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The Effect of Kindergarten Classroom Interaction Quality on Executive Function Development among 5- to 7-Year-Old Children

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Abstract: The present research addresses the impact of preschool classroom interaction quality on executive function development. CLASS methodology was used to assess the quality of teacher–child interaction in kindergarten groups; "Inhibition", "Memory for Designs", and "Sentences Repetition" subtests from the NEPSY-II (memory for designs, sentences repetition, inhibition) and Dimensional Change Card Sort were used for the evaluation of executive functions. Repeated measures were performed to assess the children's progress, based on the quality of the educational environment in their group. The total sample consisted of 447 children (48.5% boys and 51.5% girls). ANOVA and linear regression analysis demonstrated that children's progress in executive function development varies for low- and high-quality classrooms. Furthermore, different predictive potential of CLASS domains was shown for the development of executive function components in preschool children.

Keywords: preschool age; executive functions; working memory; inhibition; cognitive flexibility; CLASS; educational environment quality

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1. Introduction

The influence of educational environment on the development of executive functions (EF) has been long-studied but remains relevant and important for preschool education and child psychology [1–3]. Executive functions (EF) is one of the basic psychological indicators of preschool age and prognostic factors of children's posterior academic performance [4–8]. It is important to examine the environmental factors that foster EF development during this period. Therefore, the aim of this investigation was to study the effect of the quality of classroom interactions in kindergartens on the development of executive functions of preschoolers.

Miyake's model explains EFs as a group of cognitive skills for adaptive behavior in unfamiliar situations and targeted problem-solving [9]. It proposes that there are three main components to these cognitive skills, namely, (1) working visual and verbal memory, providing the ability to monitor and select incoming information according to its task relevance, manipulate it, and renew and maintain it with new contents if necessary; (2) cognitive flexibility in relation to switching between different rules; (3) inhibitory control, implying suppression of the initial main response in favor of the means required to perform a task [5]. The EF model originally started by following research on adults, but the possibility of its useful application to childhood development has also been shown by researchers abroad [5,10,11], as well as in Russia [12–14].

One of the most developed evaluation tools for educational environment and classroom experience is the Classroom Assessment Scoring System (CLASS) [15]. Its assessment is based on three domains: (1) emotional support, i.e., teaching behavior that allows children to feel support, warmth, and trust in relationships with their teachers and to study and communicate with comfort and pleasure; (2) classroom organization, i.e., another form of teaching behavior directed at developing self-organization skills in children, so that they can control their own behavior while making each learning day in kindergarten as productive as possible by sustaining interest in activities; (3) instructional support, i.e., teaching behavior presupposed to sustain and encourage cognitive development in children (conceptual thinking and language skills) [15]. The CLASS tool's methodology is mainly based on developmental theory, as well as a cultural–historical approach [2,16,17]. The latter generally shows that the nature of the relationships and communication between children and adults are key for the development of higher mental functions and learning abilities in children [18]. Therefore, CLASS is exclusively based on teacher–student interactions, leaving physical environment factors, kindergarten education program features, and presence of materials aside [15]. This method focuses on how the teacher uses the environment for the learning and development of children. This is consistent with Vygotsky's ideas that an adult (teacher) transmits to children social rules, norms, and cultural tools to master his/her own behavior [19]. In this regard, CLASS seemed to us to be the most successful tool for assessing the quality of the educational environment.

Numerous studies designed for the analysis of the impact of educational environment on EF emphasized the relevance of a pleasant emotional and psychological climate [2,18,20,21]. Hatfield and colleges [20] demonstrated how children in kindergarten groups with high emotional support levels exhibited lower levels of cortisol compared to children in groups with low emotional support levels. Thus, EF development is facilitated by an educational environment in which teachers create conditions that enable children to feel comfortable in the classroom. For example, they pay attention to children's ideas and help them solve emerging domestic and emotional problems [20].

