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The trajectory of balance skill development from childhood to adolescence was influenced by birthweight: a latent transition analysis in a British birth cohort

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Abstract

Objective: To identify classes of balance skills and their trajectories from childhood to adolescence and the association of birthweight with these trajectories.

Study Design and Setting: Participants (n = 13,443) from the 1970 British Cohort Study were assessed for four balance skills in childhood and adolescence. Latent class analysis was used to determine classes of balance skills over time, and latent transition analysis was used to explain the association between birthweight and the probabilities of changing classes over time.

Results: A three-class solution, good balance skills (GBS) group, intermediate in balance skills (IBS) group, and poor balance skills (PBS) group, best fit the data for both childhood and adolescence. Most (49.97%, n = 6.713) had GBS in childhood and GBS in adolescence; the probability of "staying" as GBS was 86%. Birthweight was associated with higher likelihood of remaining GBS at adolescence (OR = 1.82, 95% CI = 1.40-2.37). Those who were classified as IBS and PBS in childhood had 75.2% and 62.7% probability of becoming GBS in adolescence, respectively. A small percentage of children stayed in the PBS group (1.92%, n = 258), with probability of remaining as such being 15.1%.

Conclusions: The higher the birthweight, the better the outcomes in those with GBS and IBS in the childhood. However, although small proportion of children stayed at the lowest level of balance skills in adolescence, some clinical attention should be given to those classified at this level in childhood.

Keywords: Latent class analysis; Latent transition analysis; Balance skills; Motor development; Birthweight; Cohort studies

1. Introduction

According to Rizzuto and Knight [1], balance is a motor ability that can be operationally defined in a dynamic and a static way. Dynamically, balance is the ability to sustain a position while moving through space. Statically, balance is the capacity of maintaining a stationary position for a period of

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What is new?

Key findings

- The chance of being classified as having good balance and remaining in the group good in balance skills (GBS) is high (88%).
- Even children who exhibit poor performance in balance skills (PBS) in childhood had 64% probability of changing to GBS in adolescence.
- Birthweight was associated to changes in the trajectories of balance skills among those who were intermediate in balance skills (IBS) in childhood but was not associated for those classified as PBS.

What this adds to what was known?

- The present findings in this manuscript corroborate existing literature, in which higher birthweight increases the chance of having good balance in childhood. Nevertheless, we provide further evidence observing that higher birthweight is associated with better changes in the trajectories among those who presented intermediate performance in balance skills in childhood.

What is the implication and what should change now?

- This manuscript enlightens how the trajectories of balance skill development from childhood to adolescence are conditioned to birthweight.

time. Static and dynamic balances are crucial for the performance in activities of daily life, in predicting children's cognitive executive functioning (e.g., spatial ability and mathematical thinking), mental rotation performance, and perceived competence [2−5]. Balance is influenced by visual, tactile, kinetic, and vestibular stimuli and is necessary for normal functioning at all ages [6]. Impairments in balance can limit participation in physical activities and affect other aspects of motor skill development [7−9].

Individuals with better balance skills are more likely to participate in physical activity and less likely to live in a sedentary lifestyle. Balance deficits are associated with physical inactivity, which can lead the development of chronic diseases, such as obesity, diabetes, cholesterol, and hypertension, and can help prevent falls in older adults [10,11].

Although balance skills are critical for daily life as well as being a marker of neurodevelopment [12], only a small number of prospective birth cohort studies have assessed motor skill over time. The British Cohort Study (BCS) initiated in 1970 is the only one of four available British birth cohorts that assessed balance skills longitudinally across sensitive periods in development. Thus, it is uniquely able to figure out the trajectory of development for balance skills from childhood to adolescence, allowing empirical evidence about the natural history of patterns of motor skills. Moreover, the data allow the evaluation of the influence of birthweight, a fundamental predictor of outcomes in later life, on the developmental trajectories from childhood to adolescence.

This study aims to identify classes of balance skills and their trajectories from childhood to adolescence and the association of birthweight with these trajectories. As previous research indicated that birthweight impacted balance skills in childhood [13], we hypothesized that the change in the balance profile from childhood to adolescence might vary by birthweight, after controlling for relevant prenatal and sociodemographic features. In other words, the effects of a likely transition in the patterns of balance skills from childhood to adolescent are conditioned (moderated) by the birthweight.

