of fine and gross motor skills at 3 years of age. Further, even though there is variation in both domains, there is a ceiling effect, especially for girls. Thus, the variability captured in this study might best show variability around the performance levels expected for the late developers and show less variability in the normal range of language and motor performance.

The clinical implication of findings in the current study is that identification of difficulties at one point in time alone does not necessarily tell anything about potential future difficulties. Our results suggest that the development of language and motor skills change to become more interrelated over time. Assessing both domains more than once is recommended if a child is encountered with problems in any one domain. There is always a risk of one problem overshadowing the other unless specifically assessed. Whereas motor performance at 18 months predicted both language and motor performance at 3 (Wang et al. 2012), neither gross nor fine motor skills predicted language performance from 3 to 5 years of age. The opposite was true for language performance. This shows that the cross-correlations were different between the two studies. However, we found high stability within each domain, and a strong association between the two at all time-points. Additionally we found an increase in the variance motor skills share with language skills over time.

Conclusion

Our results are consistent with the idea of stable and associated developmental pathways for language and motor performance from 3 to 5 years of age. This study is among the first population based studies to investigate the developmental relationship between the two domains during childhood. The trend in research has turned from focusing on specific motor and/or language impairments to conceptualizing problems co-occurring in developmentally disordered children. Children with highly specific deficits are the exception rather than the rule (Andrews et al. 2009). This finding can be further nuanced by results from the current study. In general, our results confirm what has been found earlier, namely that the two domains are related but the picture seems to be more complex. First, our results indicate that the relationship is dependent of age. We clearly see a developmental relationship of language and motor performance but the relationship changes from early to later preschool years. Second, when comparing boys and girls we find that for boys, early language performance does not significantly predict later gross motor skills. Third, we found that controlling for the direct effects over time within each domain uncover a different relationships across these two domains, than when considering unadjusted correlations. Finally, both domains show stability outperforming the prediction from one domain to the other from 3 to 5 years of age.

Additional file

Additional file 1: Additional data distribution in answers on all items indicating language and motor performance at 3 and 5 years, divided by gender. Description of data: The data in the additional file describes the distribution across response categories on the items indicating language and motor performance at 3 and 5 years of age. The data are presented separately for boys and girls. Distribution in answers on items available in the data that were excluded from the analyses is also presented.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

MVW performed the statistical analyses and drafted the manuscript. RL, LEA, AH, and SS contributed to design and interpretation of results, and helped to draft or critically revise the manuscript. All authors read and approved the final manuscript.

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