Several studies have shown that CLASS-measured quality of classroom interactions predicts EF levels [1,3,22,23]. Rimm-Kaufman et al. [23] demonstrated how the effective classroom management was linked to greater behavioral and cognitive self-control in children. A study by Weiland et al. [3] found CLASS domains, such as emotional support and classroom organization, to be predictors of components of EF, such as inhibitory control, working memory, and switching. Duval and colleagues [24] received rather controversial results: emotional support in the kindergarten classroom was positively correlated with working memory and cognitive inhibition, whereas instructional support was negatively correlated with children's working memory. Further analyses demonstrated that gross family income reduced the association between instructional support and working memory. It is interesting to note that, in this study, no correlations were found between the CLASS domains and EF skills of cognitive flexibility, behavioral inhibition and planning. Hamre et al. [1] described that children belonging to groups with high scores in the instructional support domain demonstrated better performance in working memory tests than children belonging to groups with low instructional support scores. Meanwhile, in groups with high classroom organization scores, children showed better results for inhibitory control than children from low-scoring groups. It is highlighted that extensive and beneficent positive feedback from a teacher is essential for EF development [17]. Our previous study pointed out that children from groups with high classroom interaction quality performed better in visuospatial working memory tasks and inhibitory control tasks but received lower-scoring results in cognitive flexibility tasks compared to children from low classroom interaction quality groups [13].

Thus, the relationship between classroom quality and EF has generally been underexplored and is rather controversial. In this regard, studies that consider not only the correlations between educational environment quality and children's cognitive indicators, but also the contribution of the educational environment to the development of cognitive skills, are of greatest interest. Hence, this study attempts to analyze the effect of the quality of classroom interactions in kindergartens (emotional support, classroom organization, and instructional support) on the preschoolers' main EF development (working memory, inhibitory control, and cognitive flexibility). In line with previous research [1,3,22,23,25], it was expected that classroom interaction quality within kindergarten groups would be significantly associated with EF development. EFs as a set of cognitive processes critical for the development of preschool children were chosen to be assessed, as it was assumed that a high-quality educational environment would contribute to the children's development through support in activity choices and reflection, as well as through the fact that children can internalize behavioral models in such environments [22,23].

2. Materials and Methods

2.1. Participants

Twenty-six public kindergarten groups from Moscow, Russia, participated in this study. This sample consisted of 447 children (48.5% boys and 51.5% girls). The mean age was 78.31 months (SD = 3.93). The assessment was made in the penultimate year of pre-school education. One year after the first evaluation, the tests were repeated in order to assess the evolution of the initial results, although only 359 children repeated the tests. All children spoke Russian without developmental delays.

The study included public kindergartens within districts characterized by similar levels of infrastructure and designed to accommodate primarily medium-income families. Accordingly, a relatively homogeneous socioeconomic sample was recruited. All kindergartens are public and education in them is free for children. In all studied groups there were approximately the same number of children (about 30) and 1 or 2 educators (most often 2, but they work in shifts). The mean age of teachers was 45.5 years (SD = 11.8 years), and the work experience in preschool institutions was, on average, 15 years. Among them, 34.5% graduated only from a pedagogical college/school, 5% have a higher education not related to pedagogy (engineering, law, economics), and the rest have a higher pedagogical education. All kindergartens adhered to the same educational program "From Birth to School" [26].

2.2. Instruments

1. The NEPSY-II [27] "Sentences Repetition" subtest was used to evaluate the development of verbal working memory. This instrument consists of 17 sentences, which gradually became increasingly difficult to memorize due to length and grammatical structure. For each correctly repeated sentence, the child received two points. If he/she made one or two mistakes (skipping, replacing, or adding words, changing word order) during the repetition, he/she received one point. If the child made three or more mistakes or did not respond, he/she received zero points. The task concluded if the child received zero points four times in a row (maximum in this task = 34 points).
2. The NEPSY-II [27] "Memory for Designs" subtest was used to assess visual working memory development. This task included four trials. The child was presented with a grid of a field, wherein different cells contained four to eight colored drawings. The child was shown a picture for ten seconds and then it was taken away. Next, the child was provided with a blank grid and a set of cards, some of which depicted the same designs that had been presented before and some which looked similar but were not the same (distractors). The child's task was to select the correct designs and place them on a grid in the same locations as previously shown. In this test, the following total scores were recorded: (1) "content", reflecting the degree of correctness in memorizing the image detail (max. 46 points); (2) "spatial", reflecting the degree of correctness in memorizing the configuration (max. 24 points), and (3) "bonus", reflecting the consideration of both parameters simultaneously (maximum 46 points). All three indicators were summarized in the total score (max = 120).
3. The "Inhibition" subtest of NEPSY-II [27] was used to assess cognitive inhibition. In this test, the child was presented with a series of 40 figures (squares and circles). This instrument consisted of two parts: the naming task (where the child had to name the shapes as fast as possible) and the inhibition task (where the child had to do everything backwards: for example, if they saw a square, they had to say "circle",

etc.). The time spent on the task, the number of uncorrected errors, and the number of self-corrected errors were recorded in both tasks.