2. Method

2.1. Research ethics and informed consent

This research was approved by the Ethics Committee of Research at the Federal University of Sao Paulo (UNIFESP). The study participants provided relevant consent [14], and the study complied with the Declaration of Helsinki of the World Medical Association.

2.2. Sample

The 1970 BCS, a large and representative UK birth cohort study, was used. The study followed the lives of around 17,000 individuals born in Britain during a single week of April in 1970. For this study, data from the birth survey, data obtained at childhood (age 10), and data obtained at adolescence (age 16) were used. Participants with missing data for all variables were excluded. The final sample of the present study consisted of 13,443 participants (51.29% male; mean gestational age: 39.5 weeks).

2.3. Birthweight

In BCS, birthweight was recorded in the birth survey by a midwife who attended the delivery. In this study, birthweight data were converted from grams into kilograms to adopt a common unit. It ranged from 0.57 kg to 6.46 kg (mean = 3.309 kg; SD = 0.527 kg). As recommended by several studies [15−20], birthweight was used as a continuous variable, as categorization reduces the power to detect small associations between the outcomes and birthweight, unless there is a change in the relationship exactly at the arbitrary cutoff point.

2.4. Balance assessment

The assessment of balance skills was part of the motor coordination test of this cohort, which was conducted during a medical examination completed by the Community Medical Officer and school nurse [21]. Four tasks were used: walking backward along a straight line; standing on the right foot for 15 seconds; standing on the left foot for 15 seconds; and standing heel to toe for 15 seconds. All the tasks were assessed dichotomously (i.e., can or cannot do the task) in childhood (at age 10) and adolescence (at age 16). The details about success with these four tasks and their correlation with different socioeconomic and prenatal indicators can be found in Okuda, Swardfager [13].

2.5. *Control of potential confounding variables*

To capture family socioeconomic status, the model was adjusted for maternal and paternal level of education and registered father's general social class. These variables were assessed as continuous variables. Regarding sociodemographic variables, maternal age at the birth of the cohort child was included. The following indicators of maternal health behavior were also controlled for smoking during pregnancy, drinking during pregnancy (at earlier and later stages of pregnancy), and gestational age (in weeks). Smoking and drinking were assessed as ordinal variables, and the higher the values, more the mother smokes or drinks. Finally, the model was controlled for the sex of the child. These potential confounding variables were chosen because they have been identified as common causes of childhood development in previous research [22−30].

2.6. *Data analysis*

First, heterogeneity in balance skills was explored using the four dichotomous balance tasks via latent class analysis (LCA), which captures a finite number of discrete balance profiles (balance skill classes). The optimal number of latent balance skill classes was chosen by comparing models of different class numbers based on three information criteria: (1) Schwarz's Bayesian Information Criteria (BIC), (2) the sample-size-adjusted BIC (SABIC), and (3) Akaike Information Criterion (AIC), with BIC being considered as the most accurate information criteria [31,32]. For all the indices, lower values indicate a better fit of the model [31−33].

The final choice of latent class solutions should balance model parsimony (i.e., simpler models are preferred to more complex models), answer probabilities between groups, and model interpretability [34]. The entropy was reported to indicate the degree of class separation, ranging from 0 to 1, with higher values indicating clearer class separation (larger values typically indicate fewer classification errors). However, entropy was not used in this study as an indicator of the optimal number of classes [35,36], as it is intended to be used for posterior classification rather than model selection during the class enumeration process [35]. The univariate entropy of the four dichotomous balance tasks was reported for the best fitting model to evaluate each task and is more informative in identifying the latent class solution. Thus, balance tasks with univariate entropies near 0 can likely be removed from the model, as they do not provide sufficient information about the latent class variable [37].

The optimal number of latent classes was identified for childhood and adolescence separately, after using the latent transitional analysis (LTA) to evaluate the probabilities of the transition between classes from childhood to adolescence. LTA is a longitudinal extension of LCA involving multiple latent class variables, where LCA is the measurement model for each of the latent class variables [38]. LTA allows for the identification and understanding of the movement of latent subpopulations (called classes) in our naturalistic sampling, as well as the identification of the heterogeneity in balance skills in each wave. This approach has the advantage of a lower false discovery rate compared with using multilevel logistic regression models to evaluate the effects of the prenatal factors on multiple outcomes [39].