4. The Dimensional Change Card Sort (DCCS) [28] was used to assess cognitive flexibility. Children were required to sort a series of bivalent test cards (with pictures of red rabbits and blue boats), firstly according to one dimension (color) and then according to another (shape). For a third test, children were required to sort cards according to a more complicated rule with an additional factor (cards with/without borders). The accuracy score was calculated (max = 24).
5. The Classroom Assessment Scoring System (CLASS) [16] was used to assess the quality of the educational environment. This method required at least four 30 min cycles of observation (total duration = 120 min/class). The CLASS method assessed classroom experience within the three domains: emotional support, classroom organization, and instructional support. These three major domains included 10 dimensions that were evaluated using a 7-point Likert scale. From the points received in each dimension, three domain scores were calculated as the arithmetic mean.

2.3. Procedure

The EF evaluation was performed in the second half of the school year and consisted of two individual meetings with each child (lasting 20–25 min each). Children were free to quit or refuse to participate in the research at any moment.

The educational environment quality evaluation was performed during the school year by the same certified expert in the CLASS method.

All parents were informed of the purpose of the study and gave written informed consent for their children's involvement in the study. The study was approved by the Ethics Committee of the Lomonosov Moscow State University (approval no: 2018/41).

3. Results

The empirical analysis was carried out with the IBM SPSS Statistics 23 package and concluded by the Student's t-criterion, the Mann–Whitney test, and regression analysis (linear regression).

In the present study, the analysis was carried out to assess the children's progress based on the quality of the educational environment in their group. For this purpose, we calculated Δ = Time 2 (t_2) − Time 1 (t_1).

Previously, all 26 kindergarten groups were divided into two equal groups (13 each), with high and low levels of classroom interaction quality, according to the median of the sum of CLASS domains. The comparison of these two groups on separate CLASS domains was drawn using the Mann–Whitney test. The results of this test showed that groups with a high-quality educational environment had significantly higher scores on all domains of the CLASS methodology (emotional support, classroom organization, and instructional support) compared to groups with a low-quality environment ($p < 0.05$).

3.1. Comparison of Groups from Different Levels of Classroom Interaction Quality

The analysis of the differences between groups with high and low levels of classroom interaction quality according to CLASS required the Student's t-test. This was carried out on independent samples to see the differences in the progress of child development according to Δ.

Notable differences were as follows: Δ for the naming task in the inhibition test ($t = 1.904$, $p < 0.06$), Δ uncorrected errors in the inhibition task of the inhibition test ($t = 2.233$, $p < 0.03$), Δ the sum of errors for the inhibition task of the inhibition test ($t = 1.748$, $p < 0.08$; at the level of trend), and Δ the memory for designs test content score ($t = -2.784$, $p < 0.01$).

Thus, kindergarten groups with high CLASS levels had higher scores for executive functions development (inhibition and visual working memory) compared to groups with low CLASS levels.

3.2. Analysis of Progress in EF Skills and Predictions Using CLASS Domains

We performed regression analysis (linear regression) in order to determine the predictive power of the CLASS domains in terms of progress in EF development in preschoolers. Tables 1–3 summarize the data from the linear regression models where the variables of child development measures act as dependent variables and aspects of the quality of the educational environment as predictors. From all of the above, it can be deduced that the variables are as follows: Δ the sentences repetition test total score, Δ DCCS total score, Δ uncorrected errors for the naming task of the inhibition test, Δ corrected errors for the naming task of the inhibition test, Δ time taken for the naming task in the inhibition test, Δ uncorrected errors for the inhibition task in the inhibition task, Δ corrected errors for the inhibition task in the inhibition test, Δ time taken for the inhibition task in the inhibition test, Δ memory for designs test content score, Δ memory for designs test spatial score, Δ memory for designs test bonus score, Δ memory for designs test total. We summarized in Tables 2–4 only those models that turned out to be significant or significant at the trend level.