First, we conducted an LTA without the covariates. Then, we performed an LTA with two timepoints (childhood and adolescence) along with the continuous covariate of birthweight to examine its influence on the latent transition probabilities, as depicted in the Mplus User Guide (Example 8.14); under this model, we tested an interaction between birthweight and the childhood latent class on adolescence latent class. Finally, the model with the covariates was adjusted for the potential confounding variables described in Section 2.5, which were regressed concurrently on LCA measurement model of childhood and adolescence.

To evaluate the robustness of LTA fully adjusted estimates and confidence intervals given the missing data across the timepoints, imputation of both categorical and continuous covariates was performed using a sequential regression method, also referred to as the chained equations algorithm (*sequential* in Mplus). Five imputation data sets were generated and subsequently analyzed using the Rubin [40] method under the robust maximum likelihood estimator.

Finally, we tested the full measurement invariance, implying that the item conditional probabilities for each class are invariant across the two different time points as suggested by Collins and Lanza [33] and Nylund [41]. Then, we compared, via difference testing using the log-likelihood, the full invariance solution to the full noninvariance solution, where no equality was constraint across the items' parameters. We followed the consecutive steps described by Nylund [41]. All analyses were conducted in Mplus, version 8 [42].

3. Results

The descriptive statistics for the four dichotomous balance tasks across time are presented in Supplementary File 1. At both childhood and adolescence, the model fit indices (Table 1) favored a three latent class solution,

Table 1. Fit indices for latent class analysis

Time points	Classes	AIC	BIC	SABIC	Entropy
Childhood	1	63,844.762	63,874.651	63,861.939	-
	2	55,029.106	55,096.356	55,067.755	0.72
	3	**53,335.693**	**53,440.304**	**53,395.814**	**0.92**
	4	Too many cells deleted in the model			
Adolescence	1	17,154.475	17,181.199	17,168.489	-
	2	14,630.861	14,690.990	14,662.390	0.77
	3	**14,310.156**	**14,403.690**	**14,359.202**	**0.90**
	4	Too many cells deleted in the model			

Abbreviations: AIC, Akaike Information Criterion; BIC, Schwarz's Bayesian Information Criteria; SABIC, the sample-size-adjusted BIC.
The bolded values represents the best class solution in childhood and adolescence.

owing to the greatest decrease (diminished gains) in the information criteria [13].

Table 2 indicates the proportion of participants within each class at childhood and adolescence and shows the estimates of the item response probabilities of successfully executing the four tasks within the assigned class in both times. Based on the probabilities of executing the four tasks, the designations were established, with class 1 consisting of children classified as having "good" balance skills (GBS) due to high probabilities of correctly performing all the tasks. Class 2 consisted of children who were classified as having "poor" balance skills (PBS), where the probabilities of performing the tasks were the lowest. Finally, class 3 included children who were classified as having "intermediate" balance skills (IBS), where the children showed a specific difficulty with performing the *walking backward* task.

The univariate entropy for each item in childhood was walking backward along a straight line (bal1) = 0.512; standing on the right foot for 15 seconds (bal2) = 0.242; standing on the left foot for 15 seconds (bal3) = 0.304; and standing heel to toe for 15 seconds (bal4) = 0.505. In adolescence, the univariate entropy for each item was bal1 = 0.660, bal2 = 0.488, bal3 = 0.530, and bal4 = 0.614, respectively. Therefore, walking backward was identified as the best class separator.

Table 3 shows the probabilities of transition over time considering both a model without and with confounders adjusted after the multiple imputations. Of those classified as GBS at childhood, the chance of retaining this classification at adolescence was 86%. Those classified as PBS and IBS in childhood had the highest probability of change to have GBS in adolescence, being 63% and 75%, respectively. Being GBS at childhood and changing into the poorest outcome, PBS in adolescence was the least likely outcome, with it having a probability of 4%.