Table 1. Δ of child EF development significant indices in groups with low- and high-quality classroom interaction.

	Low-Quality Groups		**High-Quality Groups**	
	M	**SD**	**M**	**SD**
Δ Naming, time	48.53	12.01	46.01	12.36
Δ Inhibition, uncorrected errors	4.56	8.08	2.92	5.49
Δ Inhibition, sum of errors	3.84	8.58	2.49	5.64
Δ Visual working memory, content	−0.25	10.76	2.47	6.94

Table 2. Regressions for the Δ of child EF development indices with the CLASS emotional support domain as a predictor.

	sig.	**β**
Δ Naming, time	0.01	0.14
Δ Inhibition, time	0.08	0.09
Δ Visual working memory, content	0.00	0.28
Δ Visual working memory, spatial	0.00	0.24
Δ Visual working memory, bonus	0.01	0.14
Δ Visual working memory, total	0.00	0.23

Table 2 proposes that the CLASS emotional support domain is a significant predictor of progress in some aspects of EF. It should be noted that "emotional support" predicts progress in all aspects of visual working memory. Emotional support also predicts the time taken for naming and inhibition tasks (at the trend level). Furthermore, it is the domain that revealed the largest number of significant predictive relationships.

Table 3 reveals that the CLASS classroom organization domain is a negative predictor of change in the number of uncorrected errors on the naming and inhibition tasks. That is, higher levels of classroom organization led to a reduction in uncorrected errors in the inhibition tests.

Table 3. Regressions for the Δ of child EF development indices with the CLASS classroom organization domain as a predictor.

	sig.	**β**
Δ Naming, uncorrected error	0.00	−0.16
Δ Inhibition, uncorrected error	0.03	−0.12

Table 4 describes the negative prediction of the instructional support domain for progress in the development of EF, such as cognitive flexibility (at the trend level), time taken for the naming task, and the number of uncorrected errors in the inhibition task.

Table 4. Regressions for the Δ of child EF development indices with the CLASS instructional support domain as a predictor.

	sig.	β
Δ Cognitive flexibility	0.09	−0.09
Δ Naming, time	0.05	−0.11
Δ Inhibition, uncorrected error	0.05	−0.11

Therefore, regression analysis highlighted that CLASS domains have different predictive power for the development of cognitive functions in children of preschool age for all CLASS domains related to inhibition. The emotional support domain, however, revealed a greater number of significant relationships, e.g., with visual memory.

4. Discussion

The aim of the present research was to identify the potential of classroom interaction quality on EF development in preschool-aged children.

Our findings suggest that the processes described within the CLASS emotional support domain have the most powerful impact on the development of different aspects of EF in preschoolers. This is especially pronounced in visual–spatial working memory and inhibition. Our results are in good agreement with the results of previous studies, emphasizing the importance of the aspect of environmental quality for child development [2,3,18,20,21,24]. In particular, the results of Duval et al. showed that emotional support was positively correlated with working memory and cognitive inhibition [24]. A positive teacher–child relationship, that is, a relationship characterized by sensitivity and warmth, reduces stress [20] and makes children actively engage in learning [29,30], which affects their EF development [31,32]. Positive emotional interaction, characterized by the responsiveness and attentiveness of the teacher and the presence of feedback, is decisive for the emotional and communicative development of the child, as well as the presence of behavioral problems [33,34]. Previous studies [33] have shown that procedural characteristics of the quality of the educational environment moderate the relationship between effective self-regulation and a child's socioemotional outcomes.

As for the classroom organization domain, our study demonstrated it to be a significant predictor of Δ uncorrected errors in both naming and inhibition tasks of the inhibition test. This means that children from groups with a higher level of classroom organization had a more developed ability to inhibit impulsive responses. In a conceptual sense, this domain combines various processes regarding the organization of group work, and therefore includes ideas about managing children's behavior and attention. Various forms of organization of the daily routine and learning process can contribute to the development of voluntary control of the child's own activities. Characteristics of the interaction between a teacher and child are reflected in the level of development of EF children. The higher the quality of these indicators, the higher the level of EF development [35]. According to Vygotsky, the adult is a carrier of cultural ideal forms, such as social norms and rules of behavior. This, in turn, increases the significance of his interaction with a child, since the adult is the example by which the process of the child mastering the voluntary behavior is mediated [19]. The basic mechanism of child development is imitation [19]. Therefore, the teacher's use of effective strategies for controlling the children's behavior contributes to the development of their own inhibitory control ability.