The test of measurement invariance using the log-likelihood test did not reject the hypothesis of full measurement invariance (P-value = 0.08). Therefore, adding the constraints across time in terms of item response

Table 2. Item response probability of being able (or not) to execute the four balance tasks based on LCA in the childhood and in the adolescence

Childhood (age 10, *n* = 12,994)	Response probability	Bal1	Bal2	Bal3	Bal4
Class 1 (GBS, 54.48%, *n* = 7,080)	Can perform	100.00	95.00	87.00	94.00
	Cannot perform	0.00	5.00	13.00	6.00
Class 2 (PBS, 26.37%, *n* = 3,427)	Can perform	32.00	36.00	9.00	0.00
	Cannot perform	68.00	64.00	91.00	100
Class 3 (IBS, 19.14%, *n* = 2,487)	Can perform	4.00	62.00	60.00	100.
	Cannot perform	96.00	38.00	40.00	0.00
Adolescence (age 16, *n*= 5,890)		Bal1	Bal2	Bal3	Bal4
Class 1 (GBS, 80.45%, *n* = 4,739)	Can perform	100.00	99.00	94.00	98.00
	Cannot perform	0.00	1.00	6.00	2.00
Class 2 (PBS, 8.18%, *n* = 482)	Can perform	52.00	53.00	14.00	0.00
	Cannot perform	48.00	47.00	86.00	100.00
Class 3 (IBS, 11.35%, *n* = 669)	Can perform	17.00	70.00	65.00	100.00
	Cannot perform	83.00	30.00	35.00	0.00

Abbreviations: GBS, good balance skills; PBS, poor balance skills; IBS, intermediate balance skills.
Bal1: walking backward along a straight line; Bal2: standing on the right foot for 15 seconds; Bal3: standing on the left foot for 15 seconds; and Bal4: standing heel to toe for 15 seconds. All the results are based on individual cross-sectional analysis.

Table 3. Probability of transition between classes from childhood to adolescence based on LTA without and with adjusting for confounders after multiple imputation

	Adolescence					
	GBS	IBS	PBS	GBS	IBS	PBS
		Unadjusted			Adjusted	
Childhood						
GBS	0.88	0.08	0.03	0.86	0.10	0.04
IBS	0.77	0.15	0.08	0.75	0.17	0.08
PBS	0.64	0.21	0.15	0.63	0.22	0.15

Abbreviations: GBS, good balance skills; PBS, poor balance skills; IBS, intermediate balance skills; LTA, latent transitional analysis.
The transition probabilities were estimated under LTA model.

probabilities did not worsen the model. Supplementary File 2 shows a graphical representation of the balance skill trajectories, and Supplementary File 3 showed the item response probabilities of correctly executing the four tasks under the LTA model across the three classes across the time.

Table 4 presents the conditioned effects of birthweight on the latent profile in adolescence, given the childhood balance skill profile after the confounder adjustment, with and without multiple imputation. The higher the birthweight, the higher the chance of moving to GBS at adolescence. In terms of stratification, children who were GBS, for each additional 1 kg in birthweight, there is an increase in the odds by 1.82 (P-value <0.001) of continuing to have GBS in adolescence when compared with adolescents with PBS. In the same way, those with IBS in childhood, for each additional 1 kg in birthweight, there is an increase in the odds by 1.39 (P-value $= 0.01$) to have GBS in adolescence when compared with adolescents with PBS.

4. Discussion

The present study investigated the trajectories of balance skills from childhood to adolescence and its association with birthweight in the 1970 BCS. Based on LCA, we found a three-class solution for the balance skill profile, and using LTA, we found an association between birthweight and the probabilities of changing classes over time.

Based on four simple balance tasks, which are commonly presented in motor assessments [43–45], the LCA revealed three different balance skill profiles. Moreover, the three profiles were shown to be invariant across time and were defined as GBS (with a high probability of performing all four tasks successfully), PBS (with high probability of failing in all four tasks), and IBS (with high probability of failing to perform the *walking backward* task). In terms of cross-sectional prevalence in the two evaluated periods, GBS was the largest group in both childhood (52.8% of the total sample, $n = 7{,}093$) and adolescence (91.2% of the total sample, $n = 12{,}254$). The probabilities of successful execution across the four tasks were similar in

Table 4. Conditioned effects of birthweight on the latent profile in adolescence, given the childhood motor skill profile

Childhood profile	Birthweight effect on adolescent profile[a]	OR	95% CI		*P*-value
With multiple imputation (n = 13,433)					
GBS	Birthweight on GBS	1.82	1.40	2.37	<0.001
	Birthweight on IBS	1.32	0.97	1.79	0.08
IBS	Birthweight on GBS	1.39	1.08	1.77	0.01
	Birthweight on IBS	1.22	0.91	1.64	0.18
PBS	Birthweight on GBS	1.07	0.84	1.36	0.57
	Birthweight on IBS	1.08	0.82	1.44	0.57
Without multiple imputation (n = 8,382)					
GBS	Birthweight on GBS	1.69	0.82	3.50	0.16
	Birthweight on IBS	1.73	0.77	3.89	0.19
IBS	Birthweight on GBS	1.30	0.73	2.34	0.37
	Birthweight on IBS	1.42	0.71	2.85	0.32
PBS	Birthweight on GBS	1.29	0.82	2.01	0.27
	Birthweight on IBS	0.92	0.52	1.61	0.76

Abbreviations: OR, odds ratio; CI, confidence interval; GBS, good balance skills; PBS, poor balance skills; IBS, intermediate balance skills.
[a] PBS in the adolescence in the reference group.

childhood and adolescence for the same assigned class, providing evidence of measurement invariance, which allows for making meaningful comparisons about the classes across time [41].

The four tasks involved both static and dynamic balance skills with different levels of complexity, and the *walking backward* task was found to have the highest univariate entropy, discriminating the IBS class. Clinically, the IBS, as an intermediary class, is justifiable and important, as it involves a complex dynamic balancing task in terms of perception, proprioception, movement dissociation, spatial orientation, and neuromuscular coordination, which requires specialized control circuits [12].

Most longitudinal studies have evaluated the effects of prenatal and birth measures on motor skills at a single timepoint in development. Data from BCS permit us to identify trajectories of balance development from childhood to adolescence for the first time and to test how these trajectories are conditioned by birthweight. The present findings extend previous research that has demonstrated that higher birthweight is associated with good balance skills in childhood [25,46]. In addition, we have provided new evidence that an interaction between childhood balance skill profile and birthweight is associated with adolescence balance profiles.

Depending on the childhood balance skill profile, birthweight appears to preserve the GBS from childhood to adolescence and to move those classified as IBS in childhood to GBS in adolescence. A small percentage (1.92%, n = 258) of participants stayed in the PBS, which might indicate risk for neurodevelopmental disorders, such as developmental coordination disorder [47] or neurodegenerative disorders in adolescence [48].

Few are the randomized clinical trials showing improvement on balance skills, being focus on specific conditions as, for example, Down syndrome and cerebral palsy [49−52]. Observational studies are more common and have shown that movement programs that emphasize the development of static and dynamic balance, including strategies with the use of interactive technology (as Wii fit) [53,54] with children and adolescents, have a positive association with behavior (e.g., social skills, self-regulatory behaviors, working memory) [55,56] and heath (e.g., increased participation on physical activity) [3].

Finally, based on the results of this study, the most likely outcomes in adolescence were maintaining or attaining GBS, that is, children tended to migrate to higher levels of balance skills from childhood into adolescence (when they are IBS or PBS) or to keep good when they present high ability in the childhood. The probability of keeping good, or moving from intermediate to higher skills, was moderated by the birthweight, that is, the higher the weight, higher the probability of these outcomes. Moreover, only a small proportion of children stayed at the lowest level of balance skills in adolescence, and the probability of this outcome was higher for children who presented poor skills in childhood. Given adverse effects of impairment in balance (e.g., low adhesion to physical activity), some clinical attention should be given to those classified at this level in childhood.

4.1. Limitations of the study

Large population-based birth cohorts with detailed motor skills information measured repeatedly are rare. Thus, additional studies could not be identified for use as a reference to compare our findings [57]. Furthermore, our study was conducted using a British cohort from the 1970s, so our results may not generalize to contemporary cohorts; however, our findings do provide an important historical frame of reference when new data become available. Despite being commonly used to evaluate balance skills, the use of four simple tasks may limit the extent of the results for balance abilities in general. Finally, this study focused on likely interaction between birthweight and childhood motor skill profile on adolescent motor profile, whereas sex, paternal social class, and maternal level of education were used as confounders. Therefore, neither mediators, from childhood to adolescent balance skills, nor other moderators beyond the birthweight were explored.

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The data can be assessed at http://www.cls.ioe.ac.uk/Default.aspx, and the computing code (outputs) can be requested from the corresponding author.

Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jclinepi.2018.12.012.

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