Finally, the instructional support domain, according to our data, was a significant negative predictor of Δ in DCCS, Δ time taken for the naming task, and uncorrected errors in the inhibition task of the inhibition test. The reason for the negative relationship between the quality of instructional support and indicators of cognitive flexibility and inhibition may lie in the specifics of the EF assessment, during which we do not give high-quality feedback to children, which is unusual for them. It can also be assumed that in groups with a high quality of instructional support, there may not always be an accepting emotional atmosphere, which is most important for EF development. Often, teachers pay more attention either to teaching students or to building warm, trusting relationships with them. However, this assumption requires verification.

Our results suggest that kindergarten groups with higher levels of teacher–child interaction have a higher score for EF development (inhibition and visual working memory) in preschool children compared to groups with lower interaction quality. These data are consistent with our previous findings [13] and those of Weiland et al. [3], which showed that CLASS domains were strongly associated with inhibitory control in higher-quality classrooms, compared to lower-quality classrooms, although their study found no such relationship with aspects of EF, such as working memory, which, as the authors note, would be predictable on the instructional support domain, since the activities of children in groups with a high score on this domain are more regulated. However, in our study, data were obtained that supported the instructional support domain as a predictor of the development of cognitive flexibility in preschoolers.

The results obtained are in good agreement with previous studies showing the impact of high quality of educational environment on the cognitive development of children. Curby et al. [36] showed that in groups with a high quality of educational environment according to the CLASS method, children cope much better with solving mathematical tasks, and have more developed speech than children from groups with a low quality of educational environment. Indeed, Howes et al. [37] noted that children from groups with a positive atmosphere and discussion methods during classes have a richer vocabulary than, and superior initial reading skills to, children from other groups. The experience of education in early childhood has a long-term effect on children's cognitive and social development. Up to second grade, children attending kindergartens with different educational environments show significant differences in language ability and academic achievement [38]. A child's ability to develop cognitive skills is contingent on the opportunities provided to them by an adult to express their existing skills and develop more complex ones [15,19].

Previously, our study demonstrated no significant associations between EF indicators and the ECERS-R scale scores [39]. We assume that these results were caused by the confusion between the indicators of the physical environment quality and the interaction quality in the kindergarten. Therefore, the teacher–child interaction quality indicators need to be separated from other indicators of the educational environment. In this regard, CLASS proved to be more consistent for the educational environment quality assessment.

Thus, our results emphasize that it is the quality of teacher–child interaction in the group that has an impact on the level of EF development in children. Nevertheless, we note several limitations that should be kept in mind regarding the interpretation of the results obtained. Our study did not consider the child's individual characteristics: age [40], gender [13,41,42], and non-verbal intelligence [43], as well as family factors: socioeconomic status [24,42,44], level of education of parents [45], the quality of parent–child interactions [46], and quality of home environment [47]. These can all potentially influence the development of EF. In addition, it seems important to trace the relationship with the child's activity outside the kindergarten in future studies [48–52], and, for example, with the screen time, which allows us to clarify the existing picture regarding the data obtained. In addition, the study did not take into account the characteristics of teachers (their age and work experience, education), which are also important factors influencing interaction in the group [23]. It is also important to verify the identified relationships in a larger sample, since not all parameters of the regression models meet the requirements.

Further development of the present research is to trace the impact of the quality of teacher–child interactions in kindergarten groups on the success of children in adaptation and learning at primary school. We expect to analyze the role of the classroom interaction quality as a mediator between indicators of the cognitive development of children in kindergarten and their achievements at the primary school stage.

The study highlights the importance of firstly creating a positive emotional climate and psychological support for preschoolers, rather than improving physical conditions. The creation of such conditions requires from teachers not only a good command of the educational program, but also knowledge of child psychology and emotional intelligence, which must be taken into account during teacher training. The results obtained in the present research can be employed for preschool educational programs designed to enrich the quality of classroom interactions and mediate child cognitive development and, in particular, executive functions.

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